European Commission

NanoData Landscape Compilation

Environment

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EXECUTIVE SUMMARY

Background

This report offers a snapshot of the status of nanotechnology in the context of the environment. Environment is defined here as the totality of all the external conditions affecting the life, development and survival of an organism. Environmental degradation in terms of water, air and soil pollution, depletion of resources and climate change are a threat to human health and well-being and an increasing cost to society.

Nanotechnology is one of the emerging technologies that can help to prevent or remediate environmental degradation and improve monitoring (direct effect), or lead to reduced energy and resource consumption (indirect effect). This is described as the role of nanotechnology *for* the environment.

Introducing new substances, such as nanomaterials and nano-particles with unknown characteristics, into the environment may have negative environmental and health effects. This is described as the role of nanotechnology *in* the environment.

Aspects of nanotechnology both for and in the environment are covered in this report.

Role of nanotechnology

Applications of nanotechnology are able to address environmental issues, for example, enhancing the prevention, detection and remediation of environmental degradation and the production of better materials (lighter, more effective, lower cost). Prevention and remediation applications are relevant to water, air and soil.

Water pollution and scarcity are environmental problems that can disrupt ecosystems and seriously affect the health of humans and other species. Nanotechnology offers solutions to deal with oil spills; remove bacteria, radioactive materials; desalination of water; decompose organic molecules and remove arsenic from water.

The poor air quality across Europe has made it a political priority. Nanotechnology can play a role in the remediation of volatile organic compounds (VOCs), carbon dioxide (CO_2) and nitrogen oxides (NOx). Nanotechnology enables the removal of VOCs from the air, for example using a catalyst of porous manganese oxide in which gold nanoparticles have been embedded. To prevent or reduce the release of CO_2 into the atmosphere, nanotechnology can trap CO_2 using crystals with nanopores, convert waste carbon dioxide into methanol fuel (e.g. from emissions from power plants) and remove carbon dioxide from industrial chimney outflow using nanostructured membranes (including those using carbon nanotubes). Cobalt-platinum nanocatalysts or carbon nanotubes removes nitrogen oxides (NOx) from smoke or catalyses waste gas pollutants (from car exhausts and industrial plants) into harmless gases.

Soil contamination affects plant growth and the quality of groundwater used for human consumption. Soil remediation therefore also has a beneficial effect on water quality. Nanotechnology can be used to extract heavy metals and organic compounds from soil and can clean groundwater by removing pollutants such as pesticides and polychlorinated biphenyls (PCBs). Nanomaterials for soil remediation are, for example, nanoclays, geopolymers, nano-calcium peroxide and nano-coated hydrophobic sand.

Sensors based on nanotechnology have the potential to reduce wastage of resources (such as energy and raw materials) and to indicate the quality of the environment (air, water and soil). Nanoparticle-based biosensors are potential tools for rapid, specific and highly sensitive detection, making it possible to sense very small concentrations of contaminant.

Policies

Environmental policy dates back to the 1970s, with the first Environmental Action Programme (EAP) adopted in 1972. The current Seventh EAP recognises both the benefits and risks and uncertainties associated with (emerging) technologies including nanotechnology.

The EU, its Member States and many other countries have developed dedicated policies in support of nanoscience and nanotechnologies in the period 2000-2010, making it a relatively recent policy priority. The European Commission published "Preparing for our future: Developing a common strategy for key enabling technologies in the EU" in 2009, which sets out measures to foster KETs development and exploitation at EU and Member State level. EU and national policies support nanoscience to further our basic understanding, stimulate research and development for new innovative applications and foster industrial competitiveness to create jobs and economic growth.

Some countries, such as Finland, Portugal, Norway, Germany and Japan, explicitly prioritise the environmental sector in their funding programmes. Others address sectors that have impact on the environment, such as energy and water (e.g. the Netherlands)

In many countries, nanotechnology policy in relation to the environment is considered both an opportunity as well as an environmental risk and both aspects are included in their strategies and programmes. For example, the Austrian programme funds projects that apply nanotechnology in water purification for developing countries, but also investigates the risks, e.g. of nanosilver in tennis socks. In addition, the US National Nanotechnology Initiative brings together 25 Federal agencies each with some responsibility for nanotechnology research, application and/or regulatory activity.

EU R&D projects

Research, development and innovation is supported through the European R&D programmes, currently Horizon 2020 (2014-2020), programmes that have had a dual focus: firstly, exploring and exploiting the potential opportunities of nanotechnology, for applications in fields such as the environment and for life-cycle optimisation of industrial systems, products and services, in particular with a view to eco-efficiency and reduced emission of substances; and secondly, the safety aspects of engineered nanomaterials in order to protect public health, safety and environmental and consumer protection.

There were 289 nanotechnology environment projects in FP6 and FP7 together, approximately 8.2% of the total number of projects related to nanotechnology. The EU contribution to these projects was EUR 696.8 million (10.9% of total nanotechnology funding), of which EUR 131.1 million (7.7% of total nanotechnology funding) in FP6 and EUR 565.7 million (12.1% of total nanotechnology funding) in FP7. The largest amount of environment-related nanotechnology funding was allocated under the NMP programme for both FP6 (24 projects with 69.5% of funding, EUR 91.1 million) and FP7 (93 projects with 61.5% of funding, EUR 348 million).

The top three countries were Germany, the United Kingdom and France and these accounted for more than one third of the total EC funding for environment nanotechnology projects (EUR 271.2 million, 38.9%). The same three countries, in the same order, head the rankings for nanotechnology projects and for FP projects overall. The top six countries (Germany, the United Kingdom, France, Spain Italy and the Netherlands) accounted for 61.5% of funding received.

Higher education establishments received 37.1% of funding of funding in FP6 and FP7 for environment and nanotechnology, slightly more than research organisations at around 32%. The shares of large companies and the category other decreased from FP6 to FP7 (large companies from 12.5% in FP6 to 7.9% in FP7 and other organisations from 9.3% in FP6 to 3.0% in FP7). In contrast, higher education increased its share from 32.5% in FP6 to 38.2% in FP7 and SMEs from 14.3% in FP6 to 18.8% in FP7.

The organisations receiving the largest amounts of funding for environment nanotechnology activities were Fraunhofer Gesellschaft[1] (DE) (EUR 17.62 million for 34 projects), CEA[2] (FR) (EUR 14.88 million, 19 projects), CNRS[3] (FR) (EUR 13.51 million, 36 projects) and CNR[4] (IT) (EUR 11.34 million, 20 projects). Other organisations in this list had EC contributions below EUR 10 million, and less than 20 projects each.

The Spanish company Acciona Infraestructuras SA has been most successful in obtaining research funding in FP6 and FP7, with EUR 2.34 million and six projects. Second place in terms of funding received is Danish SME Biogasol APS with EUR 2.09 million. Out of the top 25 companies (in terms of funding received), fifteen are SMEs. There are four other companies that each participated in six projects. Germany, with seven, has the most companies in the top 25, followed by the United Kingdom (four).

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[1] Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e. V., Germany
[2] Commissariat a l'Energie Atomique et aux Energies Alternatives, France
[3] Centre National de la Recherche Scientifique, France
[4] Consiglio Nazionale delle Ricerche, Italy

Publications

Publication data for nanotechnology and environment shows that, of the 1.8 million publications globally related to nanoscience and nanotechnology between 2000 and 2014, almost 45,000 were related to the environment, around 2.5% of total output.

The strongest publishing countries in 2014 were China (2,052) and the USA (1,186), well ahead of India (475) and South Korea (348). The first European country in the list is Spain, in fifth place with 314 publications, followed by France (302), the United Kingdom (296) and Germany (275).

The EU28 & EFTA organisations with the best publishing record in 2014 for nanotechnology and environment were Delft University of Technology (NL, 32 publications), the University of Barcelona (ES, 30 publications), ETH Zürich (CH, 28 publications), the University of Aveiro (PT, 27 publications) and Katholieke Universiteit Leuven (BE, 27 publications). The companies with the most nanotechnology/environment publications globally in 2014 were Aerodyne Research (USA) and Petrochina (PRC).

Patenting

Between 1993 and 2011 the number of environment patent families identified among the nanotechnology patents is 523, 1.15% of all nanotechnology patent families. Looking at patent families by country of applicant, the league table is dominated by the USA with 244 patent families, followed by Japan with 80 and South Korea with 35. Fourth place is Germany (with 29 patent families applied for), then France (21), Spain and the United Kingdom (both with 15), Belgium and Switzerland (both with 8) and the Netherlands and Italy (both with 7). In total 12 EU countries feature in the top 25.

When looking at universities and public research organisations, the top 15 applicants feature only five non-US organisations. Most successful is Universidad de Sevilla (ES) with nine patent families, followed by the University of California (US) with eight and CNRS (FR) with six. The other three places in the top 15 are for two organisations from Korea and one from Israel). The top ten companies with the highest number of patent families belong to five different countries. Top of the table is Samsung SDI (Korea) with ten patent families. From the EU, only German (3) and French (1) companies feature.

Products and markets for environment through nanotechnology

Market segments in the environmental sector using nanotechnologies comprise products for air, water and soil remediation and sensors. Global sales of air, water and soil remediation combined amounted to USD 23.5 billion in 2014, expected to increase to USD 25.7 billion in 2015 and USD 41.7 billion in 2020. Currently the largest market is that for air remediation products with global sales of USD 9.4 billion in 2014. Strongest growth is expected in the water remediation market, with a CAGR of 12.4% to 2020, making air and water remediation comparable at USD 16.7 billion and USD 16.6 billion respectively by 2020. The soil remediation market is relatively modest, growing from USD 5.9 billion in 2014 to 8.4 billion in 2020. The market for nanosensors is emerging, with negligible sales in 2013 and 2014. Total sales are expected to remain modest compared to the remediation market, with USD 60 million by 2019.[5]

40 products related to environmental remediation and using nanotechnology have been identified as being commercially available on the market. Of those, 45% are in the area of water remediation, in particular filter systems and membranes for the purification and remediation of water. Products for air remediation include filter systems and photocatalytic coatings. In soil remediation, nanomaterials such as iron nanoparticles or carbon nanotubes remove or neutralise pollutants.

Regulation and standards

Regulation of nanomaterials is primarily covered by the existing legislation for chemical substances. Two reviews of the regulatory aspects of nanomaterials (2008 and 2012) have confirmed REACH (the overarching regulatory framework in place for chemical substances) as the main act to regulate nanomaterials. There are no provisions in REACH referring explicitly to nanomaterials; however, according to the European Commission (EC) nanomaterials are covered by the substance definition

[5] Sources including BCC Research

in REACH. The EC is also currently reviewing the recommended definition of nanomaterial published in 2011.

A review of environmental legislation for the regulatory control of nanomaterials was published in September 2011. The consultants concluded that in principle nanomaterials fall under these regulations although only a few of the acts list or precisely refer to nanomaterials.

While the EU has been developing a regulatory framework for nanomaterials under REACH, some European Member States, such as Belgium, Denmark and France, have developed their own definition and regulation of nanotechnologies.

Technical committee 27 (Environmental Management) of the International Organisation for Standardisation (ISO) cover environmental issues (including carbon black) but, in general, neither ISO not its European equivalent the European Committee for Standardisation (CEN) has developed specific standards for nanotechnology and environment although both have technical committees working on nanotechnology.

Human health and safety

The hazard assessment covers nanomaterials that are used for applications in air, soil and water remediation, such titanium oxide in polymeric membranes to remove metals and other contaminants from wastewater. The greatest risk of toxic nanomaterials is considered to be through respiratory exposure. From a hazard assessment of nanomaterials used in environmental applications, the potential risk is low during use, as the nanomaterials are either present in a closed system or in a solid matrix. The highest risk of exposure is during the production of these systems or matrices. Also, during the end-of life phase, exposure is not expected to be very high, but somewhat higher than during the use phase.

Based on the hazard and exposure banding for risk assessment, carbon nanotubes, dendrimers, graphene and graphene oxide have a high priority, indicating the need to apply exposure control methods or to assess the risks more precisely. All other materials have an intermediate priority, except calcium peroxide and titanium dioxide in the use phase, for which they have a low priority.

1 BACKGROUND

Environment can be defined[6] as the totality of all the external conditions affecting the life, development and survival of an organism. It consists of air, water and soil, which deliver vital environmental functions and ecosystem services that support life on Earth. Each organism interacts with and has an influence on its environment, including – or in particular - humans. Environmental functions and ecosystem services that are essential for social well-being and economic welfare are under threat from over-exploitation and pollution. The European Environment Agency[7] (EEA) lists as environmental topics air quality, biodiversity, chemicals, climate change, environmental health, land use, natural resources, noise, soil, waste and material resources and water.

According to the EEA's State of the Environment Report (SOER, 2015) new technologies, such as nano-, bio-, and information and communication technologies, are radically transforming the world. Such technologies can contribute to environmental monitoring, prevention and remediation of environmental damage but also bring potential risks and uncertainties[8]. This relates to the fact that nanomaterials, in particular those that are engineered[9], have properties that are not yet fully understood. This report therefore examines the use of nanotechnology *for* the environment (to reduce impact) and *in* the environment (its potential risks, uncertainties) from the perspectives of:

- The knowledge base (publications, projects, patents and the organisations involved);
- The economic importance of nanotechnology (the products and markets); and
- Regulation and standards, environmental health and safety (EHS).

Given that the environment covers all areas of human activity, there will be some overlap with economic sectors considered within the NanoData project, for example, transport, health, energy and ICT.

Unless otherwise stated in the text, the data used has been extracted[10] from the NanoData project database compiled from a range of statistical sources (e.g. European Commission, publications databases, patent office databases, etc.) and primary research via literature review and other data collection methods (e.g. interviews).The abbreviation EV-NT is used in the report for nanotechnology in relation to the environment. Nanotechnology is sometimes abbreviated to NT.

[6] https://stats.oecd.org/glossary/detail.asp?ID=813

[7] http://www.eea.europa.eu/. The European Environment Agency is an agency of the European Union with currently 33 member countries (28 EU countries, Iceland, Liechtenstein, Norway, Switzerland and Turkey).

[8] The European environment, State and outlook 2015; http://www.eea.europa.eu/soer-2015/synthesis/report/action-download-pdf-old/view, box 2.1, p. 37.

[9] EEA, Late Lessons Vol II, chapter 22 on Nanotechnology. New nanomaterials may be formed by altering the shape, size and form of existing materials at the nanoscale, or nanomaterials with new properties may be developed by combining two or more nanoscale materials or chemicals.

[10] The data was originally obtained from various sources (e.g. patent and publication databases) through the use of keywords. The keywords for each sector were identified via literature searches and discussions with experts such that there would be a unique set of keywords for each sector. The intention was that all of the data identified would be relevant to the sector. However, some data may be missing as the keywords have been limited to those relevant to photonics and not to other sectors. Where confusion or error could have resulted, the keyword has been omitted.

2 INTRODUCTION TO ENVIRONMENT AND THE ROLE OF NANOTECHNOLOGY

2.1 Overview

Europe has become increasingly aware of environmental problems in recent decades. For instance one in four Europeans still falls sick or dies from environmental pollution[11]. The European Commission (EC) puts forward policies and programmes designed to protect natural habitats, keep air, water and soil clean, ensure proper waste disposal, improve knowledge about toxic chemicals, and help to move towards a sustainable economy[12]. In the context of this report, the Regulation for the Registration, Evaluation and Authorisation of CHemicals[13] (REACH, (EC)1907/2006) is relevant and further discussed in the section on regulations and standards in this report.

Clean and sufficient water is crucial for everyday life. Water is essential for the health and hygiene of society and for economic growth[14]. Governments around the world face challenges in organising their water resources effectively. The problems are multiple and complex: billions of people are still without access to safe water and sanitation; and major investments are required to improve and maintain the water infrastructure[15]. The Urban Waste Water Treatment Directive (UWWTD) established minimum requirements for collection and treatment of urban wastewater and is one of the key policy instruments under the EU water *acquis*[16]*.* Implementation of the UWWTD has reduced discharges of major pollutants[17], but implementation is still far from complete. Some of the Member States that joined the EU in 2004, or later, face significant compliance gaps[18].

Clean air also needs special attention. A report from the WHO[19] (World Health Organisation) and UNECE[20] (United Nations Economic Commission for Europe) indicates that air pollution across Europe is costing USD 1.6 (EUR 1.44) trillion a year in deaths and diseases[21]. This is nearly one tenth of the region's gross domestic product. That means that reducing air pollution has become a top political priority[22]. Indoor air quality can also be of concern, due to improper or inadequately maintained heating and ventilation systems, contamination by construction materials (glues, fibreglass, paints, chemicals, etc.), and an increase in the number of building occupants and time spent indoors[23].

Soil is increasingly degrading, both in the EU and at global level. Examples are erosion or loss of organic matter, which have negative impacts on human health, natural ecosystems and climate, as well as on the economy[24]. Soil degradation not only has transboundary effects, it also leads to high costs. At the moment, only a few European Union (EU) countries have specific legislation for soil protection[25]. However, the EU does not have a comprehensive and coherent set of rules for soil.

2.2 Role of nanotechnology

As introduced above, nanotechnology in relation to the environment has two aspects that are covered in this report. On the one hand, nanotechnology is one of the emerging technologies that can be applied in the observation of environmental phenomena, help prevent or remediate environmental degradation (direct effect) or lead to reduced energy and resource consumption

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11 http://www.euro.who.int/en/media-centre/sections/press-releases/2015/04/air-pollution-costs-european-economies-us$-1.6-trillion-a-year-in-diseases-and-deaths,-new-who-study-says
12 http://ec.europa.eu/eurostat/web/environment/overview/policy-context
13 http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02006R1907-20140410
14 https://data.oecd.org/water/waste-water-treatment.htm
15 Ibid
16 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016DC0105&from=EN
17 Ibid
18 Ibid
19 www.who.int. A specialised agency of the United Nations that is concerned with international public health.
20 www.unece.org. A multilateral forum for the countries of North America, western, central and eastern Europe and central Asia.
21 http://www.un.org/apps/news/story.asp?NewsID=50716#.Vwpf201MrIU
22 http://www.euro.who.int/en/media-centre/sections/press-releases/2015/04/air-pollution-costs-european-economies-us$-1.6-trillion-a-year-in-diseases-and-deaths,-new-who-study-says
23 http://www.ccohs.ca/oshanswers/chemicals/iaq_intro.html
24 http://ec.europa.eu/environment/soil/three_en.htm
25 Ibid

(indirect effect).

On the other hand, introducing new substances, such as nanomaterials, to the environment may have unknown environmental and health effects (environmental health and safety). Given these uncertainties and based on an assessment of cases where early warnings were ignored, the EEA sees the "precautionary principle" as the appropriate policy approach for nanotechnology (see box).

State of the Environment 2015: Global MegaTrends GMT 4: Accelerating technological change (EEA)

"The pace of technological change, particularly in the fields of information, communication, nano- and bio-technologies, is unprecedented. This provides opportunities to reduce humanity's impact on the environment and reliance on non-renewable natural resources, while improving lifestyles, stimulating innovation and green growth.

The risks and uncertainties associated with technological innovation can be managed using regulatory frameworks and the precautionary principle. By recalibrating its institutions, policies and environmental knowledge base, Europe can support better risk management, while enhancing innovation and the diffusion of new technologies."

In the following sections, the role of nanotechnology for the environment is discussed, followed by a discussion of the role of nanotechnology in the environment.

2.2.1 Nanotechnology for the environment

Nanotechnology has applications to address environmental issues for example enhancing the prevention, detection and remediation of environmental degradation and the production of better materials (lighter, more effective, lower cost)[26]. Eurostat divides the environmental goods and services sector[27] (EGSS) into environmental protection (EP) and resource management (RM), described in the Industry chapter below. The world market for nanotechnology applications in environmental engineering has been estimated at EUR 19.4 billion in 2014[28].

Remediation applications include those for water, soil and air[29]. The properties of nanomaterials relevant to remediation include their high surface area (for contaminants to bind to them and be neutralised or extracted), their small pore size (for use as filters or membranes), and their catalytic properties (enabling them to convert a contaminant into a benign material).

Two target pollutants and contaminants for nanotechnology that are being researched and developed[30] are organic materials and heavy metals. Organic materials can potentially be removed or neutralised using a variety of techniques including:

- by photocatalytic oxidation using titanium dioxide nanoparticles;
- by reduction and adsorption using iron (including magnetite) or bi-metallic nanoparticles;
- by adsorption with nanoclays, nanotubes, fullerenes or micelles; or
- by encapsulation using dendrimers.

Heavy metals can also potentially be removed by adsorption (by nanoparticles of iron, nanoclays, nanotubes, fullerenes or dendrimers) as well as by vesicles. Both organic and inorganic compounds could be removed by filtration using nano-filters and membranes. There are disadvantages to the various methods that are yet to be overcome. These include cost, membrane fouling and the creation of waste products in the form of sludge. There may also be environmental, health and safety risks associated with the use of nanotechnology in the environment, particularly in the case of nanotubes

[26] http://www.eea.europa.eu/soer-2015/global/technology GMT 4
[27] http://ec.europa.eu/eurostat/web/environment/environmental-goods-and-services-sector
[28] BCC 2009: "Nanotechnology in Environmental Applications: The Global Market"; Market report abstract, BCC Research Inc. (www.bccresearch.com) in nano.DE-Report 2013 by the Federal Ministry of Education and Research in Germany, https://www.bmbf.de/pub/nanoDE_Report_2013_englisch_bf.pdf.
[29] Nanotechnology in Environmental Applications: the Global Market, BCC Research, September 2015. www.bccresearch.com.
[30] Annual Review of Nano Research, Volume 2, Edited by: Guozhong Cao (University of Washington, USA), Qifeng Zhang (University of Washington, USA), C Jeffrey Brinker (University of New Mexico, USA & Sandia National Laboratories, USA). http://www.worldscientific.com/series/arnr.

and fullerenes.

Some specific examples of remediation and prevention of pollution by the location of the contaminant have been identified[31]. Specific applications of nanotechnology in the areas of water, air and soil will be elaborated in the sections that follow.

WATER REMEDIATION AND POLLUTION PREVENTION

Water pollution and scarcity are environmental problems that can disrupt ecosystems and seriously affect the health of humans and other species. The adoption of nanotechnology offers new opportunities in technological developments for (waste) water treatment processes. The specific nano-based characteristics allow the development of high-tech materials for efficient water and wastewater treatment processes, such as membranes, adsorption materials, nanocatalysts, functionalised surfaces, coatings, and reagents [32].

In this section, issues will be identified that nanotechnology can help to address in the following areas: oil spills, bio(nano)remediation (detection and removal of bacteria, viruses, antibiotics and parasites), radioactive materials, water desalination, decomposition of organic molecules and arsenic cleaning.

Crude petroleum (**oil** as it comes out of the ground) and refined petroleum (fuel oil, diesel, petrol, and other processed petroleum products) reach the ocean from a number of sources and become highly disruptive pollutants. Some of the oil components can kill aquatic organisms immediately upon contact and seriously damage ocean ecosystems. Nanotechnology offers the opportunity of breaking down oil spills[33] into biodegradable compounds e.g. using high surface area photo-catalytic copper tungsten oxide nanoparticles. Furthermore, boron-doped carbon nanotubes can be used for removing oil as they absorb the oil and form a sponge-like material that can easily be extracted from water[34].

Bacteria are also a major type of water pollutant. These types of organism normally come from human and animal wastes and contaminate drinking water. Although most bacteria are harmless to humans, certain bacteria can transmit diseases such as typhoid fever, cholera or enteritis[35]. Silver nanoparticles can be used to neutralise bacteria in drinking water because of their effectiveness as antimicrobial agents[36]. Silver chloride nanowires are being investigated as a means to decompose organic molecules in water.

One of the main problems of nuclear energy production is that it produces highly **radioactive waste,** including the water used for cooling its reactor cores. Other activities, such as mining, metal processing, fossil fuel extraction and combustion, or manufacture of different materials, can also release significant amounts of radioactive material into the environment. Nanotechnology (e.g. in the form of graphene oxide) can be used to extract radioactive materials from water, forming clumps that can be taken out of the water[37] [38].

Much of the world population does not have access to safe drinking water. The access to freshwater is very limited, and about 97% of earth's water is salty. The most used desalination methods to increase the supplies of freshwater from the oceans and other salt water sources are distillation and reverse osmosis. Nanotechnology offers the opportunity of using graphene and carbon nanotube membranes[39] in order to desalinate water more cheaply than via reverse osmosis, since water flows more easily through these membranes than through traditional membranes. Another benefit is that these membranes are more energy efficient than traditional processes.

Arsenic can be released into drinking water supplies through human activities such as mining, ore

[31] Ibid

[32] Gehrke I., Geiser A., and Somborn-Schulz A. (2015), Innovations in nanotechnology for water treatment, Nanotechnology Science and applications, 8, 1-17: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4294021/

[33] http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=129566.

[34] http://news.psu.edu/story/149790/2012/04/16/oil-spill-clean-may-be-made-easier-carbon-nanotube-technology

[35] http://water.usgs.gov/edu/bacteria.html

[36] http://digitalcommons.uri.edu/cgi/viewcontent.cgi?article=1033&context=oa_diss.

[37] http://news.rice.edu/2013/01/08/another-tiny-miracle-graphene-oxide-soaks-up-radioactive-waste/.

[38] http://oaktrust.library.tamu.edu/bitstream/handle/1969.1/152067/CONCKLIN-DOCUMENT-2014.pdf.

[39] http://www.nature.com/nnano/journal/v10/n5/full/nnano.2015.37.html.

processing or even drilling wells into areas that are naturally rich in arsenic. A high concentration of arsenic is a pollutant that is toxic for those drinking it (research estimates that more than 140 million people worldwide are drinking water with arsenic concentrations over the guideline of 10 µg/litre set by the WHO), causing premature deaths from skin, bladder and lung cancer. Iron nanoparticles can be used to clean arsenic from wells.

Some of the above would also be applicable in other environments (for example, using graphene oxide to absorb radioactive materials at a nuclear plant[40] and for the disposal of nuclear waste[41]).

Other nanomaterials for water remediation include self-assembled monolayers on mesoporous silica (SAMMS); dendrimers or dendritic polymers; single nanoparticle enzymes (SENs); tuneable biopolymers; and nano-crystalline zeolites.

AIR REMEDIATION AND POLLUTION PREVENTION

Air pollution is the presence of chemicals in the atmosphere in concentrations high enough to harm organisms, ecosystems and man-made materials, or to alter the climate. Note that almost any chemical in the atmosphere can become a pollutant if it occurs at a high enough concentration. The effects of air pollution range from annoying to lethal. Among the gases that nanotechnology can help us to remediate are primarily volatile organic compounds (VOCs), carbon dioxide (CO_2) and nitrogen oxides (NOx).

Volatile organic compounds (VOCs) are organic compounds that exist as gases in the atmosphere or that evaporate from sources on Earth into the atmosphere. Nanotechnology enables their removal from the air, for example, using a catalyst of porous manganese oxide in which gold nanoparticles have been embedded[42] [43]. Another example is the remediation of chloroform[44].

CO_2 is a colourless, odourless gas. About 7% of the CO_2 in the atmosphere comes from human activities, mostly the burning of fossil fuels and the clearing of CO_2-absorbing forests and grasslands. There is considerable and growing scientific evidence that increasing levels of CO_2 caused by human activities are contributing to atmospheric warming and projected climate change, because CO_2 is being added to the atmosphere faster than it is removed by the natural carbon cycle. This can contribute to human health problems and to the reduction of food supplies in some areas, while causing water shortages, prolonged drought, or excessive flooding in other areas. Nanotechnology offers various solutions to prevent or reduce the release of CO_2 into the atmosphere, for example:

- Trapping carbon dioxide using crystals with nanopores;
- Converting waste carbon dioxide into methanol fuel[45] [46] (e.g. from emissions from power plants); and
- Removing carbon dioxide from industrial chimney outflow using nanostructured membranes (including those using carbon nanotubes).

Nitric oxide (NO) is a colourless gas that forms when nitrogen and oxygen gas react under high-combustion temperatures in automobile engines and coal-burning power and industrial plants. In the air, NO reacts with oxygen to form nitrogen dioxide (NO_2), a reddish-brown gas. Collectively, NO and NO_2 are called nitrogen oxides (NOx). Both NO and NO_2 play a role in the formation of photochemical smog—a mixture of chemicals formed under the influence of sunlight in cities with heavy traffic. Nitrous oxide (N_2O), a greenhouse gas, is emitted from fertilisers and animal wastes, and is produced by the burning of fossil fuels. At high enough levels, nitrogen oxides can irritate the eyes, nose and throat, aggravate lung ailments such as asthma and bronchitis, suppress plant growth, and reduce visibility when they are converted to nitric acid and nitrate salts. Nanotechnology can help to remove NOx from smoke using a cobalt-platinum nano-catalyst or carbon nanotubes[47]. It can be used to catalyse waste gas pollutants (from car exhausts and industrial plants) into

[40] http://www.i-sis.org.uk/Graphene_Oxide_for_Nuclear_Decontamination.php.
[41] http://www.ncbi.nlm.nih.gov/pubmed/25302669.
[42] http://www.understandingnano.com/nanoparticles-gold-voc-air-pollution.html.
[43] http://www.ncbi.nlm.nih.gov/pubmed/24566352.
[44] http://news.rice.edu/2013/04/15/chloroform-cleanup-just-the-beginning-for-palladium-gold-catalysts-2/.
[45] http://phys.org/news/2016-01-carbon-dioxide-captured-air-methanol.html.
[46] http://www.nanowerk.com/news2/green/newsid=42524.php.
[47] http://www.tandfonline.com/doi/full/10.1080/21622515.2012.733966.

harmless gases using nanocatalysts[48].

Air pollution is a key problem in energy production. On the one hand, and as mentioned above, transport requires a large amount of energy that is normally produced by the use of fuels. To some extent, nanotechnology can be used to reduce pollution by preventing the production of gas pollutants through improving the fuel efficiency and combustion of engines (see box below)[49] and it can also be used in developing fuel cells catalysed by nanomaterials[50]. On the other hand, nanotechnology can be used in generating clean energy. Coal-burning power and industrial plants are among the largest emitters of the greenhouse gas CO_2 (according to a 2007 study by the Centre for Global Development, coal-burning power plants account for 25% of all human-generated CO_2 emissions in the world). In recent years, there has been an increase in the use of sustainable energy production technologies and nanotechnology can be used to increase the efficiency of these technologies. Two examples of existing innovations are:

- Solar cells using silicon nanowires embedded in a polymer to enhance the absorption of sunlight, thereby reducing use of the expensive semiconductor materials that conventional solar cells need[51]; and
- Epoxies that contain carbon nanotubes, for stronger and lighter blades for wind turbines[52].

Nanoparticle fuel additives

Nanoparticle fuel additives

"One catalytic application already developed is the use of cerium(IV) oxide nanoparticles which are added to diesel and bio-diesel fuels in very small amounts (5-10 ppm). When diesel fuel is combusted in an engine, it is not completely oxidised and fine particles of carbon, carbon monoxide as well as unreacted fuel are emitted. The additive, cerium(IV) oxide acts as a heterogeneous catalyst and ensures that the fuel is combusted completely to carbon dioxide and water, thus leading to an improvement in fuel efficiency by as much as 4-11% and much less pollution (about 18% less particulate matter is emitted). Because of their size, the cerium(IV) oxide nanoparticles forms a homogeneous solution in the fuel and are thus easily premixed with the fuel, which then requires no special delivery equipment and does not require any modification to the vehicle engine.

The catalysts in catalytic converters for cars are nanoparticles of alloys of palladium and rhodium."

"Over the last few years, a bus company, Stagecoach, in the UK, has been experimenting with using cerium(IV) oxide nanoparticles added to the diesel fuel. The trials took place in a rural area (in the north west of England) and London. Each trial involved 300 buses. It found that there was a 6% and 5% fuel saving respectively. Now the company uses the additive in over 6000 buses."

From: http://www.essentialchemicalindustry.org/materials-and-applications/nanomaterials.html

SOIL REMEDIATION AND POLLUTION PREVENTION

Soil supplies most of the nutrients needed for plant growth and purifies and stores water. Its contamination can affect health, cause the deterioration of ecosystems, and result in the infiltration of soil contamination into groundwater aquifers used for human consumption, which can be a major problem depending on the nature of the pollutant.

Hazardous waste, for instance, can greatly affect human health and environment due to its

[48] The use of silver nanoclusters as catalysts can significantly improve reactions and reduce the polluting byproducts generated in the process used to manufacture propylene oxide. Propylene oxide is used to produce common materials such as plastics, paint, detergents and brake fluid. (http://www.understandingnano.com/silver-nanocluster-catalyst-low-by-product-reaction.html

[49] www.essentialchemistryindustry.com

[50] https://www6.slac.stanford.edu/news/2014-07-21-new-platinum-alloy-shows-promise-fuel-cell-catalyst.aspx

[51] http://www.understandingnano.com/solar-cells-silicon-wire-arrays.html

[52] http://www.jeccomposites.com/news/composites-news/wind-turbine-blade-carbon-nanotubes-polymer-nano-composites-developed

poisonous, dangerously chemically reactive, corrosive or flammable nature. Soil may be contaminated with these kinds of wastes due to various human activities. Examples of hazardous wastes include industrial solvents, hospital medical waste, car batteries (containing lead and acids), household pesticide products, dry-cell batteries (containing mercury and cadmium), and incinerator ash. Nanotechnology can be used to extract heavy metals (e.g. mercury, lead, cadmium) and organic compounds (e.g. benzene, creosote and toluene as well as chlorinated solvents) from soil. Two of the uses can be to improve bioremediation using micro-organisms to break down polluting benzene, toluene and carbon tetrachloride[53] and using geopolymers to encapsulate and immobilise hazardous or radioactive waste[54]. Another example is the use of nanoclays to absorb ions, gas and water from soil[55] or the use of nano-calcium peroxide to destroy contaminants by converting them to innocuous compounds[56].

Due to the connection between soil and groundwater aquifers, soil remediation can improve water quality. For instance, nanotechnology can be used in cleaning water in the ground, removing pollutants (such as chlorinated hydrocarbons, polychlorinated biphenyls (PCBs), pesticides and chromate compounds) using a permeable reactive barrier with nano zero-valent iron (or, for some applications, zinc, tin, palladium, silver, platinum, cobalt, copper or gold)[57] [58]. It can also help to address water scarcity using nano-coated hydrophobic sand[59] [60] to create an artificial water table in the soil, thereby retaining water in the area around the roots of the plants and preventing it from draining away.

SENSING APPLICATIONS OF NANOTECHNOLOGY IN THE ENVIRONMENT

Sensors based on nanotechnology have the potential to reduce wastage of resources (energy, for example) and to indicate the quality of the environment (air, water and soil). Nanoparticle-based biosensors are potential tools for rapid, specific and highly sensitive detection, making it possible to sense very small concentrations of contaminant. Examples include:

- Silver nanocrystal based substrates for ultra-sensitive arsenic detection using surface enhanced Raman spectroscopy[61];
- Due to the increased gas sensing properties, metal oxide-based nanosensors were found to be potential candidates for NOx, ethanol, ammonia and ozone sensing applications;
- Graphene-based electrochemical sensors are under research and development for detection of gases (including hydrogen) and heavy metal ions (such as lead, cadmium, mercury and arsenic)[62]; and
- Quantum dots are being explored for sensing based on their enhanced luminescence and band gap tenability. Applications include the detection of single cells of *E.coli* using CdSe/ZnS quantum dots.

RESOURCE EFFICIENCY

In addition to greater fuel efficiency through a more efficient combustion system, as already mentioned above, studies[63] [64] describe the potential of nanotechnology to improve the efficiency of resource use:

- **Energy consumption** can be potentially reduced through: a) better insulation systems using nano-porous materials; b) more efficient lighting since technology using nanotechnology like LEDs (Light Emitting Diodes) or QCAs (Quantum Caged Atoms) are much more energy efficient; c) the energy consumption in the mobility sector can be reduced by the use of lighter and

[53] http://link.springer.com/article/10.1007/s11157-010-9215-6
[54] http://www.wmsym.org/archives/2011/papers/11097.pdf
[55] http://www.azonano.com/article.aspx?ArticleID=3178
[56] Khodaveisi et al., 2011
[57] http://www.tandfonline.com/doi/full/10.1080/21622515.2012.733966
[58] http://ipp.nasa.gov/innovation/innovation131/4-coverstory.html
[59] http://phys.org/news/2009-02-hydrophobic-sand-combat-shortages.html
[60] http://www.nanoshell.co.uk/just-water-repelling-hydrophobic-sand-thanks-nano-coatings-technology
[61] http://superfund.berkeley.edu/research-projects/project-5-nanotechnology-based-environmental-sensing/
[62] "Nanosensors: Materials and Technologies" by Nada F Atta, 2014.
[63] Nanotechnology development in Denmark – environmental opportunities and risk, Maj Munch Andersen and Birgitte Rasmussen, Risø National Laboratory, Risø-R-1550(EN), May 2006.
[64] Royal Commission on Environmental Pollution, twenty-seventh report "Novel Materials in the Environment: the case of nanotechnology, November 2008.

stronger nanostructured materials; d) synthetic or manufacturing processes can occur at ambient temperature and pressure.

- A more efficient or renewable **energy production** can be developed: a) the development of novel ultra-hydrophobic coatings to reduce the icing-up of wind turbine blades; b) increased efficiency of light conversion in solar cells through specifically designed nanostructures (the implementation of nanodots); c) solar cells using titanium dioxide nanoparticles as light absorbing components (Grätzel cells) in order to reduce their cost.
- Reduction of **resource consumption** in the production or user phase: a) nanoparticles in paint can induce new properties to the paint, e.g. cooling effects, self-cleaning and self-repairing surfaces; b) nanotubes (or fibres built from them) can be used as reinforcement for composite materials. Because of the nature of the bonding, it is predicted that nanotube-based material could be 50 to 100 times stronger than steel at one-sixth of the weight, if current technical barriers can be overcome; c) strengthening of polymers in order to produce new materials with less consumption of raw materials that can substitute existing materials; d) reduced use of rare resources such as precious metals or toxic substances in catalysts; e) textiles with nanotechnology finish can be washed less regularly and at lower temperature.
- Improving **recycling** through: a) the use of batteries with higher energy content, or the use of rechargeable batteries or supercapacitors with higher rate of recharging using nano materials, could limit the battery disposal problem; b) integration of nanochips in materials and products containing information about material properties and composition can be used for recycling purposes (there are, however, also arguments that multifunctional nano-products may be difficult to recycle).

The next section looks at nanotechnology, and its potential impact, in the environment.

2.2.2 Nanotechnology in the environment

Nanotechnology is also a potential pollutant that could have a negative impact on the environment, in the form of nanomaterials or nanoparticles of which the behaviour is still largely unknown. Hansen et al. (2007) developed a procedure to divide nanomaterials into categories in aid of hazard identification and risk assessment, shown in the figure below. Their categorisation is based on the location of the nanoscale structure in the system. According to the EEA, most health and environmental impact concerns have been raised over nanoparticles that fall into subcategories IIIc (nanoparticles suspended in solids) and IIId (airborne nanoparticles).

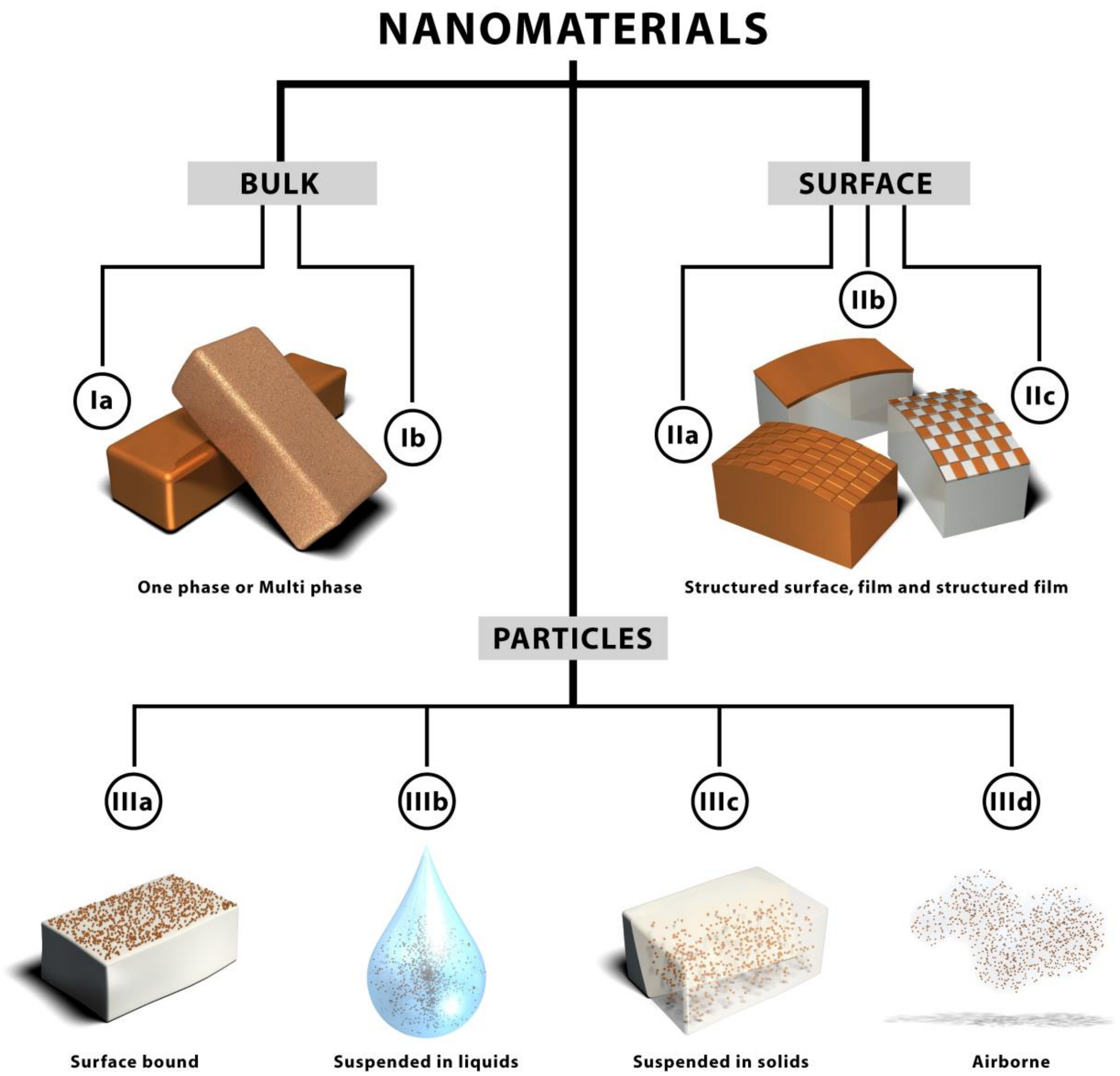

Figure 2-1: Categorisation framework to aid hazard identification of nanomaterials[65]

Different studies consider the potential risk of nanomaterials in terms of toxicity related to size, crystal structure and surface (surface area, chemistry and charge), as well as degradability (persistence) and potential for bioaccumulation. These factors could influence the properties (functionality and behaviour) of nanoparticles and must all be considered when assessing the risks to the environment and human health. Although there is still a lack of real evidence about the risks and consequences of nanoparticles entering the environment, the results from studies and analyses to date will be discussed in this section [66, 67, 68, 69] and later in the discussions on Environment, Health and Safety (EHS).

A main concern is that nanoparticles entering the environment could potentially be, or could become,

[65] Source: Hansen, S. F., Larsen, B. H., Olsen, S. I., Baun, A., 2007, Categorisation framework to aid Hazard Identification of Nanomaterials, Nanotoxicology (1) 243–250, reprinted with permission.
[66] http://www.ncceh.ca/sites/default/files/Nanotechnology_Review_Aug_2011.pdf.
[67] http://www.nanocap.eu/Flex/Site/Pagefdba.html?PageID=20815.
[68] Nanotechnology development in Denmark – environmental opportunities and risk, Maj Munch Andersen and Birgitte Rasmussen, Risø National Laboratory, Risø-R-1550(EN), May 2006.
[69] Royal Commission on Environmental Pollution, twenty-seventh report "Novel Materials in the Environment: the case of nanotechnology, November 2008.

toxic to living species in the environment. Nanoparticles may be toxic to microorganisms in soil and groundwater such as fish or insects. There is also a risk to plants from nanoparticles, which could have a follow-on effect on the food chain. The deposition of atmospheric particles on crops, for instance, could provide an entry path for toxic or reactive nanoparticles into the food chain.

Nanoparticles entering the environment can also become toxic in their lifecycle. For instance, waste nanoparticles from a manufacturing plant entering a stream could alter the pH of the stream. Altering the pH of a stream can result in metals that are not normally soluble dissolving, like aluminium. Aluminium in the water supply would be toxic to living things in the stream.

Nanoparticles may be inherently toxic even in small quantities and therefore the knowledge built up for regular chemicals cannot necessarily be transferred to nanoparticles. Some manufactured nanoparticles may be more toxic per unit of mass than larger particles of the same chemical. While the standard approach to toxicity is in relation to the mass of the chemical, in the case of nanomaterials also surface area and surface chemistry should be taken into consideration.

The EEA draws parallels with past experience of ambient ultrafine particles (smaller than 0.1 micron or <100 nm, such as diesel exhaust) and asbestos, where early signs that the size of the particle is related to harm (the smaller the more harmful) were ignored. Ultrafine particles have a different biological behaviour and mobility than larger particles. There is no linear relationship between mass and effect. It is likely that nanoparticles will penetrate cells more readily than larger particles. Studies are looking in particular at ultrafine titanium dioxide (TiO_2), carbon nanotubes (CNT) and nanometre-scale silver (nanosilver), the latter related to the widespread use in consumer products (dietary supplements, personal-care products, varnish, textile, water and air purification, printing colours, and foils for antibacterial protection, such as in washing machines, kitchenware and food storage). The scale of use and concentrations are currently unknown to the consumer, there being no labelling of this form on products.

Both the EEA and the United Kingdom's Royal Commission on Environmental Pollution point to another issue that makes nanomaterials (in particular nanoparticles) different from conventional industrial chemicals, namely their ability to agglomerate and aggregate. These larger structures may have different toxicological properties from individual particles.

Environmental hazard identification not only uses parameters of toxicity, but also the persistence (degradability) and potential for bioaccumulation. Many nanomaterials are robust and do not easily degrade, as is true for many other chemicals, and have to be recycled or disposed of. The rapid transformation of nanoparticles could also render traditional approaches to describing, measuring and monitoring air or water quality inadequate.

The evaluation of risks related to nanoparticles is complicated by the fact that they already exist widely in the natural world (e.g. as a result of photochemical and volcanic activity or created by plants and algae). Some of these are highly toxic. They have also been created for thousands of years by man as a by-product of cooking and combustion and more recently vehicle exhaust. The question is then whether manufactured nanoparticles or the use of nanoparticles in new ways present new risks.

The EEA concludes that the EU's and most Member States' regulatory activity focuses on the toxicity aspect of nanomaterials, where they treated as chemical substances under REACH.

More background about the regulatory framework is covered later in this report in the section on Regulation and Standards. The section on Environment, Health and Safety and Nanotechnology discusses the risks of and assigns a risk hazard band to the following nanomaterials: calcium peroxide nanoparticles, carbon nanotubes (single- and multi-walled), cobalt manganese oxide nanoparticles, cobalt-platinum nano-catalyst, copper tungstate, dendrimers, fullerenes, graphene and graphene oxide, iron nanoparticles, iron oxide nanoparticles, gold nanoparticles, micelles, nanoclay, nano-porous materials, nano-coated hydrophobic sand, silicon nanowires, silver nanoparticles, single enzyme nanoparticles and titanium dioxide nanoparticles.

The next section looks at the policies at European Union and Member State levels that are supporting the development of nanotechnology and environment and assessing the risks and uncertainties of nanotechnology in relation to the environment.

3 EU POLICIES AND PROGRAMMES FOR NANOTECHNOLOGY AND ENVIRONMENT

3.1 Environment policies

The EU's overarching policy for growth is "Europe 2020: A strategy for smart, sustainable and inclusive growth"[70]. This strategy sets priorities[71] and targets[72] for *, inter alia,* science, research and innovation, energy and climate. The strategic areas, their priorities and targets are addressed in flagship initiatives such as "Innovation Union", "Resource Efficient Europe" and "An Industrial Policy for the Globalisation Era".

In 2009, the European Commission published a Communication on "Preparing for our future: Developing a common strategy for key enabling technologies in the EU"[73]. Key enabling technologies (KETs, which include nanotechnology and nano-electronics) are recognised as one of the driving forces of new goods and services for the market but also to address major societal challenges (such as climate change and improving resource and energy efficiency). The Communication sets out measures to foster the development and exploitation of KETs at EU and Member State levels. It also includes an explicit link with climate change policy stating that "the leading role of the EU in the fight against climate change has to be based on the most modern technologies, in particular KETs. The combination of fostering KETs and fighting climate change would offer important economic and social opportunities".

EU environmental policy dates back to the 1970s and, as a result, the European Commission's Environment Directorate-General has many ongoing dossiers[74] in thematic domains such as air, water, waste and chemicals. Policy and implementation are guided by the multi-annual Environmental Action Programmes, of which the first was adopted in 1972[75].

The current Environmental Action Programme until 2020 is entitled 'Living well, within the limits of our planet' (7th EAP)[76]. The 7th EAP recognises both the benefits of and risks and uncertainties associated with (emerging) technologies. On nanomaterials, Article 50 states:

"However, there is still uncertainty about the full impacts on human health and the environment of the combined effects of different chemicals (mixtures), **nanomaterials**, chemicals that interfere with the endocrine (hormone) system (endocrine disruptors) and chemicals in products. Research indicates that some chemicals have endocrine-disrupting properties that may cause a number of adverse effects on health and the environment, including with regard to the development of children, potentially even at very low doses, and that such effects warrant consideration of precautionary action" and "The safety and sustainable management of nanomaterials and materials with similar properties will be ensured as part of a comprehensive approach involving risk assessment and management, information and monitoring".

In October 2011, the EC published a *Recommendation on the definition of a nanomaterial* (2011/696/EU). The purpose was to enable the determination of when a material should be considered a nanomaterial for regulatory purposes in the European Union. The definition covers natural, incidental and manufactured (or engineered) materials and is based solely on the size of the constituent particles of a material, without regard to specific functional or hazard properties or risks. Regulations where the definition is already being used or under preparation are:

- Biocides regulation 528/2012 (EU BPR), which covers a diverse group of products (disinfectants, pest control, preservatives);

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[70] http://ec.europa.eu/europe2020/index_en.htm, the agenda for growth and jobs from 2010-2020.
[71] Such as investing in education, research and innovation, transition to a low carbon economy.
[72] Such as 3% of the EU's GDP to be invested in R&D, greenhouse gas emissions 20% lower than 1990, 20% of energy from renewables, 20% increase in energy efficiency.
[73] Communication from the Commission to the European Parliament, the Council, the European and Economic and Social Committee and the Committee of the Regions, COM(2009) 512 final, 30 September 2009. KETs comprise micro and nanoelectronics, nanotechnology, industrial biotechnology, advanced materials, photonics, and advanced manufacturing technologies.
[74] http://ec.europa.eu/dgs/environment/index_en.htm
[75] http://www.eea.europa.eu/environmental-time-line/1970s
[76] http://ec.europa.eu/environment/action-programme/index.htm, Decision 1386/2013/EU of 20 November 2013.

- Medical devices regulation 542/2012;
- Cosmetic products regulation 1223/2009, such that packaging must now list the use of nanomaterials[77]; and
- Food information regulation 1169/2011 on labelling, presentation and advertising of food stuffs and labelling of nutrition information, which should now include information on engineered nanomaterials in the ingredients[78].

2011 EC recommended definition of nanomaterial

'Nanomaterial' means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm- 100 nm.

In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50%.

The Commission is also looking at ways to use the definition in the context of any potential nanomaterial specific provisions related to REACH. EU agencies such as the European Chemicals Agency[79] (ECHA) and the European Food Safety Authority[80] (EFSA) have started to use the definition in their work. It should be noted that in a number of these regulations, the definition of nanomaterial is restricted to intentionally manufactured or engineered nanomaterials.

One of the articles in the Recommendation announces a review to be carried out to collect experience and the most up-to-date scientific and technological developments by December 2014. Therefore, at the request of EC Environment Directorate General and other Commission services, the Joint Research Centre[81] (JRC) of the European Commission in 2014 undertook such a comprehensive review of this 2011 definition. This resulted in three reports[82] entitled "Towards a review of the EC Recommendation for a definition of the term "nanomaterial":

- Part 1: Compilation of information concerning the experience with the definition;
- Part 2: Assessment of collected information concerning the experience with the definition; and
- Part 3: Scientific-technical evaluation of options to clarify the definition and to facilitate its implementation.

In Article 54, the 7th EAP states that "in order to safeguard the Union's citizens from environment-related pressures and risks to health and well-being, the 7th EAP shall ensure by 2020 that: (f) safety concerns related to nanomaterials and materials with similar properties are effectively addressed as part of a coherent approach in legislation".

Investments in further data collection and research are aimed at providing the evidence-base for decision-making. Such investments can come from Member States either directly through national programmes, indirectly via the programmes administered by the European Commission and its agencies or a combination of those two (such as Joint Programming Initiatives, Joint Technology

[77] http://www.cirs-reach.com/Cosmetics_Registration/eu_cosmetics_directive_cosmetics_registration.html
[78] http://ec.europa.eu/food/safety/labelling_nutrition/labelling_legislation/index_en.htm
[79] www.echa.europa.eu. EU agency with independent authority to support and monitor implementation of the EU's chemicals legislation.
[80] www.efsa.europa.eu. EU agency that provides independent scientific advice to member national authorities on existing and emerging risks in food safety.
[81] ec.europa.eu/jrc. JRC is the European Commission's in-house science service.
[82] Part 1: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/towards-review-ec-recommendation-definition-term-nanomaterial-part-1-compilation-information;
Part 2: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/towards-review-ec-recommendation-definition-term-nanomaterial-part-2-assessment-collected;
Part 3: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/towards-review-ec-recommendation-definition-term-nanomaterial-part-3-scientific-technical.

Initiatives[83] and TFEU article 185[84] public research and innovation programmes jointly funded by Member States and the Commission). In addition, research and development is funded by companies (intra- and extra-mural R&D) and by philanthropic bodies and individuals. This report concentrates mainly on funding via the European Commission (EU funding), Member State funding and the outputs of industry funding of its own R&D.

EU funds for research and innovation are provided through multi-annual programmes. The most important are the Framework Programmes (formerly the Framework Programmes for Research and Technological Development (FP1 through FP7), currently Horizon 2020), covering all research fields and fully dedicated to funding research and innovation activities.

This section will examine the role of the EU Framework Programmes in supporting nanotechnology in relation to the environment.

3.2 The EU Framework Programmes: supports for nanotechnology

The Framework Programmes (FPs) being the largest source of EU funds for R&D, they have the greatest role in EU funding of nanotechnology R&D. In the Fifth Framework Programme (FP5, 1998-2002), support for nanotechnology projects was in the region of EUR 150 million[85]. Support specifically named as being for nanosciences and nanotechnologies was first provided at a significant level in the Sixth Framework Programme (FP6, 2002-2006)[86] with a significantly increased funding of EUR 1.3 billion. The focus was two-fold: 1) on exploring and exploiting the expected opportunities of nanotechnology, for applications in fields such as the environment and life cycle optimisation of industrial systems, products and services in particular with a view to eco-efficiency and reduced emission of substances that are harmful to the environment (for example, research into nano purification systems and nano-sensors) and 2) safety aspects of engineered nanomaterials. From the outset, public health, safety and environmental and consumer protection were part of the European strategy for nanotechnology "Towards a European Strategy for Nanotechnology"[87]. In FP6 environmental research was included as part of sustainable development (triple-P of people, planet, profit), with research priorities sustainable surface transport, sustainable energy systems and global change and ecosystems.

Nanotechnology funding in FP6 was followed up with targeted funding in the Seventh Framework Programme (FP7, 2007-2013), the largest part specific to nanotechnology being the "Nanosciences, Nanotechnologies, Materials and new Production Technologies (NMP)" theme under the Co-operation Programme. This specific activity for nanotechnology has played the most significant role in supporting nanotechnology research and technology development, with EUR 3.5 billion having been allocated to NMP over the duration of FP7.

The emphasis in FP7 was on nanosciences and nanotechnologies to study phenomena and manipulation of matter at the nanoscale and developing nanotechnologies leading to the manufacturing of new products and services. FP7 NMP, like FP6, also included both research and technology development for new applications, products, processes and materials as well as risk assessment (e.g. nano-toxicology and eco-toxicology) and safety. New production, materials etc. towards sustainable production and consumption patterns and waste reduction were included, as well as integration of technologies to develop new environmental and health applications. The programme also included the option to flexibly respond to emerging policy needs such as potential

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[83] Joint Technology Initiatives are public-private partnerships between the European Commission and industry, based on TFEU article 187.

[84] The Treaty on the Functioning of the European Union (TFEU) in article 185 allows the setting up of programmes funded jointly by participating Member States and the European Commission. Examples are Eurostars, an R&D programme for SMEs and the European Metrology Programme for Innovation and Research (EMPIR).

[85] This figure relates to projects supported under the four FP5 thematic programmes (Quality of life, Information society, Sustainable growth, Environment, energy and sustainable development). The nanotechnologies were also an important theme in the actions for the mobility and training of researchers and are central to several coordination networks under the pan-European COST initiative. Source: https://ec.europa.eu/research/fp6/pdf/nanotech_en.pdf

[86] FP6 NMP: Nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices: thematic priority 3 under the 'Focusing and integrating community research' of the 'Integrating and strengthening the European Research Area' specific programme, 2002-2006.

[87] COM(2004) 338 of 12 May 2004, http://cordis.europa.eu/nanotechnology/actionplan.htm (archived)

environmental and health impacts arising from nano-technologies.

Environment (including climate change) was a separate priority in FP7 Cooperation, with a budget of EUR 1.9 billion and, in addition, environmental aspects are included in almost all other thematic priorities (such as energy, agriculture and health). Research into, and development of, new technologies to achieve a sustainable use of resources, to mitigate and adapt to climate change and to protect ecosystems and the man-made environment are mentioned, but without specific reference to nanotechnology.

Horizon 2020[88] includes nanotechnologies as one of the enabling and industrial technologies in one work programme with advanced materials, biotechnology and advanced manufacturing. Horizon 2020 puts significant emphasis on a synergy of actions between generic, enabling and industrial technologies and the societal challenges such as climate action, environment, resource efficiency and raw materials. Again, similar to FP6 and FP7, for nanotechnology and biotechnology in particular, engagement with stakeholders and the general public is addressed to raise awareness of risks and benefits, as well as safety assessment and the management of overall risks. Ensuring the safe and sustainable development and application of nanotechnologies in relation to health and the environment is one of the activities being supported through Horizon 2020 projects. Under societal challenge *Health, demographic change and well-being*, the JRC will contribute to the assessment of risks and opportunities of new technologies, including nanomaterials, in food, feed and consumer products.

Within FP7 and Horizon 2020, non-specific basic research is funded and each of these provides potential funding for nanoscience and technology. Significant examples of these are:

- The European Research Council (ERC): total funding of over EUR 7.5 billion in FP7 (and EUR 13.1 billion in 2014-2020 under Horizon 2020[89]) for investigator-driven, bottom-up research ideas in science, engineering and interdisciplinary research, awarded through open competition;
- Future and Emerging Technologies (FET): funding of EUR 2.7 billion in Horizon 2020 to achieve scientific breakthroughs in energy-related concepts and enabling technologies such as nanoscience and materials science.

Other mechanisms for collaboration on nanotechnology, *inter alia*, include Joint Programming (ERA-NETs, Networks of Excellence and EMPIR) and ESFRI, as outlined below.

The ERA-NET scheme began under FP6 to support collaboration between and co-ordination of national research programmes. (Joint Programming) and was continued under FP7 and Horizon 2020. There are 21 ERA-NET initiatives related to the environment, and one related to nanotechnology: ERANET SIINN[90] – Research funding and networking in the safety of nanotechnology, which started August 2011.

The European Metrology Programme for Innovation and Research[91] (EMPIR) is a public programme established on the basis of Article 185 of the Treaty on the Functioning of the EU (TFEU) set up between EURAMET (representing the national metrology institutes in the Member States) and the European Commission. The objective is for the national metrology institutes to undertake joint R&D and innovation activities in order to develop new measurement techniques to provide accurate and reliable measurements of, for example, the environment given new developments in areas such as nanotechnology.

The EMPIR 2016 work programme states that "*Metrics currently and commonly used have limited validity for application to nanoparticles. Emerging parameters are potentially more reliable as indicators of possible health effects, but the metrology for them is not well established and often lacks traceability. The next generation of air quality legislation is being held up as a result of these deficiencies and this need to be addressed urgently. Metrology R&D is required for this and also for other pollutants where current metrological capability does not satisfy requirements – especially for low concentration and isotopically matched reference materials*".

A key metrology challenge for pollution monitoring, and in support of resource sustainability,

[88] Horizon 2020 is the Framework Programme for Research and Innovation for the period 2014-2020. The programme has three priorities: excellent science, industrial leadership and addressing societal challenges.
[89] http://erc.europa.eu/
[90] http://www.siinn.eu/
[91] http://msu.euramet.org/ and http://www.euramet.org/research-innovation/empir/

includes the development of new and improved metrics and metrology to characterise particulates in the environment with focus on particulates in ambient air. Traceable measurements are required for size, number concentration, mass and surface area for particles from a few nanometres (nm) up to several micro-metres or microns (µm), especially at low concentrations and for nanoparticles of different type and morphology. The chemical composition of particulates also remains a key issue for air quality. Robust measurand definitions and measurement methods are required for emerging pollutants and for quantities of interest in particulates, e.g. Cr(VI), oxidative capacity and total carbon.

Networks of Excellence (NoE) were introduced in the Sixth Framework Programme (FP6) with the objective of combatting fragmentation in the European Research Area (ERA) by integrating the critical mass of resources and expertise needed to enhance Europe's global competitiveness in key areas relevant to a knowledge-based economy. These bottom-up initiatives are led by consortia targeting specific research or technological challenges. These bottom-up initiatives are led by consortia targeting specific research or technological challenges. Examples related to nanotechnology and environment are INSIDE-PORES and NANOMEMPRO[92].

- INSIDE-PORES (with 17 partners from 9 Member States receiving EU funding of EUR 6.8 million over 4 years under FP6) focused on nano-porous catalyst and membrane materials to replace traditional polluting and energy-consuming processing techniques in chemical processing.
- The NANOMEMPRO consortium (with 13 organisations from 13 Member States receiving EU funding of EUR 6.4 million over four years under FP6) focused on membrane materials. Its scientific objective was to research the synthesis of nanostructured artificial membranes to mimic the functions of naturally-occurring cellular membranes that control many functions of life, membranes used industries including water treatment.

European research is also being strengthened through collaboration on the development, establishment and running of large research infrastructures, so large that they cannot easily be funded by one agency or country alone. Under the auspices of the European Strategic Forum on Research Infrastructures (ESFRI)[93], Member States are coming together to fund infrastructure related to the environment, energy, ICT, health, marine and other fields. EU grants support the preparatory phases of all selected projects and assist in implementation and operation of prioritised projects. The EU funding was EUR 1.85 billion in FP7 and is about EUR 2.5 billion in Horizon 2020. The 2016 ESFRI roadmap[94] includes five "landmarks" (implemented projects) and five "projects" (in progress) related to the environment. For example, one project is the European Carbon Dioxide Capture and Storage Laboratory infrastructure (ECCSEL)[95] and a landmark the Integrated Carbon Observation System (ICOS)[96]. Research infrastructures relevant to energy include the project on Integrating European infrastructure to support science and development of Hydrogen and Fuel Cell technologies (H2FC)[97]; Solar Facilities for the European Research Area — second phase (SFERA-II)[98]; and Solar Photovoltaic European Research Infrastructure (SOPHIA)[99].

Other mechanisms to support research and innovation in nanotechnology and environment are outlined in the section on Other EU Policies: Industry, later in this chapter. They include:

- EUREKA's Eurostars;
- European Technology Platforms; and
- Joint Technology Initiatives (and Joint Undertakings);
- European Institute of Innovation and Technology (EIT)[100];
- LIFE[101];

92 https ://ec.europa.eu/research/industrial_technologies/pdf/noes-122007_en.pdf.
93 http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=home.
94 http://www.esfri.eu/roadmap-2016
95 www.eccsel.org
96 https://www.icos-ri.eu/
97 http://www.h2fc.eu/
98 http://sfera.sollab.eu/
99 http://www.sophia-ri.eu/
100 The EIT is a body of the European Union based in Budapest, Hungary. It was established by the Regulation (EC) No 294/2008 of the European Parliament and of the Council of 11 March 2008. It became operational in 2010. http://eit.europa.eu/
101 For environment, biodiversity and climate change.

- CIP Eco-Innovation; and
- The European Structural and Investment Funds (ESIF).

The next section reports on funding and participation data for the Sixth and Seventh EU Framework Programmes, FP6 and FP7.

3.3 The EU Framework Programme: funding and participation data for FP6 and FP7

3.3.1 Overview

Project-related data was extracted from the eCorda database for the EU Sixth Framework Programme (FP6) and the EU Seventh Framework Programme (FP7)[102]. The total number of projects was 35,265, of which 25,238 were FP7 projects and 10,027 were FP6 projects. There were 210,177 participations, of which 133,615 were in FP7 and 76,562 were in FP6.

From the initial set of 35,265 projects, 3,544 were found to be related to nanotechnology in that they contained the term "nano"[103] in the title or abstract of the project. Thus, nanotechnology projects form approximately 10% of the total FP projects. The share of nanotechnology projects increased slightly between FP6 (9.1%) and FP7 (10.4%).

74% of the 3,544 projects were FP7 projects and 26% were FP6 projects. The relative shares of nanotechnology projects were similar to those found for FP projects in general (72% in FP7 and 28% in FP6).

Table 3-1: Number of projects and shares for total projects and for nanotechnology

		Total	FP7	FP6
FP total	Number of FP Projects	35,265	25,238	10,027
	Share of FP Projects (total)	100%	71.6%	28.4%
Nanotechnology	Number of FP Projects	3,544	2,636	908
	Share of FP Projects (NT)	100%	74.4%	25.6%
Share of nanotechnology of total FP (projects)		11.7%	10.0%	10.4%

Number and share of nanotechnology environment projects

The number of projects (in FP6 and FP7 together) that were related to both environment and nanotechnology was determined, by the use of a keyword search[104], to be 289, approximately 8.2% of the total number of projects related to nanotechnology. The percentage of environment nanotechnology projects was higher in FP7 (8.7%) than in FP6 (6.5%). This is an indication that the relevance of environment has increased within nanotechnology FP-activities from FP6 to FP7.

[102] Extraction of data from eCorda January 2015.

[103] The term "nano" could appear as a part of a word (e.g. nanotechnology, nanoscience, nanomaterial, nanoscale), as a part of compound word separated with hyphen (e.g. nano-science) or as an independent word "nano".

[104] See Annex for details.

Table 3-2: Number of projects and shares for nanotechnology and environment nanotechnology

	Numbers of projects		
	Total	**FP7**	**FP6**
Total FP projects, all topics	35,265	25,238	10,027
Nanotechnology FP projects	3,544	2,636	908
Environment nanotechnology FP projects	289	230	59
	Shares (number of projects)		
	Total	**FP7**	**FP6**
Total FP projects, all topics	100%	71.6%	28.4%
Nanotechnology (NT) FP projects	100%	74.4%	25.6%
Environment NT FP projects	100%	79.6%	20.4%
Environment NT projects as % of all NT projects	8.2%	8.7%	6.5%
Environment NT projects as % of all FP projects	0.8%	0.9%	0.6%

Of the 289 projects related to environment and nanotechnology, 230 (79.6%) were granted under FP7 and 59 (20.4%) under FP6. The proportion of FP7 environment and nanotechnology projects (79.6%) is slightly higher than that of FP7 nanotechnology projects overall (74%).

Funding of projects on nanotechnology and environment

The 289 nanotechnology environment projects received an EC contribution of EUR 696.8 million. The EC contribution for environment projects was EUR 131.1 million (18.8%) in FP6 and EUR 565.7 million (81.2%) in FP7. In FP6, the EC contribution for nanotechnology and environment represented 7.7% of the total nanotechnology EC contribution, whereas in FP7 it was 12.1% indicating a significant increase of environment-related funding within nanotechnology funding, as shown in the figure below.

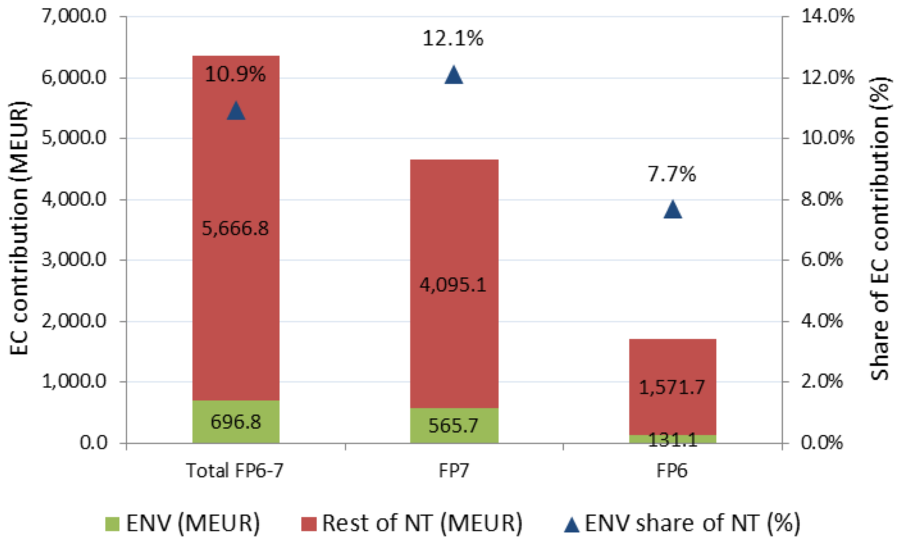

Figure 3-1: Funding of environment nanotechnology for FP6 and FP7 together, for FP7 and for FP6

3.3.2 Activities by programme and sub-programme

3.3.2.1 FP6 environment nanotechnology activities

In FP6, there were 59 environment and nanotechnology related projects. This represents 6.5% of all nanotechnology projects in FP6 (908) and 0.6% of FP6 projects as a whole.

FP6 was structured in three main blocks of activities:

1) Focusing and integrating the ERA - divided into *Thematic Priorities* and *Specific Activities*;
2) Structuring the ERA – including research and innovation, research mobility, infrastructure development and science and society; and
3) Strengthening the ERA – for co-ordination and policy activities.

There was, in addition, the EURATOM activity.

In FP6, the EUR 131.1 million funding specific to nanotechnology and environment projects made up approximately 7.7% of funding for all nanotechnology activities (EUR 1,702.7 million). They took place mainly under the priority of (1) Focusing and integrating the ERA. In fact, 86.2% (or EUR 113 million) of all funding for environment activities under FP6 came from this priority. The remaining 13.8% (EUR 18.1 million) was funded under block (2) Structuring the ERA.

Within these blocks of activity:

- Thematic priority NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) with 24 projects received 69.5% of the total funding (EUR 91.1 million);
- Thematic priority Information Society had three projects and EUR 16.7 million (12.7% of total funding); next in importance in this block are the specific activities of Policy Support (three projects and 2.6% of funding), Horizontal Research Involving SMEs (one project and 0.4% of funding) and International Cooperation (one project and 0.3% of funding); and
- Human resources and mobility activities, with 23 projects, accounted for EUR 14.3 million (10.9% of total funding). With two projects, the Science and Society activities accounted for 1.6% of total funding. Research Infrastructures activities, with one project, accounted for 1.3% of total funding.

Table 3-3: FP6 environment nanotechnology activities by programme and sub-programme

FP6 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP6	FP6 NT	FP6 EV	FP6	FP6 NT	FP6 EV	FP6	FP6 NT	FP6 EV
I Focusing and Integrating ERA	**4,735**	**455**	**33**	**13,445.0**	**1,383.6**	**113.0**	**80.5%**	**81.3%**	**86.2%**
Thematic Priorities	3,374	389	28	12,027.5	1,314.8	108.6	72.1%	77.2%	82.9%
1. Life Sciences	602	20	0	2,336.5	54.1	0.0	14.0%	3.2%	0.0%
2. Information Society	1,089	80	3	3,798.9	346.1	16.7	22.8%	20.3%	12.7%
3. NMP	444	271	24	1,534.2	870.1	91.1	9.2%	51.1%	69.5%
4. Aeronautics and Space	241	5	0	1,066.1	11.6	0.0	6.4%	0.7%	0.0%
5. Food Quality and Safety	189	0	0	754.2	0.0	0.0	4.5%	0.0%	0.0%
6. Sustainable Development	666	10	1	2,300.9	30.5	0.8	13.8%	1.8%	0.6%
7. Citizens and Governance	143	3	0	236.6	2.4	0.0	1.4%	0.1%	0.0%
Specific Activities	1,361	66	5	1,417.5	68.8	4.4	8.5%	4.0%	3.3%
Policy Support	520	29	3	604.2	40.7	3.4	3.6%	2.4%	2.6%
Horizontal Research Involving SMEs	490	29	1	463.1	24.7	0.5	2.8%	1.4%	0.4%
International Co-operation	351	8	1	350.3	3.4	0.4	2.1%	0.2%	0.3%
II Structuring the European Research Area	**5,096**	**449**	**26**	**2,744.2**	**303.1**	**18.1**	**16.4%**	**17.8%**	**13.8%**
Research and Innovation	240	3	0	224.0	3.9	0.0	1.3%	0.2%	0.0%
Human Resources and Mobility	4,546	420	23	1,723.1	219.2	14.3	10.3%	12.9%	10.9%
Research Infrastructures	147	17	1	717.6	74.3	1.7	4.3%	4.4%	1.3%
Science and Society	163	9	2	79.5	5.8	2.1	0.5%	0.3%	1.6%
III Strengthening the ERA	118	3	0	317.3	8.0	0.0	1.9%	0.5%	0.0%
Co-ordination of Activities	99	3	0	303.8	8.0	0.0	1.8%	0.5%	0.0%
Research & Innovation Policies	19	0	0	13.5	0.0	0.0	0.1%	0.0%	0.0%
EURATOM	78	1	0	185.7	8.0	0.0	1.1%	0.5%	0.0%
TOTAL	10,027	908	59	16,692.3	1,702.7	131.1	100.0%	100.0%	100.0%

3.3.2.2 FP7 environment nanotechnology activities

The 230 environment nanotechnology projects in FP7 represented 8.7% of nanotechnology projects and 0.9% of the total number of FP7 projects. Regarding funding, environment nanotechnology projects in FP7 accounted for 12.1% of nanotechnology funding and 1.3% of total FP7 funding.

The broad objectives of FP7 group into four categories: Co-operation; Ideas; People; and Capacities.

The largest proportion of funding for environment nanotechnology is seen under the Co-operation Specific Programme with EUR 446.9 million (79% of total environment nanotechnology funding in FP7) with 119 projects. Within this Specific Programme, the NMP thematic area received the highest funding (EUR 348 million), followed by ICT (EUR 22.8 million), Environment (EUR 21.7 million), Food, Agriculture and Fisheries, and Biotechnology (EUR 20.9 million), Energy (EUR 19.6 million), and then Transport, Health, Security and Joint Technology Initiatives, all together accounting for EUR 13.9 million.

Secondly, the Ideas Specific Programme, implemented via the European Research Council, had a funding of EUR 44.5 million (7.9%) with 24 projects. Marie-Curie Actions follow with 65 projects (EUR 36.2 million, 6.4% of funding).

Table 3-4: FP7 environment nanotechnology activities by programme and sub-programme

FP7 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP7	FP7 NT	FP7 EV	FP7	FP7 NT	FP7 EV	FP7	FP7 NT	FP7 EV
COOPERATION	7,834	756	119.0	28,336.3	2,803.8	446.9	63.1%	60.2%	79.0%
Health	1,008	33	1	4,791.7	157.0	4.1	10.7%	3.4%	0.7%
Food, Agri and Bio	516	25	4	1,850.7	97.1	20.9	4.1%	2.1%	3.7%
ICT	2,328	175	6	7,877.0	561.3	22.8	17.5%	12.0%	4.0%
NMP	805	412	93	3,238.6	1,595.6	348.0	7.2%	34.2%	61.5%
Energy	368	24	3	1,707.4	81.5	19.6	3.8%	1.7%	3.5%
Environment	494	10	8	1,719.3	26.9	21.7	3.8%	0.6%	3.8%
Transport	719	12	2	2,284.2	61.5	4.9	5.1%	1.3%	0.9%
Socio-economic Sciences	253	0	0	579.6	0.0	0.0	1.3%	0.0%	0.0%
Space	267	14	0	713.3	31.7	0.0	1.6%	0.7%	0.0%
Security	314	5	1	1,295.5	14.1	3.4	2.9%	0.3%	0.6%
General Activities	26	0	0	312.7	0.0	0.0	0.7%	0.0%	0.0%
Joint Technology Initiatives	736	46	1	1,966.4	177.0	1.4	4.4%	3.8%	0.2%
IDEAS	4,525	572	24	7,673.5	1,026.1	44.5	17.1%	22.0%	7.9%
European Research Council	4,525	572	24	7,673.5	1,026.1	44.5	17.1%	22.0%	7.9%
PEOPLE	10,716	1,158	65	4,777.5	579.9	36.2	10.6%	12.4%	6.4%
Marie-Curie Actions	10,716	1,158	65	4,777.5	579.9	36.2	10.6%	12.4%	6.4%
CAPACITIES	2,025	149	22	3,772.0	249.9	38.1	8.4%	5.4%	6.7%
Research Infrastructures	341	18	0	1,528.4	72.2	0.0	3.4%	1.5%	0.0%
Research for the benefit of SMEs	1,028	70	16	1,249.1	86.1	21.0	2.8%	1.8%	3.7%
Regions of Knowledge	84	4	0	126.7	7.3	0.0	0.3%	0.2%	0.0%
Research Potential	206	27	5	377.7	55.1	13.5	0.8%	1.2%	2.4%
Science in Society	183	16	0	288.4	16.5	0.0	0.6%	0.4%	0.0%
Research Policies	26	0	0	28.3	0.0	0.0	0.1%	0.0%	0.0%
International Cooperation	157	14	1	173.4	12.7	3.5	0.4%	0.3%	0.6%
EURATOM	138	1	0	358.1	1.1	0.0	0.8%	0.0%	0.0%
Fusion	4	0	0	5.2	0.0	0.0	0.0%	0.0%	0.0%
Fission	134	1	0	352.8	1.1	0.0	0.8%	0.0%	0.0%
TOTAL	25,238	2,636	230	44,917.3	4,660.8	565.7	100.0%	100.0%	100.0%

3.3.3 Activities by participant type

The table below shows the participations in FP6 and FP7 for the Higher Education Sector (HES), Public Research Organisations (PROs), large companies (PCO), SMEs and other organisations. As well as the number of participations (Particip.), the table shows the total EC funding and share of funding for each, for all FP6 and FP7, for nanotechnology and for nanotechnology and environment (EV-NT).

Table 3-5: Participations in FP6 and FP7 including funding and share of funding[105]

	Total FP6 and FP7			NT in FP6 & FP7			Environment NT, FP6 & FP7		
	Particip.	EC Funding	Share of Funding	Particip.	EC Funding	Share of Funding	Particip.	EC Funding	Share of Funding
HES	76,777	25,736.0	41.8%	7,671	3,019.5	47.5%	732	258.4	37.1%
REC	53,384	17,304.4	28.1%	4,696	1,778.1	28.0%	671	222.7	32.0%
PCO	25,067	7,021.3	11.4%	2,275	615.4	9.7%	352	60.8	8.7%
SME	29,428	6,882.6	11.2%	3,239	769.1	12.1%	564	125.2	18.0%
Other	24,961	4,626.8	7.5%	1,059	174.2	2.7%	164	29.3	4.2%
Total	**209,617**	**61,571.1**	**100.0%**	**18,940**	**6,356.2**	**100.0%**	**2,483**	**696.5**	**100.0%**

Higher education institutes (HES) received more than one third (37.1%) of the EC contribution to nanotechnology and environment, as shown in the table above and the figure below. They are followed by research organisations (REC, 32%), small and medium-sized companies (SME, 18%), large companies (PCO, 8.7%) and other organisations (OTH, 4.2%).

The proportion of environment and nanotechnology funding going to organisations in the higher education sector (37.1%) is quite a bit lower than that corresponding to their share of nanotechnology funding (47.5%), and their share for FP funding overall (41.8%). The relative importance of HES grew from 32.5% in FP6 to 38.2% of all nanotechnology and environment funding in FP7. For research organisations, their share of funding for nanotechnology and environment related projects (32.0%) is higher than the shares in the case of nanotechnology projects (28.0%) or FP projects (28.1%) in general. This share grew slightly from FP6 (31.3%) to FP7 (32.1%). The funding received by SMEs rose from FP6 (14.3%) to FP7 (18.8%). Large companies, on the other hand, dropped from 12.5% to 7.9%. There is a higher presence of SMEs in nanotechnology and environment-related activities than in nanotechnology (NT) activities or FP activities in general.

The distribution of funds among different types of participants in nanotechnology & environment related projects differs slightly from those corresponding to nanotechnology projects in general or FP6 & FP7 projects as a whole. This could point to environment nanotechnology projects being more applied / market-oriented than nanotechnology projects or FP6-FP7 projects in general.

[105] The EC contribution in eCorda projects and the participant database differ by a small amount. The figures reported here for participants therefore do not exactly match those for projects in previous sections. For more information, see the information about the methodology in the annex.

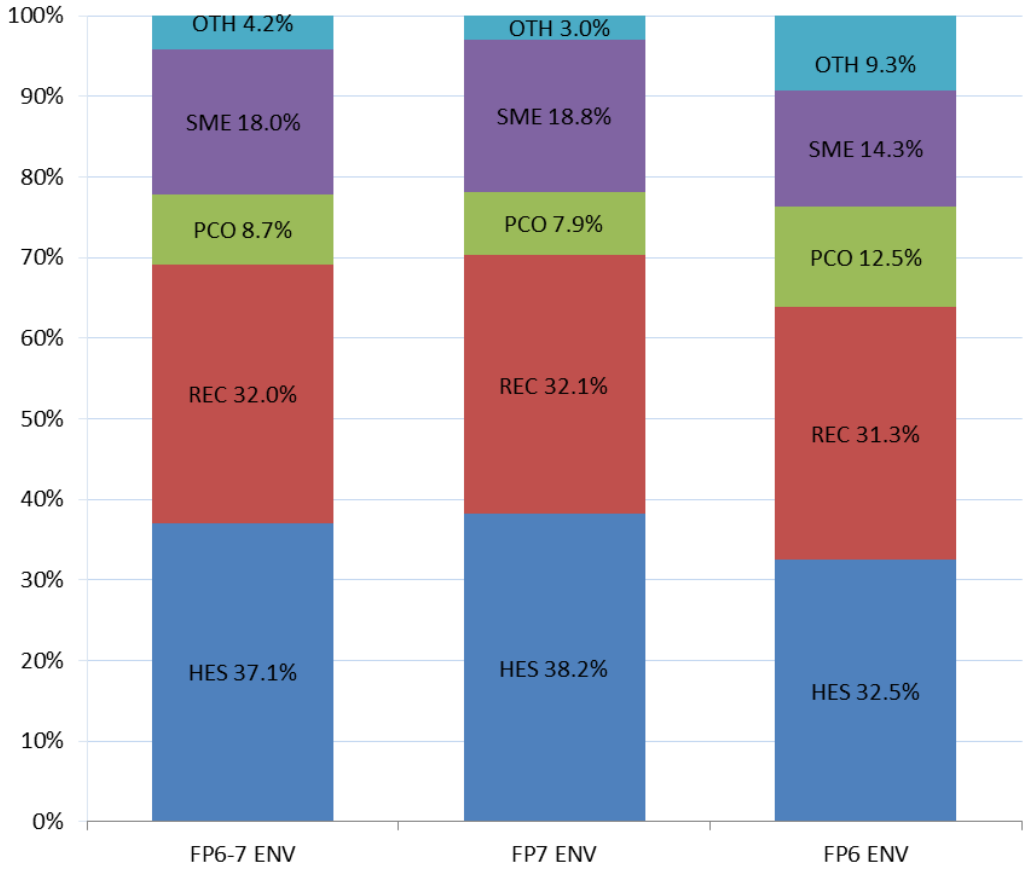

Figure 3-2: Shares of EC contribution by organisation type for nanotechnology and environment

3.3.4 Activity by organisations receiving funding

The organisations receiving the largest amounts of funding for environment nanotechnology activities were Fraunhofer-Gesellschaft[106] (DE) (EUR 17.62 million for 34 projects), CEA[107] (FR) (EUR 14.88 million, 19 projects), CNRS [108](FR) (EUR 13.51 million, 36 projects) and CNR[109] (IT) (EUR 11.34 million, 20 projects). The rest of the organisations in this list had EC contributions below EUR 10 million, and less than 20 projects each.

Out of the top 25 recipients, 12 were higher education institutions (HES) and 13 were research organisations (REC). The top ten organisations are from Germany, France, Italy, Denmark, Spain, Finland, the UK and Norway.

[106] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Germany. www.fraunhofer.de
[107] Commissariat a l'Energie Atomique et aux Energies Alternatives, France. www.cea.fr
[108] Centre National de la Recherche Scientifique, France. www.cnrs.fr
[109] Consiglio Nazionale delle Ricerche, Italy. www.cnr.it/en

Table 3-6: Organisations participating in FP6 and FP7, top 25 ranked by funding received

	Environment NT - Top participants	Country	No. of Projects	EC Funding (MEUR)	Share of EV-NT Funding
1	Fraunhofer-Gesellschaft[110]	DE	34	17.62	2.53%
2	CEA[111]	FR	19	14.88	2.14%
3	CNRS[112]	FR	36	13.51	1.94%
4	CNR - Consiglio Nazionale Delle Ricerche	IT	20	11.34	1.63%
5	Danmarks Tekniske Universitet	DK	17	7.00	1.00%
6	CSIC[113]	ES	15	6.87	0.99%
7	Teknologian Tutkimuskeskus VTT	FI	11	5.70	0.82%
8	Joint Research Centre, European Commission	EU	17	5.36	0.77%
9	University of Nottingham	UK	3	5.19	0.75%
10	Stiftelsen SINTEF	NO	6	4.79	0.69%
11	Universiteit Gent	BE	5	4.70	0.67%
12	Foundation for Research and Technology Hellas	EL	7	4.68	0.67%
13	Universitaet Wien	AT	7	4.64	0.67%
14	Ludwig-Maximilians-Universitaet Muenchen	DE	6	4.61	0.66%
15	Imperial College of Science, Technology and Medicine	UK	13	4.51	0.65%
16	Vlaamse Instelling voor Technologisch Onderzoek N.V.	BE	12	4.40	0.63%
17	Katholieke Universiteit Leuven	BE	10	4.30	0.62%
18	TNO[114]	NL	14	4.06	0.58%
19	Institute of Solid State Physics, Bulgarian Academy of Sciences	BG	1	4.05	0.58%
20	Universitaet Stuttgart	DE	5	4.01	0.58%
21	Fundacion Tecnalia Research & Innovation	ES	12	3.89	0.56%
22	Univerza V Novi Gorici	SI	1	3.88	0.56%
23	Westfaelische Wilhelms-Universitaet Muenster	DE	7	3.77	0.54%
24	Helsingin Yliopisto	FI	3	3.77	0.54%
25	Universiteit Utrecht	NL	6	3.68	0.53%

The table below indicates the most active companies in FP environment nanotechnology projects by funding. In this sector, 15 of these were SMEs.

The Spanish company Acciona Infraestructuras SA was funded with EUR 2.34 million over six projects. Biogasol APS (DK) followed with EUR 2.09 million and one project, Johnson Matthey Plc (UK) came next with EUR 1.75 million and six projects and MBN Nanomaterialia SPA (IT) was the fourth company, receiving EUR 1.64 million for six projects.

[110] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[111] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[112] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr
[113] Consejo Superior de Investigaciones Cientificas, the Spanish National Research Council www.csic.es
[114] Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek (TNO) https://www.tno.nl/

Table 3-7: Companies participating in FP6 and FP7, top 25 ranked by funding received

	Environment NT - Top Company Participants	Country	SME	No. of Projects FP6-7	EC Funding (MEUR)
1	Acciona Infraestructuras SA	ES		6	2.34
2	Biogasol APS	DK	SME	1	2.09
3	Johnson Matthey Plc.	UK		6	1.75
4	MBN Nanomaterialia SPA	IT	SME	6	1.64
5	Airbus Defence and Space GmbH	DE		5	1.52
6	AIF Projekt GmbH	DE	SME	1	1.46
7	Osram Opto Semiconductors GmbH	DE		1	1.41
8	Nanomaterials Ltd	IL	SME	1	1.35
9	NANOCYL SA	BE	SME	6	1.28
10	M-Squared Lasers Ltd	UK	SME	3	1.25
11	HyGear B.V.	NL	SME	1	1.16
12	BASF SE	DE		6	1.11
13	Borregaard Industries Ltd	UK		2	1.11
14	Mast Carbon International Ltd	UK	SME	3	1.10
15	TRW Automotive Espana SL	ES		1	1.08
16	D'AppolonIA SPA	IT		3	1.06
17	Compagnie Industrielle DES Lasers Cilas SA	FR	SME	1	1.06
18	Nanologica AB	SE	SME	3	1.03
19	Grimm Aerosol Technik GmbH & Co KG	DE	SME	2	1.02
20	B.T.G. Biomass Technology Group BV	NL	SME	1	1.01
21	Plasmachem Produktions- und Handel GmbH	DE	SME	5	0.99
22	IVAM UVA	NL	SME	3	0.97
23	NordMiljö O. Grahn AB	SE	SME	3	0.96
24	Evonik Industries AG	DE		2	0.88
25	Solvay SA	BE		4	0.87

3.3.5 Participation by country

In total, 61 countries took part in environment nanotechnology projects funded under FP6 and FP7. The top fifteen are shown in the table below, with funding and share of total EV-NT funding (EUR 696,5 million) for each country.

Table 3-8: Top fifteen countries for FP participation ranked by funding received

Rank	Country	EV-NT funding (MEUR)	% of funding
1	DE	111.0	15.9%
2	UK	91.4	13.1%
3	FR	68.8	9.9%
4	ES	63.6	9.1%
5	IT	57.1	8.2%
6	NL	37.0	5.3%
7	BE	29.5	4.2%
8	SE	29.4	4.2%
9	FI	24.8	3.6%
10	DK	23.8	3.4%
11	CH	22.8	3.3%
12	GR	19.2	2.8%
13	NO	15.2	2.2%
14	IL	13.1	1.9%
15	IE	12.1	1.7%
	Total	**618.8**	**88.9%**

Table 3-9: Country ranking by FP funding for top ten in FP, NT and environment nanotechnology

(Listed in order of received environment nanotechnology funding, highest at the top of the table)

	FP Total			Nanotechnology			Environment and Nanotechnology		
	MEUR	Rank	Share of FP	MEUR	Rank	Share of NT	MEUR	Rank	Share of EV
DE	10,164.1	1	16.5%	1,121.5	1	17.6%	111.0	1	15.9%
UK	9,295.2	2	15.1%	845.9	2	13.3%	91.4	2	13.1%
FR	7,319.3	3	11.9%	760.9	3	12.0%	68.8	3	9.9%
IT	5,046.5	4	8.2%	505.2	4	7.9%	63.6	4	9.1%
ES	4,200.6	6	6.8%	481.0	5	7.6%	57.1	5	8.2%
NL	4,438.4	5	7.2%	444.3	6	7.0%	37.0	6	5.3%
BE	2,518.0	7	4.1%	258.4	9	4.1%	29.5	7	4.2%
CZ	415.7	20	0.7%	58.5	18	0.9%	29.4	8	4.2%
GR/EL	1,425.5	12	2.3%	128.5	14	2.0%	24.8	9	3.6%
SE	2,386.7	9	3.9%	271.6	8	4.3%	23.8	10	3.4%
Total	47,210.0		76.7%	4,875.9		76.7%	536.5		77.0%

The top three countries accounted for more than one third of the total EC funding for EV-NT projects (38.9%). The same three countries, in the same order, head the rankings for nanotechnology projects and for FP projects overall, as seen in the table below. The list is topped by Germany with a share of 15.9%, followed by the UK (13.1%), France (9.9%), Spain (9.1%) and Italy (8.2%). Other countries, like the Netherlands and Belgium, followed behind.

The figure below shows the ranking of countries participating in environment nanotechnology projects. In some cases, the share of funding for environment nanotechnology projects is lower than the shares for both nanotechnology projects and FP projects as a whole. However, there are some cases in which the opposite is true, the most notably Spain, Finland and Denmark, which have higher percentages of funding for environment nanotechnology projects. These countries show higher specialisation in the field of environment and nanotechnology.

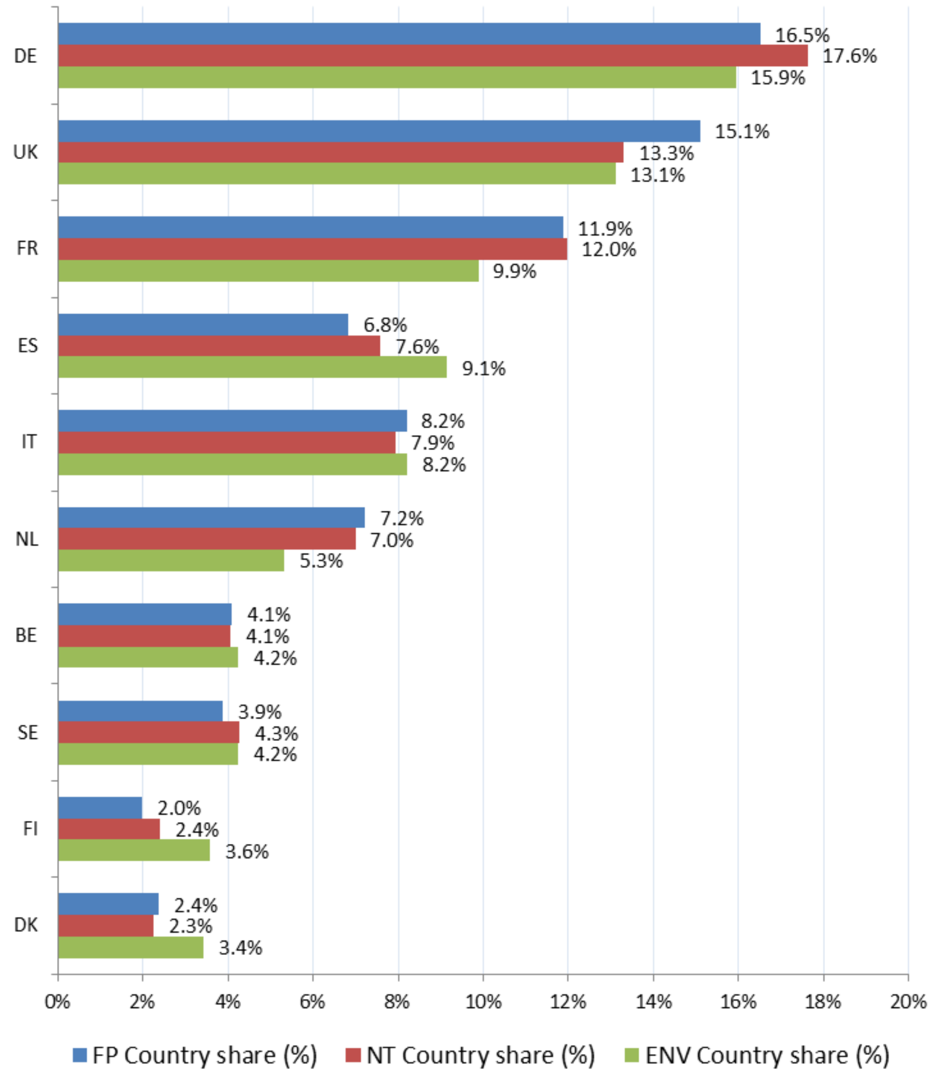

Figure 3-3: Percentage shares of FP funding by country in FP, NT and environment nanotechnology

In the figure below (the EC funding for environment nanotechnology projects in FP6 and FP7 (bars) and the country shares (red dots for FP6, green diamonds for FP7)), five countries have increased their share of funding for environment nanotechnology projects from FP6 to FP7. These are Germany, the Netherlands, Belgium, Finland and Denmark. The Netherlands is the most significant case, as it increased its share of funding from 3.3% to 5.8%.

Some countries decreased their share of funding from FP6 to FP7, the most noticeable cases being France with a reduction of share from 13.1% to 9.1%, and Sweden with a reduction of share from 6.6% to 3.7%.

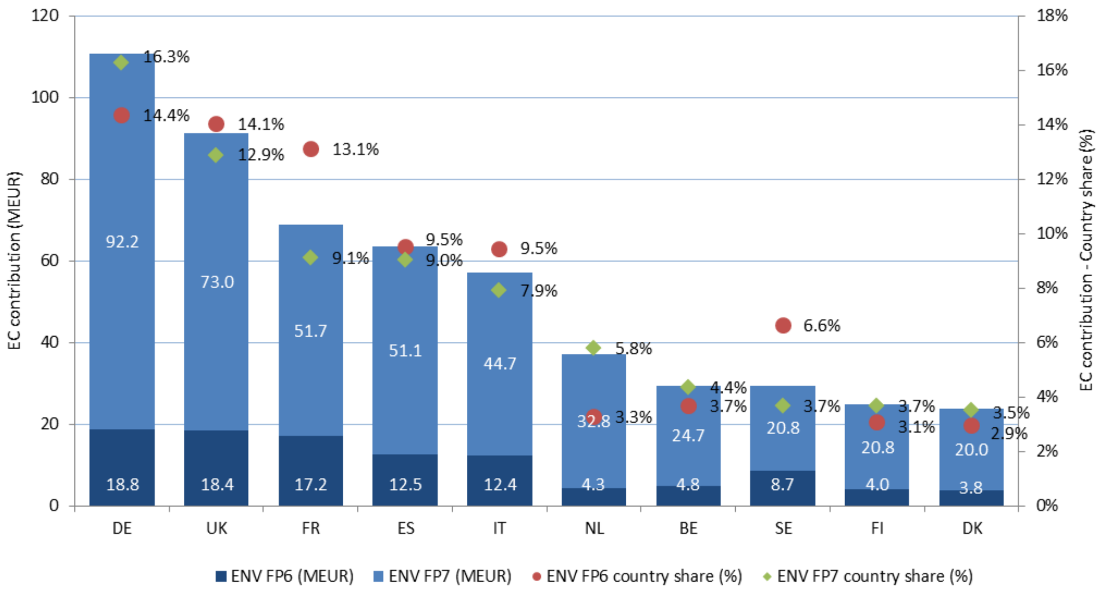

Figure 3-4: EC funding for environment NT activities in FP6 and FP7 in MEUR and country shares

3.3.6 Snapshot of outputs from FP7

A review was undertaken of 106 FP7 nanotechnology projects reported on via the SESAM system in which participants themselves report on their project. The projects are random, being the first ones to report, which they can only do when the project has finished. In addition, the information has not been normalised to take into account the type and size of project. It is therefore not intended to present the information here as a rigorous review, only as a snapshot at a point in time of FP7 projects that have reported to date.

In the review of the 106 SESAM reports, it was found that there are 22 projects highly related to environment in the nanotechnology-related SESAM reports: sixteen regarding Environmental Health and Safety (EHS) and six regarding the use of nanotechnology for the environment.

The sixteen EHS FP projects resulted in 247 publications (with an average of 15 publications per project) and five patent publications. The two projects with the most publications in this category where entitled "Do nanoparticles induce neurodegenerative diseases? Understanding the origin of reactive oxidative species and protein aggregation and misfolding phenomena in the presence of nanoparticles" (59 publications) and "Comprehensive assessment of hazardous effects of engineered nanomaterials on the immune system" (47 publications). The project with the most patents was entitled "Novel Concepts, Methods, and Technologies for the Production of Portable, Easy-to-Use Devices for the Measurement and Analysis of Airborne Engineered Nanoparticles in Workplace Air" (three patents). This last project was the nanotechnology project with the second highest workforce (187 workers: 138 men and 49 women).

The six projects identified as being related to the use of nanotechnology for the environment resulted in 75 publications and two patents. Four of the projects were related to the use of nanotechnology for water treatment. The project with most publications was entitled "Surface ionisation and novel concepts in nano-MOX gas sensors with increased Selectivity, Sensitivity and Stability for detection of low concentrations of toxic and explosive agents" (24 publications). The project with the most patents was entitled "Development of new nanocomposites using materials from mining industry" (two patents) and involved 192 workers (110 men, 82 women), the highest workforce.

Although the projects mentioned above are just the highly environment-related ones, there were also various projects that resulted in the improvement of environmental conditions because of the development of more environmentally-friendly materials due to the use of nanotechnology.

The next section considers EU policies and programmes that complement the supports for nanotechnology and environment described previously in this section for the EU Framework Programmes.

3.4 Other EU policies and programmes

3.4.1 EU policies and programmes: Industry

Policies and programmes to support industrial innovation are the previously mentioned flagship initiative "Innovation Union" and the Framework Programmes for Research and Innovation (policy: Innovation Union, programme: Horizon 2020 Industrial Leadership). For competitiveness, there are the flagship initiatives "An industrial policy for the globalisation era" and "Resource efficient growth" and programmes on Competitiveness of Enterprises, SMEs (COSME) and LIFE.

Research by SMEs in the EU is also supported through the EUREKA Eurostars[115] initiative established under TFEU Article 185, in partnership between the Eureka countries and the European Commission. Eurostars supports European R&D performing SMEs to commercialise their research. It helps them to accelerate the time to market of products, processes and services. It also encourages them to develop and internationalise their business. Funding of up to EUR 100 million was made available through EUREKA for the period 2008-2013, the EU contribution comprising a maximum of one third of the funding provided by the participating countries. Funding for Eurostars has continued with a total public budget of EUR 1.14 billion in 2014-2020, EUR 861 million of national funding and EUR 287 million of EU funding from Horizon 2020. In the 39 success stories identified for Eurostars, two are related to nanotechnology.

Another type of mechanism is the European Technology Platform (ETP) including the European Technology Platform Water Supply and Sanitation Technology Platform (WssTP). ETPs are bottom-up, industry-led stakeholder fora, the aim of which is to increase interaction between research actors and to facilitate the development of medium to long-term research and technological goals and associated roadmaps. They do not fund research projects but are a co-ordination mechanism. ETPs now exist across the themes of energy, environment, ICT, production and processes, transport and the bio-based economy. WssTP is the only ETP mentioned under the theme of environment. In November 2015, WssTP started a working group (WG) on "Nanotechnologies for water treatment" (Nano4water WG) which will look at the development and use of novel and cost-effective technologies for nano-selective separations, catalytic degradation, adsorptive removal and detection of contaminants. This WG continues the work of the Nano4water cluster set up under FP7. A cross-cutting ETP is NANOfutures.

Joint Technology Initiatives (JTIs) are long-term Public-Private Partnerships managed within dedicated structures based on TFEU Article 187. JTIs support large-scale multinational research activities in areas of major interest to European industrial competitiveness as well as issues of high societal relevance. JTIs arose out of the work of the European Technology Platforms (ETPs) in those cases where the scale and scope of the initiatives made their co-ordination through ETPs and support by the regular instruments of the Framework Programme for Research and Development[116] was insufficient. Currently there are six JTIs[117]: Electronic Components and Systems (ECSEL); Innovative Medicines (IMI2); Fuel Cells and Hydrogen (FCH2); Aeronautics (Clean Sky 2); Bio-Based Industries (BBI); and Shift2Rail, falling under the Horizon 2020 innovation investment package[118]. The activities of three of these have an impact on (improving) the environment:

The JTI FHC[119] Fuel Cells and Hydrogen Initiative Joint Undertaking (JU) was established in 2008 (launched under FP7) with the aim of establishing the necessary conditions for fuel cells and hydrogen technology to be introduced to the market. This goal included creating a critical mass of research resources that would persuade industries, investors and public authorities to embark on a long-term programme. As the enormous challenges posed by the transition from an oil- to a hydrogen-based economy have not yet been overcome, despite significant investment of resources, the timescale for FHC was extended from its original end-date of 2013. Activities are continuing

[115] https://www.eurostars-eureka.eu/
[116] http://era.gv.at/directory/142
[117] Only JTIs are included here; also based on article 187 is Joint Undertaking SESAR to ensure Europe's modernisation aire traffic management as part of the European Single European Sky initiative.
[118] Innovation Investment Package: IMI2, FCH2, CS2 and ECSEL are continuations from the JTIs set up under FP7 (whereby ECSEL is a merger of ENIAC and ARTEMIS), BBI and Shift2Rail are new programmes. The budget comes from the Horizon 2020 programme, http://ec.europa.eu/programmes/horizon2020/en/area/partnerships-industry-and-Member-States
[119] http://www.fch.europa.eu/

under Horizon 2020 (H2020, 2014-2020) with a total budget of EUR 1.33 billion provided on a matched basis between the EU (represented by the European Commission), industry and research.

The Bio-Based Industries[120] (BBI) Joint Undertaking is a EUR 3.7 billion public-private partnership, between the EU and the Bio-based Industries Consortium, which became fully operational in October 2015. The funding is EUR 975 million of EU funds (H2020) and EUR 2.7 billion of private investments. BBI aims to create a strong European bio-based industrial sector, thereby significantly reducing the EU's dependency on fossil-fuels, helping the EU meet climate change targets, and leading to greener and more environmentally-friendly growth. Its focus is on developing biorefining technologies, growing associated markets and jobs (particularly in rural and under-developed areas). Benefits envisaged by BBI include the productive use of waste, agricultural and forestry residues; diversification and increase of the income of farmers; replacement of at least 30% of oil-based chemicals and materials with bio-based and biodegradable ones by 2030; and reduction of CO_2 emissions by at least 50% compared to fossil alternatives.

Clean Sky (CS)[121]: established in 2008 with a budget of EUR 1.6 billion (50/50 Commission/Industry), it aims to increase aircraft fuel efficiency and reduce NOx and noise emissions. It has six Integrated Technology Demonstrators: SMART Fixed Wing Aircraft, Green Regional Aircraft, Green Rotorcraft, Sustainable and Green Engines, Systems for Green Operations and Eco-Design. The initiative has been extended for 2014-2020 through Clean Sky 2 (CS2) and received EUR 4 billion (EUR 1.8 billion from the EU and EUR 2.2 billion from industry).

The Clean Sky 2016-2017 work plan states that: "the goal is to identify, develop and validate the key technologies necessary to achieve major steps towards the ACARE (Advisory Council for Aeronautics Research in Europe) Environmental Goals for 2020 when compared to Year 2000 levels: fuel consumption and carbon dioxide (CO2) emissions reduced by 50%, nitrous oxides (NOx) emissions reduced by 80%, reduction in perceived external noise of 50%; another goal is to improve the environmental impact of the life cycle of aeronautical products (manufacturing, operation, maintenance and disposal)". The work plan further mentions the use of carbon nanotubes to enhance an innovative electro-thermal heating system.

In 2013, under Horizon 2020, the European Commission launched the contractual Public Private Partnerships (cPPPs) to leverage more than EUR 6 billion of investments through H2020 calls. There are three cPPPs in the Nanotechnologies, Advanced Materials, Advanced Manufacturing and Processing, and Biotechnology part of Horizon 2020. These are Factories of the Future, Energy-efficient Buildings and Sustainable Process Industry. A fourth cPPP with relevance to the environment is European Green Vehicles Initiative. All four have an (indirect) relation with environment in that their objective is to attain greater sustainability, reduce waste and reduce the use of (primary) resources[122].

3.4.2 EU policies and programmes: LIFE[123]

DG Environment and DG Climate Action jointly manage the LIFE programme. This is the EU's funding instrument for the environment and climate action. The general objective of LIFE is to contribute to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value.

LIFE began in 1992 and to date there have been four complete phases of the programme (LIFE I: 1992-1995, LIFE II: 1996-1999, LIFE III: 2000-2006 and LIFE+: 2007-2013). During this period, LIFE has co-financed some 3954 projects across the EU, contributing approximately EUR 3.1 billion to the protection of the environment. The budget for the 2014-2020 period is EUR 3.4 billion.

The thematic priorities for Environment and Health (including chemicals and noise) include supporting activities for the implementation of 1) Regulation (EC) No 1907/2006 of the European Parliament and of the Council (REACH) and 2) Regulation (EU) No 528/2012 of the European Parliament and of the Council (2) (Biocidal Products Regulation) to ensure a safer, more sustainable or economical use of chemicals (including nanomaterials).

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[120] http://www.bbi-europe.eu
[121] http://www.cleansky.eu/
[122] http://ec.europa.eu/research/industrial_technologies/ppp-in-research_en.html
[123] http://ec.europa.eu/environment/life/about/index.htm

LIFE projects focus on:

- Reducing the impact of chemicals (including nanomaterials and biocidal products) on the environment or human health by a safer or more sustainable use of chemicals or by the minimisation of exposure to toxic chemicals in products or in the environment, through their substitution with safer substances or with non-chemical solutions.
- Improving the use of chemical monitoring data (e.g. environmental monitoring, human bio-monitoring, product monitoring, indoor air monitoring) in the protection of human health and the environment, by making chemical monitoring data available, accessible, comparable and inter-operable, and allowing for linking them with monitoring of human and environmental health and for assessment of exposures from chemical mixtures via various routes of exposure.

3.4.3 Other EU policies and programmes: CIP Eco-innovation

Launched in 2008, the Eco-innovation initiative was part of the EU's Entrepreneurship and Innovation Programme (EIP), set up to support innovation among SMEs and to improve their competitiveness. From 2008 – 2013, nearly EUR 200 million was made available to fund projects.

The EIP was part of the wider Competitiveness and Innovation Framework Programme[124] (CIP), managed by EC DG Enterprise and Industry, aimed at encouraging the competitiveness of European companies, in particular SMEs. The Eco-innovation initiative was one of the measures designed to implement the EU's Eco-innovation Action Plan (EcoAP).

CIP Eco-innovation had five strands:

1. Materials recycling and recycling processes;
2. Sustainable building products;
3. Food and drink sector;
4. Water efficiency, treatment and distribution; and
5. Greening business.

From 2014 onwards, the topic of eco-innovation has become part of Horizon 2020, under societal challenge *Climate action, environment, resource efficiency and raw materials* efficiency

3.4.4 Other EU policies and programmes: Energy efficiency and environment

Energy efficiency is central to the establishment of a resource-efficient EU economy. Minimising the use of energy is a cost-effective way to reduce consumption, concerns about energy security (as the need for imports will be lessened) and emissions of greenhouse gases and other pollutants.

In 2010, the European 2020 Energy Strategy[125] defined European energy goals to 2020. The Strategy stated the aim to achieve an 80% to 95% reduction in greenhouse gases compared to 1990 levels by 2050 and to:

- Reduce greenhouse gases by at least 20%;
- Increase the share of renewable energy in the EU's energy mix to at least 20% of consumption; and
- Improve energy efficiency by at least 20%.

While many of these are not directly related to nanotechnology, measures such as increased demand for improved levels of vehicle performance, reductions in emissions and alternative fuels will inevitably lead to an increase in research, development and deployment of new and improved technological innovations such as those resulting from nanotechnology.

[124] The EU's programme for the Competitiveness of Enterprises and SMEs (COSME, 2014-2020) is the successor to CIP for general support to enterprise. Its instruments are primarily aimed at organisations facilitating or supporting SMEs, not project funding and therefore the programme is not included here.

[125] https://ec.europa.eu/energy/en/topics/energy-strategy/2020-energy-strategy

3.4.5 Other EU policies and programmes: European Institute of Innovation and Technology

The European Institute of Innovation and Technology (EIT)[126] aims to enhance Europe's ability to innovate, adapting quickly to the fast pace of development, being one step ahead in providing solutions to rapidly emerging societal problems and developing products that meet the demands and desires of consumers. The remit of the European Institute of Innovation and Technology (EIT)[127] is to connect education and entrepreneurship in order to enhance Europe's ability to innovate. The EIT has set up five public-private partnerships called "Knowledge and Innovation Communities" (KICs) that each focus on a societal challenge: climate change mitigation and adaption (Climate-KIC), energy (KIC InnoEnergy), sustainable exploitation of raw materials (EIT Raw Materials), healthy living and ageing (EIT Health), and information and communication technologies (EIT Digital).

Related to the environment:

- Climate KIC partners work together to address climate change. There are four themes: Urban Transitions (towards zero-carbon and resilient cities), Sustainable Land Use, Sustainable Production Systems (towards low-carbon value chains based on the circular economy and bio-economy), and Decision Metrics & Finance.
- KIC InnoEnergy's goal is to achieve a sustainable energy future for Europe. Thematic fields are: clean coal technologies; energy storage; energy efficiency; energy from chemical fuels; renewable energies; smart and efficient buildings and cities; smart electric grid; and sustainable nuclear and renewable convergence.
- The primary goal of EIT Raw Materials128 is to make the EU independent of other regions for its raw materials, but at the same time to make the raw materials value chain sustainable ("towards the circular economy"). The development or application of nanotechnologies is not specifically mentioned, but likely to play a role given the involvement of chemicals companies such as BASF and Arkema, recycling companies such as Umicore and Recylex and research organisations such as CEA.

3.4.6 Other EU policies and programmes: Structural and Investment Funds

Four (out of five) European Structural and Investment Funds (ESI Funds) provide support for research and innovation activities:

- The European Regional Development Fund (ERDF), for economic regeneration and safeguarding employment. Its main priorities are the support of small to medium-sized enterprises; the creation of a low carbon economy; research and innovation; information and communications technology; environmental protection, climate change adaptation; risk prevention and management; transport and social inclusion.
- The European Social Fund (ESF), for the enhancement of employment opportunities, social inclusion and skills, supports skills and training; access to employment for all including women and migrants; improvement of public services; innovation in SMEs; and access to start-up capital.

The ERDF and ESF together have a budget of about EUR 280 billion over 2014-2020.

- The European Agricultural Fund for Rural Development (EAFRD), which aims to strengthen the links between agriculture, food production and forestry and those performing research and innovation activities. Groups of collaborators are funded under the European Innovation Partnership on Agricultural Productivity and Sustainability. The Fund has a budget of EUR 95.6 billion over 2014-2020.
- The European Maritime and Fisheries Fund (EMFF) with a budget of EUR 6.4 billion over 2014-2020 for the development of businesses through research and innovation. It can also fund research studies for the development of policies for the management of fisheries.

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[126] The EIT is a body of the European Union based in Budapest, Hungary. It was established by the Regulation (EC) No 294/2008 of the European Parliament and of the Council of 11 March 2008. It became operational in 2010. http://eit.europa.eu/

[127] http://eit.europa.eu/.

[128] http://eitrawmaterials.eu/.

3.4.7 EU policies and programmes: Cohesion funds

SMART SPECIALISATION AND REGIONAL RDI POLICY

The European Commission's Cohesion Policy aims to reduce differences between regions in Europe and to ensure growth across the continent. Structural Funds are among the main tools to implement the policy, and it is within this framework that smart specialisation was introduced. The Smart Specialisation Strategies (RIS3) [129] aim to focus regional innovation policies on regional priorities based on existing areas of strength; competitive advantage; and potential for excellence in each region.

Smart Specialisation is about identifying the unique characteristics and assets of each country and region, highlighting local competitive advantages, and aligning regional stakeholders and resources around an excellence-driven vision of their future. It aims to:

- Focus policy support and investments on key national/regional priorities and challenges;
- Build on each country/region’s strengths, competitive advantages and potential for innovation excellence;
- Exploit potential synergies with other countries and regions;
- Support all forms of innovation, and encourage innovation and experimentation; and
- Stimulate private sector investment;

The RIS3 database shows that seven regions[130] have indicated nanotechnologies as one of their priorities.

The next section considers Member State policies and programmes for nanotechnology and environment.

[129] http://s3platform.jrc.ec.europa.eu/eye-ris3. As of December 2015, 260 regions and countries that prioritise KETs; out of these there are 7 regions that have set a priority in nanotechnology.

[130] Sachsen (DE), Etelä-Savo (FI), Toscana (IT), Eastern Netherlands (NL), Lubelskie (PL), Podkarpackie (PL), Bratislava (SK)

4 POLICIES AND PROGRAMMES IN MEMBER STATES FOR NANOTECHNOLOGY AND ENVIRONMENT

While European funding is important for many researchers, it makes up only about 8% of total public funding for R&D in the European Union. Member States channel the remaining 92% into national research and development, mostly retaining it within their own borders. However, much of that funding is employed in projects, the results of which feed into European networks and collaborations. As Member States chose to prioritise nanosciences and nanotechnologies for funding at European level, it is hardly surprising that they largely have the same view at national level. While some countries fund nanotechnology R&D as a designated priority area, others choose to integrate it into broader programmes.

For nanotechnology, nanomaterial and environment, specific initiatives at Member State level, past[131] or present include:

Austria: The Austrian NanoInitiative[132] (2004-2011, total funding EUR 70 million, administered by the Austrian Research Promotion Agency (FFG)). The initiative works on a collaborative basis across Austria and transnationally with consortia of research institutes, universities and firms working on problem-driven basic research questions with a medium-term perspective (5-7 years). The focus of the programme, matching the remit of its funding agency FFG, was to invest in projects with considerable market potential, relevant to Austrian companies. The type of activities begun under the programme are now continuing under the thematic areas FFG's research funding programmes. Since 2012, nanotechnology has been supported, largely under open calls, via FFG's thematic research funding e.g. Production of the Future. Nanotechnology in relation to the environment is considered both an opportunity (manufacture of plant-like nano solar cells, nano-coating on windows that make cleaning obsolete or nanotechnology water purification in developing countries) and a potential risk (nanosilver in tennis socks)[133]. The Nano-EHS programme initiates research into environment, health and safety aspects of nanomaterials[134].

Also in Austria, at regional level, Styria's Economic Strategy 2020 (Wirtschaftsstrategie Steiermark 2020 (2011)[135] is a successor to the State Government's previous economic strategy 2006. The 2006 strategy identified so-called economic and technological strong-points ("Stärkefelder") of the region, on which innovation policy activities were focused[136]. The 2011 strategy bundles activities in these fields under three major leading themes: i) eco-technology, ii) mobility, and iii) health technology.

Belgium: In 1984, the Government of Flanders granted EUR 62 million (as initial investment) to create the first associated lab of IMEC[137] in Leuven. IMEC is a research institute that provides laboratories, facilities and technical support rooms. For the period 2002-2006, the Government of Flanders' contribution was EUR 34 million (24% of IMEC's total revenue, with over EUR 100 million coming from contract research). In 2007, the Government of Flanders granted additional funding of around EUR 48 million.

The Federal Public Service for Employment, Labour and Social Dialogue on its website[138] explains nanotechnology, materials and particles and lists a number of promising applications such as decontamination of polluted soils, self-cleaning windows, sensitive sensors and intelligent food packaging. They go on to say that with the current methods it is not yet possible to answer the

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[131] FinNano, the Finnish nanoscience and nanotechnology programme, was established in 2005 and is coordinated jointly by Tekes and the Academy of Finland. Over EUR 120 million were invested by the programme between 2005 and 2010, with the aim of providing support across the whole innovation chain from basic research to commercial products. One priority area of the programme was the application of nanotechnology for Health and Well-being. More recently, Finland has moved away from specific funding of nanotechnology activity.

[132] https://www.ffg.at/nano-das-programm

[133] http://nanoinformation.at/umwelt/umwelt-und-nano.html

[134] http://nanoinformation.at/wissenschaft-forschung/nano-ehs-programm.html

[135] http://www.wirtschaft.steiermark.at/cms/beitrag/10430090/12858597

[136] material sciences; mechanical engineering/automotive and transport technologies; chemical and process engineering; human technology; information and communication technologies; environmental technologies; energy; building services engineering (including timber construction); nanotechnology; computer simulation and mathematical modelling.

[137] http://www2.imec.be/be_en/about-imec.html;

[138] http://www.employment.belgium.be/home.aspx

question if nanotechnology can be harmful and therefore cooperation between research, government and industry is needed.

Denmark: Under the Danish Council for Strategic Research, the Programme Commission on Strategic Growth Technologies[139] has had annual calls of total annual value approximately EUR 10 million for research projects on ICT, nanotechnology and biotechnology. The programme is now managed by the Innovation Fund Denmark. Between 2005 and 2010, EUR 116 million has been allocated to strategic research centres, research alliances and research projects, EUR 62 million being for nanotechnology, biotechnology and ICT.

The Danish Environmental Protection Agency commissioned a study about the environmental risk and opportunities of nanotechnology development in Denmark [140], as part of a larger study "Green Technology Foresight about Environmentally Friendly Products and Materials – Challenges from Nanotechnology, Biotechnology and ICT". This study fed into the European Environmental Technology Action Plan process[141] and a Danish environmental technology action plan (Danish Eco-Innovation Programme, the first of which was launched in 2006; budget in 2013 was EUR 17.5 million and in 2014 EUR 12 million, note that nanotechnology is not specifically mentioned[142]). The areas considered most promising in terms of eco-innovation potential were: 1) energy production (hydrogen society), 2) catalysis as a source of gas cleaning as well as resource and energy-efficient chemical production, and 3) sensors as a source of more resource-efficient production processes or products.

Finland: FinNano, the Finnish nanoscience and nanotechnology programme, was established in 2005 and is coordinated jointly by Tekes and the Academy of Finland. Over EUR 120 million were invested by the programme between 2005 and 2010, with the aim of providing support across the whole innovation chain from basic research to commercial products. Its goals for 2006–2009 were to draft "common guidelines for the development of nanotechnology and its commercial applications" with the joint efforts of business and academia. One of the economic clusters addressed was Energy and Environment; results are cleaner and more efficient solutions in terms of environmentally-benign materials, solar cells, fuel cells for portable devices and energy-efficient solutions.[143] Tekes collaborates also with China in the China-Finland ICT Alliance through joint calls in the area of ICT, nanotechnology and cleantech.[144]

In March 2011 the Finnish Institute of Occupational Health was appointed as coordinator of the European NanoSafety Cluster, a cluster of projects promoting nanomaterial safety. The EU provided funding of EUR 112 million for some 30 research projects. The FinNano programme identified the release of free-form nanoparticles into air or water and ultimately the accumulation in soil, water or plant life as potential risk. The programme therefore supported the FP6 SKEP ERA-NET call "impacts of converging technologies for environmental regulation" in 2009[145].

France: The French Agence National de la Recherche (ANR) channels public funding into priority areas. Of relevance for nanotechnology and environment are the priority areas of Engineering Processing and Security (EPS) and Environment and Biological Resources (EBR). EPS includes funding for chemistry and processes, materials, nanotechnologies and nanosystems and EBR includes funding for risks and contaminants. Since 2006, the P2N programme[146] aims to strengthen national excellence in the areas of micro and nano-engineering (ranging from core technologies to systems), and speed up technology transfer to French firms in order to exploit the potential of the nanotechnologies. Miniaturisation, new technologies and new devices for electronics and nanophotonics are among the thematic priorities that have been targeted in annual calls. At the end of 2009, the EUR 35 billion economic stimulus package "Investissements d'Avenir" (Investments for the Future) was launched, followed by the Nano-Innov plan with an additional budget of EUR 70

[139] http://en.innovationsfonden.dk/strategic-research/
[140] Nanotechnology development in Denmark – environmental opportunities and risk, Maj Munch Andersen and Birgitte Rasmussen, Risø National Laboratory, Risø-R-1550(EN), May 2006
[141] http://eng.ecoinnovation.dk/publications/
[142] http://eng.ecoinnovation.dk/the-danish-eco-innovation-program/
[143] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf
[144] http://www.tekes.fi/en/programmes-and-services/grow-and-go-global/china/
[145] https://www.era-learn.eu/network-information/networks/skep-fp6; SKEP ran from 6/2005-5/2009
[146] http://www.agence-nationale-recherche.fr/en/projects-and-results/calls-for-proposals-2013/aap-en/nanotechnologies-and-nanosystems-p2n-2013/

million[147]. France's objective is to maintain its position in nanoscience (3500 publications per year, fifth place behind US, Japan, China and Germany), help turn their scientific research into technical innovation, and so boost their position in nanotechnology (2% of worldwide patents) to improve their industrial competitive position.

The Centre National de la Recherce Scientifique (CNRS) on its website refers to the ethical issues of nanotechnology and Article 42 of the Grenelle Law, passed August 2009, deals with risks related to nanomaterials.

Germany: In 2011, the Federal Ministry of Education and Research (BMBF) published the Action Plan Nanotechnology 2010-2015 as part of their High-Tech Strategy. Nanotechnology is expected to make a major contribution to progress in the health sector and agriculture, in energy and resource efficiency, in environmental and climate protection and in the field of civil security. The plan covers both the opportunities and the potential risks. One goal of the plan was to develop technology for the protection of the environment and climate, securing the energy supply and the creation of a knowledge-based bioeconomy. An example is the use of environmental technologies for the removal and avoidance of noxious substances (air, water and soil), procedures of product-integrated environmental protection with optimised energy- and material flows as well as efficient methods of conversion, storage, distribution and use of energy. Other applications with an indirect impact on the environment are the use of nano-encapsulated substances in plant protection (agriculture), which can be applied more efficiently and environmentally-friendly and energy-saving mobility (use of nanotechnology in electric batteries, hydrogen storage and development of fuel cells). Specifically in the field of climate change adaptation, there is interest in the application of nano-based filter materials or modified geotextiles which increase water retention capacity, e.g. as preventive measure for the reinforcement of dykes of lakes and rivers.

Another goal was to make nanotechnology safe and sustainable through the clarification of the impacts of nanomaterials on humans and environment, to research their potential risks and, if required, to establish the respective risk management. This is the responsibility of the Federal Environment Agency. Federal funding for nanotechnology amounted to about EUR 400 million in 2010, fourth behind the USA, Russia and Japan.

Italy: The Italian National Research Programme 2004-2006 stresses the importance of nanotechnology and among the focus area mentioned there is Nanofabrication and electronics. In September 2014, MISE (Ministry for Economic Development) within the FCS (Fondo per la crescita sostenibile, Fund for sustainable growth), allocated EUR 300 million low interest loans (of which 60% earmarked for SMEs), covering areas including nanotechnology, ICTs, advanced manufacturing, etc. (only technologies associated with H2020). [148]

The Netherlands: NanoNed, the Nanotechnology R&D initiative in the Netherlands, clustered the Dutch expertise on nanotechnology and enabling technologies into a national network. The initiative ran from 2004 to 2010, with total funding of EUR 235 Million, and was administered by the Dutch Ministry of Economic Affairs. NanoNed was organised into eleven independent programmes or flagships.

In 2011, NanoNed was followed by NanoNextNL[149], a consortium of more than a hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities. Various stakeholders collaborate in fundamental as well as applied research projects. NanoNextNL has 10 themes and a programme aimed at commercialisation of technology (valorisation). The themes with a relation to environment are 1. Risk analysis and technology assessment[150] (with separate programmes for human health risks, environmental risks and technology assessment); 2) Clean water[151], with a research programme for nanotechnology in water applications; 3) Energy[152], for efficient and sustainable energy generation and consumption of energy; . NanoNextNL is expected

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[147] http://www.enseignementsup-recherche.gouv.fr/cid25281/nano-innov-un-plan-en-faveur-des-nanotechnologies.html and http://www2.cnrs.fr/en/1669.htm. Investments for the Future and Nano-Innov were temporary measures as part of France's economic recovery plan

[148] https://rio.jrc.ec.europa.eu/en/country-analysis/Italy/country-report

[149] http://www.nanonextnl.nl/

[150] http://www.nanonextnl.nl/themes/risk-analysis-and-technology-assessment/. Theme co-ordinator is the National Institute for Public Health and the Environment (RIVM)

[151] http://www.nanonextnl.nl/themes/clean-water/. Theme co-ordinator is Wetsus

[152] http://www.nanonextnl.nl/themes/energy/. Theme co-ordinator is Eindhoven University of Technology

to grow into an open-innovation ecosystem, with new partners joining the consortium. Industry has committed to continue its support to NanoNextNL after 2015.

Innovation in the Netherlands is organised under the *Top Sectors Policy*[153] [154] [155] announced in 2010. Businesses, researchers and government work closely together in knowledge and innovation consortia (TKI). As part of the government's objective to increase private investment in R&D, a target has been set for public and private parties to participate in public-private consortia for an amount of at least €500 million by 2015, 40% of which should be financed by private industry. The formal objective set for the top sector policy is that it should contribute to "a stronger innovative capacity in the Dutch economy." i.e. that the Netherlands will be ranked among the top five knowledge economies worldwide by 2020 and will spend 2.5% of GDP on R&D by 2020.

One of the nine top sectors is High Tech Systems and Materials with its roadmap on nanotechnology (implemented by TKI NanoNext) as an enabling and cross-cutting technology. The aim of the roadmap is to enable research that will lead to new applications to address the challenges that society currently faces. The technologies (for example, relating to materials, electronics/optics and sensors) can be deployed in multiple application areas (such as lighting, energy, health, water). Advances in mechatronics and manufacturing are being coupled with those in nanotechnology for areas including energy efficiency in buildings (energy-efficient building cooling, heating and lighting control using low costs micro- and nanotechnology-based autonomous sensors and control systems with local intelligence).

Portugal: The International Iberian Nanotechnology Laboratory[156] was established as the result of a joint decision of the Governments of Portugal and Spain, in November, 2005. It is an international research organisation in the field of nanoscience and nanotechnology. Established as an Intergovernmental Organisation (IGRO), the INL is developing itself into a state-of the art research environment for nanobiotechnology, nanoelectronics, nanomedicine and materials science at nanoscale. One of their four research areas is *Environment monitoring, security and food quality control*, with a research groups looking at nanotechnological solutions for water and food biotoxins. In addition to being a facility for researchers in Portugal and Spain, it hosts those from non-EU countries such as Brazil

Spain: In Spain, the Sixth National Scientific Research, Development and Technological Innovation Plan (2008-2011) had five strategic actions including Energy and Climate Change and Nanoscience and Nanotechnology, New Materials and New Industrial Processes (SANSNT)[157]. Strand 3 of the strategic action for nanoscience and nanotechnology focused on nanotechnology in relation to industry and the environment (such as development of materials and systems for effluent treatment) and strand 6 on the development and validation of new industrial models and strategies. This included tools for "eco-design", encompassing new materials, raw material reduction, noise and energy consumption, easy disassembly, modularity, re-utility, recyclability, low costs, safety, etc. as well as measuring and monitoring systems on environmental impact in production systems.

Within the new Spanish State Plan for Scientific and Technical Research and Innovation 2013-2016, endorsed in February 2013, different funding support instruments will be available for the development and dissemination of Key Enabling Technologies, including nanotechnology, and societal challenges e.g. *Climate change and efficient use of resources and raw materials* and *Safe, efficient and clean energy*

The United Kingdom: In the United Kingdom in 2010, the Ministerial Group on Nanotechnologies, the Nanotechnology Research Co-ordination Group (NRCG) and the Nanotechnology Issues Dialogue Group (NIDG) issued the UK Nanotechnologies Strategy - Small Technologies, Great Opportunities which addressed energy generation through solar technology as a national priority. Advanced materials for energy is also a thematic priority area in the Enabling Strategy 2012-2015 of InnovateUK (formerly the Technology Strategy Board).

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[153] http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/smart-industry
[154] http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/nanotechnology
[155] http://www.awti.nl/upload/documents/publicaties/engels/Status-op-the-top-sectors-in-2014-Summary.pdf
[156] www.inl.int
[157] www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Politicas_I+D+i_PlanNacional/PLAN_NACIONAL_2008-2011_ingles.pdf

The UK Enabling Technologies Strategy 2012-2015[158] also addresses four enabling technologies - advanced materials; electronics, sensors and photonics; information and communication technology (ICT); and to support business in developing high-value products and services in areas such as transport, energy, the built environment, food and healthcare. Nanotechnology is identified as having a significant underpinning role across most of these technology areas. Although the need for a sustainable approach to production and consumption is recognised, environmental applications of nanotechnology or potential risks related to its use are not part of the strategy.

In 2004 the Royal Society and the Royal Academy of Engineering published their report "Nanoscience and nanotechnologies: opportunities and uncertainties"[159]; the report stresses the need to validate the claims about environmental benefit, such as improved energy efficiency, through life cycle assessment (LCA). It furthermore discusses the health, environmental and safety aspects of nanoparticles and nanotubes, social and ethical issues and the need for stakeholder and public dialogue. The Nanotechnology Strategy Forum[160] (NSF) was set up to promote discussion and engagement between government and key stakeholders on strategic issues in order to advance nanotechnology industries responsibly in the UK. The NSF is an ad-hoc expert advisory body with a membership drawn from industry, regulators, academia and NGOs. However, the last meeting on its website was 10 March 2014.

Nanotechnology is one of the "Dialogue Projects" of Sciencewise[161], the UK's national centre for public dialogue in policy making involving science and technology issues.

Many Member State nanotechnology policies and programmes are identified in the table below. In addition to individual Member State initiatives, there are bilateral and multilateral collaborations between countries, agencies and research organisations. There is also additional information in the Annex: Additional Information on Member State Policies and Programmes (an Annex which is common to all the NanoData Landscape Compilation reports).

In addition to individual Member State initiatives, there are bilateral and multilateral collaborations between countries, agencies and research organisations. National websites also highlight the importance nanotechnology for and some countries actively promote themselves as leaders in nanotechnology. For example:

- From France, the web site of Campus France[162] states:

  "With more than 5,300 researchers and 240 laboratories working in the nanosciences and nanotechnologies, French institutions are engaged in a great many nano-research projects in the broad fields of electronics, communications, materials, energy (including lithium-ion batteries and hydrogen cells for increased autonomy of electric cars and motors), biotechnologies, pharmacology, medicine, health, and the environment. [….] With the research infrastructure built since the 1990s, France is one of the leaders in basic research in the nanosciences. The country ranks second in Europe, after Germany, in the amount invested in nanoscience research, and fifth in the world in number of publications in the field."

- From Germany, the Trade and Invest Agency[163] website provides the information that: "Approximately half of the nanotechnology companies in Europe are from Germany; the country is number one in Europe in the nanotechnology industry. German companies manufacture products in the areas of nanomaterials, nanotools, nanoanalytics, and nanotools accessories (e.g. vacuum and cleanroom technology, plasma sources, etc.). They also manufacture and utilise nano-optimised components and systems, and they provide services in the areas of consulting, contract coating, technology transfer, and commissioned analysis and research …".

Some of the policies and programmes for nanotechnology, and where appropriate nanotechnology and environment, in countries outside of the EU are reported in the next section.

[158] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015
[159] http://www.raeng.org.uk/publications/reports/nanoscience-and-nanotechnologies-opportunities
[160] https://www.gov.uk/government/groups/nanotechnology-strategy-forum
[161] http://www.sciencewise-erc.org.uk/cms/
[162] http://ressources.campusfrance.org/catalogues_recherche/recherche/en/rech_nano_en.pdf
[163] http://www.gtai.de/GTAI/Navigation/EN/welcome.html#invest

Table 4-1: Member State policies and programmes for nanotechnology

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
AT	Austrian NANO Initiative[164] (NANO)	2004-2011	Directly Targeting NT	Multiannual, funding collaborative R&D, co-ordinating NANO-related policy measures at national and regional levels. Since 2012, NT is supported via FFG's thematic research funding e.g. Production of the Future	IND SME HEI PRO	FFG	70 over 8 years
AT	------	From 2012	Thematic, not NT Specific	Since 2012, NT R&D is being supported via FFG's thematic research funding e.g. Production of the Future	All	FFG	450 for all disciplines (over the preceding 4 years when funding was managed by BMVIT)
BE	IMEC	From 1984	Thematic, not NT Specific	Since 1984 the Government of Flanders is supporting IMEC research institute	All	Government of Flanders	Initial investment: 62 For every period the contribution increased until reaching around 48 in 2011.
DK	Strategic Research in Growth Technologies[165]	From 2005	Directly Targeting NT	Programme to strengthen research at the bio-nano-ICT interface for socio-economic benefit	IND SME HEI PRO	Innovation Fund Denmark	c. 10 per annum
FI	FinNano[166]	2005-2009	Directly Targeting NT	Multiannual funding for nano S&T to study, exploit and commercialise nano.	IND SME HEI PRO	Tekes	70 over 5 years
FR	Nanomaterials Mandatory Reporting Scheme[167]	From 2013	Directly Targeting NT	Mandatory reporting scheme for nanomaterials of 100g and above	All	ANSES	n/a
FR	PNANO P2N	2002-5 2006 -13	Directly Targeting NT	R&D on • Nanotechnologies, Nanodevices, Micro-Nanosystems • Simulation and Modelling of Nanosystems • Nanotechnologies for Biology, Health and Agro-food • Nanotechnologies for Energy and Environment • Integrative Research Projects for Nanosystems	IND SME HEI PRO and Individuals	ANR[168]	139.8 for P2N over 8 years
FR	Investissements d'avenir	From 2011	Generic	Excellence initiatives including nanobiotechnology and bioinformatics	IND SME PRO	ANR	12 per annum
DE	Nanotechnology	2004-	Directly	Five leading-edge innovation programmes including	All	BMBF	24 over 3 years

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164 https://www.ffg.at/nano-aktuell ; https://www.ffg.at/11-ausschreibung-produktion-der-zukunft
165 http://innovationsfonden.dk/en/about-ifd
166 www.tekes.fi
167 https://www.anses.fr/fr/lexique/nanotechnologies
168 http://www.agence-nationale-recherche.fr/

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
	Conquers Markets	2006	Targeting NT	NanoforLife – pharmaceuticals and medical			
DE	Nano Initiative – Action Plan	2006-2010	Directly Targeting NT	Cross-departmental initiative led by BMBF: to speed up the use of the results of nanotechnological research for innovations; introduce nanotechnology to more sectors and companies; eliminate obstacles to innovation by means of early consultation in all policy areas; and (4) enable an intensive dialogue with the public.	All	BMBF	640 over 5 years
DE	Innovation Alliances	2007-2012	Directly Targeting NT	For strategic long-term co-operation between multiple industry and public research partners. Funds R&D, other innovation-related activities. Public and private funds are combined in a 1:5 ratio.	All	BMBF	500 over 6 years
IT	Fondo per la Crescita Sostenibile (FCS) (Fund for sustainable growth)	2002-2004	Targeting NT	In September 2014 MISE issued the call for industrial R&D projects of the FCS, covering the fields of ICTs, nanotechnology, advanced manufacturing, advanced materials, biotechnology, technologies associated with the EU Horizon 2020 programme.	Mainly SMEs	MISE	300
LT	High Technology Development Programme	2012-Ongoing		The High Technology Development Programme in 2012 aims to encourage scientists, researchers and students to establish start-up or spin-off companies. 13 new companies obtained public funding. The high-tech areas concerned are: information technology, nanotechnology, mechatronics lasers technology and biotechnology	SMEs	MITA	13 companies obtained public funding for a maximum of around EUR 20,000 each
NL	NanoNed	2004-2011	Directly Targeting NT	NanoNed was organised into eleven independent flagships based on regional R&D strength and industrial relevance, including NanoFabrication and NanoElectronics	IND SME HEI PRO and Individuals	Dutch Ministry for the Economy	235 over 8 years
NL	NanoNextNL	2011-2015	Directly Targeting NT	Consortium-based system (over one hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities). Stakeholders collaborate on fundamental and applied research projects. It includes NanoFabrication.	IND SME HEI PRO and Individuals	Dutch Ministry for the Economy	125 over 5 years
NL	Top sectors	2010 to date	Directly Targeting NT	The Top Sector Policy involves government support in nine key economic areas (the top sectors) through a combination of generic (i.e. financial) instruments and a focused emphasis on achieving optimum cooperation in the „golden triangle" formed by companies, research institutions and government. The policy works through Top Consortia for	IND SME HEI PRO	Dutch Ministry for the Economy	Objective for public and private sector to participate in the Top Consortia for Knowledge and Innovation (TKIs) for an amount of at least EUR

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
				Knowledge and Innovation (TKIs).			500 million by 2015, 40% of which from trade and industry.
ES	Strategic Action of Nano Science, Nano technologies, new materials and new industrial processes	2008-2011	Directly Targeting NT	To enhance the competitiveness of industry by generating new knowledge and applications based on the convergence of new technologies, where nanotechnology plays a central role.	IND SME HEI PRO	Ministry	33 over 4 years
PT	International Iberian Nanotechnology Laboratory	2005 to date	Directly Targeting NT	International research organisation in the field of nanoscience and nanotechnology, the result of a joint decision of the Governments of Portugal and Spain. Becoming a state-of the art research environment (including nanofabrication facilities) for nano-biotechnology, nano-electronics, nanomedicine and materials science at nanoscale. INL hosts researchers from the EU and non-EU countries including Brazil.	IND SME HEI	Governments of Portugal and Spain	46.5 (of which 30 from ERDF Spain – Portugal" Operational Programme) over 7 years
SK	Action Plan for the Innovation Strategy for Smart Specialisation (RIS3) 2014-2020	2014-2020	Targeting NT, but not only	The Action Plan focused on measures to encourage R&D expenditure of companies and applied research. The Action Plan identified also seven priority areas that include material research and nanotechnologies and information and communication technologies.	Industry	MESRS	Around 42 for nanotechnology Around 10 for ICT
UK	Micro and Nanotechnology Manufacturing Initiative[169]	2003-2007	Directly Targeting NT	Support for collaborative R&D and capital infrastructure, co-financed by industry	Industry	DTI	329 over 4 years, over 100 from public funds
UK	UK Nanotechnologies Strategy	2009-2012	Directly Targeting NT	Targets the ways by which nanotechnologies can address major challenges facing society such as environmental change, ageing and growing populations, and global means of communication and information sharing.	IND SME HEI PRO	TSB, EPSRC, BBSRC and MRC	
UK	Key Enabling Technologies Strategy	2012-2015	NT as Underpinning Technology	Addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having	Business mainly	Innovate UK	GBP 20m a year in higher-risk, early-stage innovation across advanced materials; biosciences; electronics, sensors and photonics;

[169] http://www.innovateuk.org/

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
				a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.			and ICT

5 POLICIES AND PROGRAMMES IN OTHER COUNTRIES[170]

5.1 Europe

5.1.1 Non-EU Member States

5.1.1.1 Norway

From 2002 to 2011, Norway addressed nanotechnology through its Programme on Nanotechnology and New Materials (NANOMAT)[171], the first thematic investment area being *Energy and the environment*.

In 2012, a follow-on programme to run until 2021 was initiated, the Nanotechnology and Advanced Materials Programme (NANO2021)[172]. Managed by the Research Council of Norway[173], this large-scale programme covers research on nanoscience, nanotechnology, micro-technology and advanced materials. The programme is designed to further raise the level internationally of the Norwegian knowledge base in nanotechnology and advanced materials. NANO2021 receives funding from the Ministry of Education and Research and the Ministry of Trade and Industry. The annual budget in the period 2013-2021 has been set at NOK 92.1 million (EUR 10 million[174])[175]. NANO2021 supports:

- Development of basic knowledge and technology use in priority areas such as the environment, energy, climate impacts and the use of natural resources.
- Socially responsible technology development, which investigates the impact of nanomaterials on human health and the ecosystem and addresses ethical and social issues relating to the development, production and application of the technologies.

5.1.1.2 The Russian Federation

The Russian Federation came comparatively late to nanotechnology as a topic for research, development and innovation policy. It was only in 2007 that a comprehensive government effort in the field began with the launch, in April of that year, of a strategy for the development of the 'nano-industries'. The strategy was to be realised through a series of Federal Target Programmes, amongst which was one specifically dedicated to the development of nanotechnology and the creation of new government bodies for that purpose. The main focus of Russian nanotechnology efforts since that time has been on the development of a domestic infrastructure for nanotechnology research and development as well as for innovation, commercialisation and manufacturing of nano-products. This is expected to remain the major theme for the coming years.

State institutions have been the principal actors in the field of nanotechnology in Russia for the intervening period. The State Corporation, RUSNANO, has had primary responsibility for the development of nanotechnology innovation and its commercialisation. RUSNANO was the outcome of a re-organisation in 2011 of the State "Russian Corporation of Nanotechnologies" that was established in 2007. It was set up as one of several State Corporations intended to lead the economic modernisation that was proposed in the *Concept for the Long-Term Socio-Economic Development of the Russian Federation*.

RUSNANO now combines an open joint-stock company and a Fund for Infrastructure and Educational Programmes (FIEP). It had capital funding in 2008-2009 of over USD 4 billion (EUR 2.8 billion[176]) but this dropped to USD 2.6 billion (EUR 1.9 billion[177]) by the end of 2010, falling further thereafter. A gradual privatisation of RUSNANO began in 2011. The mission of RUSNANO is to grow the national nanotechnology industry through the commercialisation of nanotechnology and the co-ordination of

[170] The UN method of classifying countries by macro geographical (continental) regions and geographical sub-regions was followed (http://unstats.un.org/unsd/methods/m49/m49regin.htm)
[171] http://www.forskningsradet.no/prognett-nano2021/Artikkel/About_the_programme/1253970633592?lang=en
[172] http://www.forskningsradet.no/servlet/Satellite?c=Page&pagename=nano2021%2FHovedsidemal&cid=1253969916237&langvariant=en
[173] http://www.forskningsradet.no
[174] At the current exchange rate, October 2015
[175] Nanotechnology and Advanced Materials – NANO2021: Work Programme
[176] Average yearly conversion rate, 2008-2009 (*source*: www.wolframalpha.com)
[177] Average yearly conversion rate, 2010 (*source*: www.wolframalpha.com)

nanotechnology-related innovation. It acts as a co-investor in nanotechnology projects having substantial economic or social potential.

RUSNANO has a very wide range of activities spanning from research to foresight to infrastructure, education, standards and certification. In its 2013 Strategy until 2020[178], Rusnano identifies the following industry sectors as the focus of investment: healthcare; metallurgy and metal fabrication; power production; mechanical engineering; instrument engineering; chemistry and petroleum chemistry; electronics; optoelectronics; telecommunications; construction materials; industrial materials; biotechnologies. Environment is only indirectly referred to in applications such as energy efficiency and coating application.

The role of nanotechnology for environmental applications is a subject of research in Russia, for example, a study into the effect of basic materials modification (using carbon nanotubes) on reduction of global anthropogenic greenhouse gas emissions was carried out by the Centre for Energy Efficiency XXI century and was published in 2015[179].

5.1.1.3 Switzerland

Basic (fundamental) research is funded at national level through the Swiss National Science Foundation (SNF) and the Commission for Technology and Innovation (CTI) and takes place mainly in the Swiss Federal Institute of Technology (ETH) and the universities, as well as some 30 research organisations. Applied research and the transfer of research to market innovation takes place in industry and "Fachhochschulen" (Universities of Applied Research). Two-thirds of R&D investment (which in Switzerland is almost at the EU target of 3% of GDP) comes from private industry.

CTI funds the Swiss MNT network (micro and nanotechnology) as one of the core innovative themes of national and international importance[180]. The Swiss MNT Network is an R&D consortium of the major public R&D institutions in micro and nanotechnology whose goal is to simplify access to industries looking for competences and expertise for their projects[181]. Members include ETH Zürich, Hightech Zentrum Aargau, Centre of Micronanotechnology (EPFL), Adolphe Merkle Institute and companies such as IBM, BASF and Novartis. There are also some regional networks that include nanotechnology as priority: i-net innovation networks Switzerland – i-net Nano[182], and Nano-Cluster Bodensee[183]. Most activities are strongly focused on R&D to support industry.

5.2 The Americas

5.2.1 North America

5.2.1.1 Canada

The National Research Council is the Government of Canada's premier organisation for research and development and is a co-funder of the National Institute for Nanotechnology (NINT), located in Alberta.

NanoCanada[184] is a national initiative that brings together the community to stimulate innovation, enhance R&D capacity and stimulate the development of nanotechnology applications in collaboration with industry.

The Canadian Forest Service (Natural Resources Canada) invested CND 3 million (EUR 2 million[185]) a year in the period 2007-2009 to develop nanotechnology products and processes for the forest sector. Environmental benefits are, for example, nano-filtration (selective separation of ions) to reduce the effect the effluents in pulp and paper waste water, thereby enabling industry to recycle more waste water and consume less fresh water, and reduction of emissions in order to promote a

[178] Strategy of open joint-stock company "Rusnano"until 2020, December 2013, http://en.rusnano.com/upload/images/documents/RUSNANO_Strategy_2020.pdf
[179] Research report stage 3, Moscow 2015, CENEf-XXI, http://en.rusnano.com/upload/images/documents/Research_Report_Stage3.pdf
[180] https://www.kti.admin.ch/kti/en/home/unsere-foerderangebote/Unternehmen/internationale-netzwerke-und-forschungskooperationen-neu/spezialthema-japan-schweiz1/foerderlandschaft-schweiz.html
[181] http://www.swissmntnetwork.ch/content/
[182] http://www.i-net.ch/nano/
[183] http://www.ncb.ch/wordpress_neu/
[184] http://nanocanada.com/
[185] Current conversion rate, June 2016

healthier climate for Canada's forests.

A NanoPortal[186] was set up as gateway to the Government of Canada's information on nanotechnology, including information about Ethics and Society and Regulation and Standards.

Nanotechnology is also promoted in Canada at the level of its Provinces, for example in Alberta and Quebec.

Alberta

The National Institute for Nanotechnology (NINT) is a research institution located in Edmonton on the main campus of the University of Alberta. Its primary purpose is nanotechnology research. The Institute was established in 2001 as a partnership between the National Research Council of Canada (NRC), the University of Alberta and the Government of Alberta. As an institute of the NRC, its core funding comes from the Government of Canada and additional funding and research support from the university, the Government of Alberta and various federal and provincial funding agencies. Its activities include Environmental Health and Safety practices to enable nanotechnology development and deployment. Research programmes related to the environment are Energy Generation and Storage, Nano-enabled Bio Materials (to reduce dependence on fossil fuels) and Metabolomics Sensor Systems (toxicology).

Following the announcement in 2007 of the Government of Alberta's Nanotechnology Strategy, nanoAlberta was created as an implementation organisation for that Strategy. NanoAlberta provides leadership to and co-ordination of the Province's wide range of capabilities, organisations and individuals with the aim of gaining a return of CND 20 billion (EUR 13.4 billion[187]) in market share for nano-enabled commerce by 2020 by developing nano-enabled products and applications specific to industries in the energy and environment, health and medical technologies, and agriculture and forestry sectors.

Quebec

NanoQuébec is a not-for-profit organisation funded by the MEIE (Ministère de l'Économie, de l'Innovation et des Exportations du Québec). Its mission is to strengthen nanotechnology innovation, increase its diffusion and raise both capabilities and capacities in the Province in order that Quebec becomes a centre of excellence for nanotechnology. The overarching and long-term aim is that of maximising economic impacts from nanotechnology in Quebec. Since December 2014, following a merger with the Consortium Innovation Polymères, NanoQuébec has formed part of Prima Québec, Quebec's advanced materials research and innovation hub.

Quebec's Nano Action Plan 2013-2018[188] specifically targets four priority sectors: microsystems, health, industrial materials and forestry. It covers infrastructure, financing of innovation, knowledge transfer and technology transfer, and national and international outreach horizontally across the four priority areas.

Via a central point (QNI or Quebec Nanotechnology Infrastructure), it co-ordinates and provides infrastructure for 300 experts using a fund of CND 300 million (EUR 200 million[189]). QNI has particular strengths in micro-nanofabrication, characterisation, synthesis and modelling. Other infrastructure can be accessed but is not funded via QNI.

The Action Plan has also led to the financing of technological feasibility projects (maximum six months); collaborative industry/university research projects (one to two years); and international research projects with strategic NanoQuébec partners. Knowledge and technology transfer are supported through training, industry internships, and dissemination and awareness activities; by establishing networks and by organising interactive visits by experts. Outreach actions aim to attract new projects and finance to Quebec and to increase the engagement in international projects by people from Quebec.

[186] http://nanoportal.gc.ca/default.asp?lang=en&n=9156F3D3-1
[187] Conversion rates, October 2015
[188] http://www.nanoquebec.ca/media/plan-action_en1.pdf
[189] Conversion rates, October 2015

5.2.1.2 The United States of America (US)

The National Nanotechnology Initiative[190] was launched in 2000 across a group of eight Federal agencies with some responsibility for nanotechnology research, application and/or regulatory activity, and has grown to include 25 Federal agencies. It aims to create collaborations and bring together expertise to work on shared goals, priorities, and strategies thereby leveraging the resources of the participating agencies. The goals of the NNI Goals are to advance world-class nanotechnology research and development; foster the transfer of new technologies into products for commercial and public benefit; develop and sustain educational resources, a skilled workforce and the supporting infrastructure and tools to advance nanotechnology; and support the responsible development of nanotechnology.

The NNI is managed within the framework of the National Science and Technology Council (NSTC), a cabinet-level council under the Office of Science and Technology Policy at the White House. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the NSTC facilitates planning, budgeting, programme implementation and review across the NNI agencies. The National Nanotechnology Co-ordination Office (NNCO) was established in 2001 to provide technical and administrative support to the NSET Subcommittee, serve as a central point of contact for Federal nanotechnology R&D activities and perform public outreach on behalf of the National Nanotechnology Initiative.

The NSET Subcommittee is composed of representatives from agencies participating in the NNI and NSET has Working Groups on Nanotechnology Environmental & Health Implications (NEHI) which includes the Environmental Protection Agency; Global Issues in Nanotechnology; Nano-manufacturing, Industry Liaison, & Innovation; and Nanotechnology Public Engagement and Communications.

In February 2014, the National Nanotechnology Initiative released a Strategic Plan[191] outlining updated goals and five "programme component areas" (PCAs). The goals focus on extending the boundaries of research; fostering the transfer of technology into products; developing and sustaining skilled people (with the right infrastructure and toolset) for nanotechnology; and supporting responsible development of nanotechnology. The five PCAs include a set of five Nanotechnology Signature Initiatives (NSIs) as well as PCAs for foundational research; nanotechnology-enabled applications, devices, and systems; research infrastructure and instrumentation; and environment, health, and safety.

The Nanotechnology Signature Initiatives (NSIs) relevant to the environment are:

- Water sustainability through nanotechnology: nanoscale solutions for a global-scale challenge;
- Nanotechnology for sensors and sensors for nanotechnology: improving and protecting health, safety and the environment;
- Sustainable nano-manufacturing: creating the industries of future; and
- Nanotechnology for solar energy collection and conversion: contributing to energy solutions for the future.

The NNI's budget supplement proposed by the Obama administration for Fiscal Year 2015 provided for USD 1.5 billion (EUR 1.2 billion[192]) of funding. Cumulative NNI investment since fiscal year 2001, including the 2015 request, totals almost USD 21 billion (EUR 17 billion[193]). Cumulative investments in nanotechnology-related environmental, health, and safety research since 2005 is nearly USD 900 million (EUR 680 million[194]). The Federal agencies with the largest investments are the National Institutes of Health (NIH), the National Science Foundation (NSF), the Department of Energy, the Department of Defence, and the National Institute of Standards and Technology (NIST).

The 2014 NNI Strategic plan also identifies the different priorities and interests of agencies. For example, the Consumer Product Safety Commission (CPSC) looks at the behaviour of nanomaterials in the environment and the human body. CPSC has developed an internal nanotechnology team composed of various technical experts (e.g. engineers, toxicologists, and economists) to advise the

[190] http://www.nano.gov/
[191] http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf
[192] Average yearly conversion rate, 2015 (*source*: www.wolframalpha.com)
[193] Average yearly conversion rate, 2001-2015 (*source*: www.wolframalpha.com)
[194] Average yearly conversion rate, 2005-2015 (*source*: www.wolframalpha.com)

Commission on the safe use of nanotechnology in consumer products. As part of the NNI, the CPSC nanotechnology team participates in the interagency collection and analysis of data and in the development of reports that focus on the potential EHS issues associated with the use of nanotechnology.

Some of the above-mentioned institutions (like NIST, with its main focus on measurement sciences and standards development) have areas dedicated to nanoscience and nanotechnology, but they do not have a specific sector focus. For instance, a fundamental part of NIST's mission is related to the development of the reference materials and data necessary to accurately measure key nanomaterial properties needed for the responsible development and use of nanotechnology. The NNI has enabled NIST to prioritise and coordinate nanotechnology research in areas such as the environmental, health, and safety aspects of nanomaterials (nanoEHS). NIST receives input through the activities of the NEHI Working Group on the critical science and measurement tools—protocols, standards, instruments, models, and validated data—required for risk assessment and management of engineered nanomaterials (ENMs) and nanotechnology-enabled products (NEPs).

The Department of Energy (DOE) participates in NNI due to its interest in the role of nanoscience and nanotechnology in solving energy and climate change challenges. They foresee the impact to be on solar energy collection and conversion, energy storage, alternative fuels, and energy efficiency.

The National Institute for Occupational Safety and Health (NIOSH) conducts research on hazard identification, exposure assessment, risk characterisation, and risk management to protect the health and safety of workers exposed to ENMs and NEPs. NIOSH also conducts toxicology studies to provide better understanding of the ways in which some types of ENMs may enter the body and interact with the body's organ systems.

The U.S. Geological Survey (USGS) nanotechnology research involves evaluating the effects of nanoparticles at various levels of biological organisation, from the molecular to the ecosystem level. Much of USGS nanotechnology research focuses on assessing the occurrence, fate, and effects of naturally occurring and engineered chemical contaminants in aquatic environments or on methods for detecting metal nanomaterials. Several programmes provide information on nanoparticles or other contaminants, including the Contaminant Biology Program, the Toxic Substances Hydrology Program, the National Research Programme, and the Water Resources Research Institutes.

The Environmental Protection Agency's (EPA) role in the NNI is to better understand the implications and applications of ENMs to help protect human health and the environment. The EPA's main interest is to understand how ENMs can be designed and used to minimise potential adverse public health or environmental impacts. Second, the EPA is interested in the potential of using advances in nanotechnology to improve the environment, including its use for environmental sensing, remediating pollutants, and for developing more environmentally-friendly substances. Both interests focus on the sustainable use of nanotechnology. The EPA considers nanotechnology to offer potentially transformative capabilities for a vast array of products and processes, including those that enhance environmental quality and sustainability.

Another important actor active in nanotechnology is the NSF. This federal agency, with an annual budget of USD 7.3 billion (EUR 6.8 billion[195]) (FY 2015), funds approximately 24% of all federally-supported basic research (except for medical sciences) conducted by America's colleges and universities[196].

5.2.2 South America

5.2.2.1 Argentina

A first initiative to foster nanotechnology in Argentina was established in 2003 when the national Science and Technology Secretariat started to organise research networks in the field. In 2004, the Secretariat, looked to address gaps in what being done under the National Agency for Scientific and Technological Promotion (ANPCYT, Agencia Nacional de Promoción Científica y Tecnológica[197]) as a result of which four nanoscience and nanotechnology networks were approved in 2005, bringing

[195] Conversion rate, November 2015 (*source*: www.wolframalpha.com)
[196] http://www.nsf.gov/about/
[197] http://www.agencia.mincyt.gob.ar/frontend/agencia/fondo/agencia

together around 250 scientists. In the same year, the Argentinian-Brazilian Nanoscience and Nanotechnology Centre (CABN, Centro Argentino-Brasileno de Nanociencia y Nanotecnología) was created as a binational co-ordination body integrating research groups, networks of nanoscience and nanotechnology, and companies in Argentina and Brazil, in order to support scientific and technological research in the area and to improve the human and scientific resources of both countries.

The Argentinian Foundation for Nanotechnology (FAN)[198] was initiated in 2005 by the Economy and Production Ministry, with the aim of stimulating training and developing technical infrastructure to promote advances in nanotechnology and the adoption of nanotechnology by industry. It also aimed to encourage the participation of researchers, institutions and companies from Argentina in international networks.

While previous national programmes had differentiated between funding either for the public sector (essentially the research networks) or for the private sector (projects of the FAN), the nanotechnology sector funds (FS-NANO) launched in 2010 provided funding to projects dedicated to basic and applied science via public-private partnerships. One of FAN's initiatives is Nano-sustainable, which addresses the risks and impacts and potential impacts of nanotechnology coordinating efforts with regulatory agencies.

In 2011, the Ministry of Science, Technology and Productive Innovation published the Argentina Innovadora 2020 (Innovative Argentina Plan 2020): National Plan of Science, Technology and Innovation. The plan focuses on three general-purpose technologies (nanotechnology, biotechnology and information and communication technology (ICT)) addressing six strategic groups, including industry.

5.2.2.2 Brazil

Systematic policy support for nanotechnology started in 2001, when the Brazilian Ministry of Science and Technology (MCT) through the Brazilian National Research Funding Agency (Conselho Nacional de Desenvolvimento Científico e Tecnológico or "CNPq") earmarked BRL 3 million (USD 1 million) (EUR 1.12 million[199]) over four years to form Co-operative Networks of Basic and Applied Research on Nanosciences and Nanotechnologies. Four national research networks were established: semiconductors and nano-structured materials; nano-devices; molecular nanotechnologies and interfaces; and nano-biotechnology. In late 2004, a network on Nanotechnology, Society and Environment was created that was independent of the formal funding mechanisms.

Since 1999, Brazil's national plan has comprised an annual budget and a four-year strategic plan (the Plano Plurianual or PPA). In 2003, the Ministry created a special division for the general co-ordination of nanotechnology policies and programmes whose work resulted in a proposal for specific nanotechnology-related funding. That proposal was taken up in the PPA in 2004-2007, which provided for BRL 78 million (c. USD 28 million) (EUR 22 million[200]) over 4 years for the Programme for the Development of Nanoscience and Nanotechnology. The aim of the programme was "to develop new products and processes in nanotechnology with a view to increasing the competitiveness of Brazilian industry", which it implemented by supporting networks, research laboratories and projects.

A review of the funding in the light of the 2004 policy on Industrial, Technological and Foreign Trade, the government reconsidered the original budget and increased Federal investment for 2005 and 2006 from the original USD 19 million (EUR 15 million[201]) to c. USD 30 million (EUR 24 million[202]) for those two years. Ten new research networks were set up to continue previous research activities but linking more closely to broader industry, technology, and trade policies. Industrial policy helped to reinforce the strategic status attributed at national level to nanotechnology and its role in enhancing Brazil's competitiveness. Of particular important in the programmes were the development of qualified human resources, the modernisation of infrastructure and the promotion of university-industry co-operation.

[198] http://www.fan.org.ar/en/
[199] Average yearly conversion rate, 2001(*source*: www.wolframalpha.com)
[200] Average yearly conversion rate, 2004-2007 (*source*: www.wolframalpha.com)
[201] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[202] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)

In 2012, the Brazilian Ministry for Science, Technology and Innovation (MCTI) launched the SisNANO[203] initiative, enabling scientists throughout Brazil to conduct experiments at 26 "open" laboratories offering the very best equipment for research in nanotechnology. University students and staff can use the facilities free of charge – provided that they submit a good research proposal – while scientists working in industry are able to access specialist equipment and expertise at highly subsidised rates.

In 2013, MCTI launched the Brazilian Nanotechnology Initiative (IBN) with funding estimated to be BRL 440 million (EUR 148 million[204]) for the 2013-2014 period. The implementation of IBN was an effort to further strengthen nanotechnology in Brazil by strengthening academic and industry linkages thereby to promote the scientific and technological development of the nanotechnology sector. The goal is to total investment in IBN to reach BRL 300 million per year, with BRL 100 million invested directly in SisNANO.

Also in 2013, the Brazilian Congress rejected a bill that aimed to introduce labelling on all food, drugs and cosmetics containing nanostructures, arguing that it was alarmist and without scientific basis[205]. Some experts argued that regulation would make nanotechnology and its industrial applications more transparent and would help define, evaluate and minimise potential risks to human health and the environment.

Brazil has a collaboration with the International Iberian Nanotechnology Laboratory (INL)[206] which has already received more than 25 researchers from Brazilian research centres dedicated to research at the nanoscale.

5.3 Asia

5.3.1 Eastern Asia

5.3.1.1 China

The transition of China from a centrally-planned to a more market-oriented economy, begun in the 1980s, has also led to greater decentralisation of the science and technology (S&T) system. Central government is increasingly co-ordinating S&T, rather than managing research and development (R&D), with research institutions taking on a greater role in policy, setting their own research agendas in the context of the National Five-year Plans.

The National High Technology Research and Development Programme (the 863[207] programme announced in 1986) focuses on key high-technology fields of relevance to China's national development, supporting research and development, strengthening technological expertise and laying the foundations for the development and growth of high technology industries. Its goals are 'promoting the development of key novel materials and advanced manufacturing technologies for raising industry competitiveness' including nanomaterials. The programme is supervised by the National Steering Group of S&T and Education, and is managed by the Ministry of Science and Technology.

The 863 Programme has been implemented through successive Five-Year Plans. In addition to nanotechnology research funding, the Tenth Five-Year Plan (2001-2005) targeted commercialisation and development of nanotechnology. The Government disaggregated nanotechnology development into short-term projects (development of nanomaterials), medium-term projects (development of bio-nanotechnology and nano medical technology), and long-term projects (development of nano electronics and nano-chips). The Eleventh Five-Year Plan (2007-2012) emphasised innovative technologies, including the development of new materials for information technology, biological and aerospace industries, and commercialising of the technology for 90-nanometer and smaller integrated circuits.

The 1997 "National Plan on Key Basic Research and Development" together with the "National

[203] Sistema Nacional de Laboratórios em Nanotecnologias ftp://ftp.mct.gov.br/Biblioteca/39717-SisNANO.pdf
[204] Average yearly conversion rate, 2013-2014(*source*: www.wolframalpha.com)
[205] http://www.scidev.net/global/technology/feature/brazil-struggles-to-regulate-emerging-nanotechnology.html
[206] http://inl.int/about-inl/what-is-inl
[207] The programme is named for its date, the 86 for 1986 and the 3 for the third month, hence 86/3 or 863. Likewise for the 973 programme launched in March 1997.

Programme on Key Basic Research Project (973 Programme)" sought to strengthen basic research in line with national strategic targets[208]. The 973 Programme complements the 863 programme, funding basic research on nanomaterials and nanostructures (i.e. carbon nanotubes). The National Steering Committee for Nanoscience and Nanotechnology (NSCNN) was established in 2000 to coordinate and streamline all national research activities including overseeing the 863 and 973 programmes. The NSCNN consists of the Ministry of Science and Technology (MOST), the Chinese Academy of Sciences (CAS), the National Natural Science Foundation (NSFC), the National Development and Reform Commission (NDRC), the Ministry of Education (MOE) and the Chinese Academy of Engineering (CAE).

The Medium-and Long-term National Plan for Science and Technology Development 2006-2020 (MLP) aims to achieve the promotion of S&T development in selected key fields and to enhance innovation capacity. The MLP calls for more than 2.5% of GDP to be invested in R&D; for S&T to contribute at least 60% to economic growth; for dependence on foreign technologies to decrease to under 30%; and for China to rank in the top five in the world for patents and citations in international publications.

Nanotechnology is given priority status under the MLP, being seen as one of the Chinese 'megaprojects' in science. Transportation is also one of the priority areas and its importance is also highlighted in areas such as Energy efficiency applied to transport industry. As the MLP is implemented in the context of the Five-Year Plan for S&T Development (2011-2015), it is relevant that it also emphasises key technologies for strategic and emerging industries (including nanotechnology with ICT, photonics, manufacturing and agriculture).

In addition, China is promoting itself in nanotechnology. From http://www.china.org.cn/: "China is positioning itself to become a world leader in nanotechnology … nanotechnology has many potential applications with significant economic consequences in industrial design, medicine, agriculture, energy, defence, food, etc. In medicine for example, these include nanoscale drug particles and delivery systems and nano-electronic biosensors…. Today, China leads the world in the number of nanotechnology patents".

5.3.1.2 Japan

Strategic prioritisation of nanotechnology started in Japan under the Second Science and Technology Basic Plan (STBP) 2001-2005. Among the eight priority R&D topics of national importance were nanotechnology, as well as manufacturing technology and materials, energy, ICT, environmental sciences and life sciences, and the cross-cutting areas of infrastructure and frontier research. Nanotechnology was seen as being relevant to a broad range of fields and it was expected to help Japan to maintain its technological edge. Total governmental funding of this field grew in these years from JPY 85 billion (EUR 782 million)[209] in 2001 to JPY 97 billion (EUR 709 million[210]) in 2005.

In the subsequent STBP[211], which ran from 2006 to 2010, Japan established nanotechnology and materials as one of its four priority research fields, the others being information and communications, environmental sciences; and life sciences. Together with manufacturing, energy, environment, and frontiers, these formed eight Promotion Areas. The total budget over the five years was JPY 250 trillion (EUR 200 billion)[212]. There were five sub-areas under nanotechnology and materials – nano-electronics; fundamentals for nanotechnology and materials; materials; nanotechnology and materials science; and nano-biotechnology and biomedical materials.

In 2010, a 'New Growth Strategy' was introduced to combat the lengthy stagnation of the Japanese economy. The strategy sought to create jobs by tackling the issues faced by the economy and society. This took the form of a reorientation of priorities towards green innovation (reducing

208 http://www.chinaembassy.bg/eng/dtxw/t202503.htm

209 Average yearly conversion rate, 2001 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)

210 Average yearly conversion rate, 2005 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)

211 https://www.jsps.go.jp/english/e-quart/17/jsps17.pdf

212 Average yearly conversion rate, 2006 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)

emissions and addressing climate issues); life innovation (healthy and long living); the Asian economy (issues of specific Asian concern including falling birth rates and ageing societies); and tourism and the regions. Growth-related strategies for ('making Japan a superpower in') science, technology and ICT, for employment and human resources, and for the financial sector were also identified as essential in supporting growth. The strategy also addressed the issues arising from the earthquake, tsunami and nuclear crisis of 2011.

The same priorities were incorporated in 2011 into the Fourth Science and Technology Basic Plan (2011-2015) with a budget of EUR 250 billion (JPY 25 trillion). As with the New Growth Strategy, and in contrast to the previous Basic Plan for Science and Technology, the Fourth Basic Plan shifted away from emphasising technologies towards "demand driven and solution-oriented topics" as well as to "problem solving and issue-driven policies" and the "deepening the relationship between society and science and technology." Two broad based areas are prioritised: Life Innovation and Green Innovation and an emphasis has been placed on technologies to reduce global warming, provision and storage of energy supply, renewable energies, and diffusion of such technologies. As there is no specific emphasis on individual technologies, nanotechnology is incorporated across research and development without being specifically targeted. In the still limited information existing about the Fifth Science and Technology Basic Plan (2016-2020) nanotechnology is mentioned as a technology to be consolidated[213]. It also recognises that the possible impact of such technologies on humans and society should be considered. The Plan will address economic and social issues, including improving energy efficiency and ensuring food safety, living environments and occupational health.

5.3.1.3 Korea (South)

Long a topic of relevance in Korea, support for nanoscience and nanotechnology reached a new level in December 2000 with the announcement by the National Science and Technology Council (NSTC)[214] of the Korean National Nanotechnology Initiative (KNNI). Nanotechnology was also identified as one of six priority fields in the National Science and Technology Basic Plan (2002–2006). The NT Development Plan was approved by the NSTC on in July 2001 and the NT Development Promotion Act passed in November 2002 by the National Assembly. The initiative is now in its 3rd phase (2011-2020), with focus on 'clean nanotech'. Investment in phase 1 (2001-2005) was 105.2 billion Won (EUR 83 million[215]); phase 2, 277.2 billion Won (EUR 1,541.8 million[216]).

Under its KNNI, Korea has focused on establishing specific support mechanisms (programmes, systems and societies) and centres of excellence across the country. The launching of the National Programme for Tera-Level Nano-devices (2000) was followed by the founding of the Nanotechnology Industrialisation Support Centre (2001) and the Korean Advanced Nanofabrication Centre[217] (KANC) (2003). In more recent times, building on former centres, Korea established two NST centres at the Institute for Basic Science: the Centre for Nanoparticle Research and the Centre for Nanomaterials and Chemical Reactions (2012)[218]. In total, 24 nanotechnology-related centres now exist in Korea.

Under the Nanotechnology Development Promotion Act 2002, Korea also established in 2004 the Korean Nano Technology Research Society (KoNTRS)[219] as a mechanism for co-operation between researchers working on nanotechnology throughout the country, to develop collaborative research programmes between institutions (public and private) and to support the government in establishing appropriate national NST policies.

Korea has since continued to invest in nanotechnology, with the review by NSTC in 2006 of the first five years of its NNI leading to support continuing for an additional ten years. In this third phase of the NT Development Plan (2011-2020), there is greater focus on clean nanotechnology and overall the policy has evolved, moving away from funding fundamental research towards more application-

[213] http://www.jeupiste.eu/news/5th-science-and-technology-basic-plan-adopted
[214] http://www.nstc.go.kr/eng/
[215] Average yearly conversion rate, 2001-2005 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[216] Average yearly conversion rate, 2006-2010 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[217] http://www.kanc.re.kr/kancEnglish/center/center_overview.jsp
[218] https://www.ibs.re.kr/eng/sub02_04_03.do
[219] http://kontrs.or.kr/english/index.asp

driven actions.[220]

Korea has also sought to develop its nanotechnology policy and policy system, with the production of the Korean Nanotechnology Roadmap in 2008 and the establishment of the National Nanotechnology Policy Centre (NNPC) in 2010. The NNPC announces on its web site[221] the national vision for Korea to be "the world's number one nanotechnology power" and the four goals:

- "To become a leading nation in nanotechnology with systematic nanotechnology R&D programmes;
- To create a new industry based on nanotechnology;
- To enhance social and moral responsibility in researching and developing nanotechnology; and
- To cultivate advanced nanotechnology experts and maximise the utilisation of nanotechnology infrastructure."

Mid-term and long-term strategies for nanotechnology in Korea, which have been developed and implemented since about 2009, include:

- The Fundamental Nanotechnology Mid-term Strategy [NT 7-4-3 Initiative] through which the Ministry of Education, Science and Technology (MEST) supported 35 green nanotechnologies in seven areas as well as funding four infrastructure projects;
- The Nano Fusion Industry Development Strategy by MEST and the then Ministry of the Knowledge Economy (MKE), which sought to support nanotechnology all across the value chain, from the research laboratory to the marketplace;
- The National Nano Infrastructure Revitalisation Plan, also by MEST and MKE, to link nanotechnology infrastructures together, thereby giving them new impetus; and
- The Nano Safety Management Master Plan 2012-2016 to define methods and processes for the identification and manage any safety risks that emerge with the development, commercialisation and manufacture of nanotechnology products.

2012 saw the creation of the Nano-Convergence Foundation (NCF)[222] whose remit is to increase the commercialisation of national NST research outcomes. It operates under the joint support of the Ministry of Science, ICT & Future Planning (MSIP) and the Ministry of Trade, Industry & Energy (MOTIE). Korea plans to invest 930 billion Korean Won (ca. USD 815 million, EUR 740 million[223]) by 2020 in the NST, with projects in the Nano Convergence 2020 programme eligible to receive up to 2 billion Korean Won (EUR 1.5 million[224]) each.

5.3.1.4 Taiwan (Chinese Taipei)[225]

The National Nanoscience and Nanotechnology Programme[226] was approved for a period of six years by the National Science Council (NSC) in 2002. With a budget envelope of USD 700 million (EUR 740 million[227]) and actual expenditure estimated to be USD 625 million (EUR 486 million[228]) over 2003-2008, the aim of the programme was to foster nanotechnology research and development in research institutes, universities and private companies, achieving academic excellence and supporting commercialisation. The Academic Excellence part of the programme includes physical, chemical and biological properties of nano-sensors, nano-structures, nano-devices and nano-biotechnology. Industrial applications are the remit of the Industrial Technology Research Institute (ITRI). ITRI has 13 research laboratories and centres of which the most relevant to the environment is the Green Energy and Environmental Research Laboratories. It develops novel green energy and environmental technologies (renewable energy, energy efficiency, energy management and policy, clean environment and natural resources).

The National Nanoscience and Nanotechnology Programme also co-ordinates the nanotechnology research efforts of government agencies mainly through the establishment of common core facilities

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[220] http://www.nanotechmag.com/nanotechnology-in-south-korea/
[221] http://www.nnpc.re.kr/htmlpage/15/view
[222] http://www.nanotech2020.org/download/english_brochure.pdf
[223] Current exchange rate, November 2015 (*source*: www.wolframalpha.com)
[224] Current exchange rate (November 2015) (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[225] http://www.twnpnt.org/
[226] http://www.twnpnt.org/english/g01_int.asp
[227] Average yearly conversion rate, 2002 (*source*: www.wolframalpha.com)
[228] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2768287/

and education programmes, by promoting technology transfer and commercialisation into industrial applications and establishing internationally competitive nanotechnology platforms. Among the thematic priorities of the programme overall have been the design and fabrication of interconnects, interfaces and system of functional nano-devices, and the development of MEMS/NEMS technology.

Taiwan's Nanotechnology Community (NTC) was established in 2003 to identify commercial applications of nanotechnology and, in 2004, the Taiwan Nanotechnology Industrialisation Promotion Association (TANIPA) was set up by the Industrial Development Bureau at the Ministry of Economic Affairs (MOEA), with a strategic remit related to industrial applications of nanotechnology and to facilitate public-private co-operation.

Phase I of the National Nanoscience and Nanotechnology Programme was completed in 2008. Phase II was approved by the NSC in April 2008 to run for another six years (2009-2014) with the goal of strengthening and concentrating public resources on "Nanotechnology Industrialisation", i.e. the development of nanotechnology for domestic industry relevant to Taiwan and its growth into high-tech industry. Building on Phase I, Phase II covers nano-instrumentation, nano-optoelectronics, nano-electrics, energy and environmental nanotechnology, nano-materials and nano-biotechnology and applied nanotechnology in traditional industries.

5.3.2 Southern Asia

5.3.2.1 India[229]

The Nanomaterials Science and Technology Initiative (NSTI) was launched by the Ministry of Science and Technology's (MST) Department of Science and Technology (DST) in October 2001 to support priority areas of research in nanoscience and nanotechnology; strengthen national characterisation and infrastructural facilities; enhance nanotechnology education in order to generate trained manpower in the area; and create an applications-related interface between educational institutions and industry. The Indian government committed to investing USD 16 million (EUR 14 million[230]) in nanomaterials research and commercial development over the five-year duration of the initiative, 2002-2006. The funding was used for projects, centres of excellence, conferences, advanced courses (schools) and post-doctoral fellowships. Within its basic and application-oriented research programmes, it supported work on nanomaterials.

A capacity-building programme for nanoscience and nanotechnology (called Nano Mission)[231] was announced in 2007. It was implemented by DST with a budget of EUR 155 million over 5 years. In that time, India raised its publication output in nano-science and –technology generating about 5000 research papers and about 900 PhDs directly from Nano Mission funding. Under the programme, scientists were given access global state-of-the-art facilities in countries including Japan and Germany. The programme is also seen as having resulted in products including nano hydrogel-based eye drops, pesticide removal technology for drinking water, water filters for arsenic and fluoride removal and nano silver based antimicrobial textile coatings. Finally, it facilitated discussions on standards for nanotechnology at national level.

The continuation of the Nano Mission was approved by the Government in February of 2014 and EUR 91 million (INR 650 crore) were sanctioned for the time period 2012 to 2017[232]. The programme will continue to support nanoscience and technology by promoting basic research, human resource development, research infrastructure development, international collaborations, national dialogues, and nano-applications and technology development. In the area of development of products and processes, the programme has focused, and will continue to focus, on areas of national relevance including sensor development, safe drinking water, materials development and drug delivery.

In addition to DST, several other agencies support nanotechnology research and development:

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[229] http://www.oecd.org/science/nanosafety/37277620.pdf; http://nanomission.gov.in/; http://www.ris.org.in/images/RIS_images/pdf/DP%20193%20Amit%20Kumar.pdf, http://erawatch.jrc.ec.europa.eu/erawatch/opencms/information/country_pages/in/country?section=ResearchPolicy&subsection=ResPolFocus

[230] Average yearly conversion rate, 2002-2006 (*source*: www.wolframalpha.com)

[231] http://nanomission.gov.in/;

[232] http://timesofindia.indiatimes.com/home/science/Govt-approves-Rs-650-crore-for-Nano-mission/articleshow/30722422.cms

- The Council of Scientific and Industrial Research (CSIR)[233] has a network of 38 laboratories and other partners involving about 4600 scientists in research and development across a wide range of disciplines, including nanotechnology, and for application areas including aerospace and energy.
- In 2003, the CSIR launched the New Millennium Indian Technology Leadership Initiative (NMITLI) to foster public-private partnerships via grant-in-aid funding to public partners and soft loans to their industrial partners. The initiative specifically targeted nanosciences and nanotechnologies; biotechnology; energy and materials.[234]
- The CSIR's International Science and Technology Directorate (ISAD) facilitates nanotechnology workshops and projects in collaboration with partners from South Africa, France, South Korea, China and Japan[235].
- The MST's Science and Engineering Research Council (SERC)[236] supports frontier and interdisciplinary research. Support for nanotechnology projects has been provided through its R&D schemes for basic science and engineering science.

5.3.2.2 Iran[237]

The Islamic Republic of Iran ranked 23rd in the world in nanotechnology in 2007, second to Korea in citations in Asia[238], but, by 2012, it had moved to 10th place[239, 240]. In 2013, Iran ranked 20th in science production in the world (Thomson Reuters) and 18th in science production for medicine. According to the Ministry, its share of global science production rose from 1.39% in 2013 to 1.69% percent in 2014, as measured by indicators including the number of scientific papers, the quality and quantity of documents, patenting inventions, industrial plans, partnership with foreign universities, and the use of technology in domestic organisations.

There are nine scientific committees responsible for organising and coordinating science activities in Iran including committees for nanotechnology, aerospace, renewable energies, environment, information technology and biotechnology.

Iran began its nanotechnology activities with a Study Committee for Nanotechnology in 2001. Its work led to the development of the Iran Nanotechnology Initiative Council (INIC)[241], established in 2003 to develop policies to foster nanotechnology in Iran and monitors their implementation. The Council also funds researchers, having supported over 1400 researchers for nanotechnology activity between 2004 and 2010, at a cost of USD 12 million[242] (EUR 9 million[243]).

INIC has also funded the development of research and training facilities for nanotechnology research, such as the Institute for Nanoscience and Nanotechnology (INT) at the Sharif University of Technology. The INT, established in 2004, was the first institute to offer a PhD in nanotechnology in Iran[244]. INIC undertakes education and awareness-raising activities including a students' Nano Club, seminars, workshops, publications and a multi-lingual (Arabic, Persian, Russian and English) website[245].

Also in 2004, INIC was instrumental in establishing the Iran Nanotechnology Laboratory Network to optimise Iran's nanotechnology infrastructure. Forty-two laboratories across Iran operate under the network. The role of INIC includes evaluation and ranking of member laboratories and providing support for them in areas such as training workshops, lab equipment, and in gaining accreditation as testing and calibration labs.

INIC operates through working groups on areas including Human Resource Development; Technology Development and Production; and Education and Awareness. It also addresses standards

233 www.csir.res.in/
234 http://www.csir.res.in/external/heads/collaborations/NM.pdf
235 http://www.teriin.org/div/ST_BriefingPap.pdf
236 www.dst.gov.in/about_us/ar05-06/serc.htm
237 See also http://www.sciencedev.net/Docs/Iran_Nano.pdf (2010)
238 http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file11959.pdf
239 http://statnano.com/report/s29
240 http://www.nanotech-now.com/news.cgi?story_id=45237
241 http://nano.ir/index.php?lang=2
242 http://www.nanotech-now.com/news.cgi?story_id=36557
243 Average yearly conversion rate, 2004-2010 (*source*: www.wolframalpha.com)
244 http://blogs.scientificamerican.com/guest-blog/science-and-sanctions-nanotechnology-in-iran/
245 http://nano.ir/index.php?ctrl=static_page&lang=2&id=397&section_id=22

and regulations through the Iran Nanotechnology Standardisation Committee (INSC)[246], a body established in 2006 as a collaboration between the INIC and the Institute of Standard and Industrial Research of Iran (ISIRI)[247].

Continuing to support nanotechnology and the work of INIC, a "Future Strategy" was adopted in 2005 by the Cabinet, a 10-year nanotechnology development (2005 - 2014). Its mission was to place Iran among the top fifteen advanced countries in nanotechnology in the world. The focus was placed on building and using infrastructure and human resources; improving communication and networking both within Iran and internationally; and generating economic added value from nanotechnology as a means of achieving economic development[248].

Internationally, in the context of the Economic Co-operation Organisation (ECO), Iran promoted the establishment in 2009 of an ECO Nanotechnology Network, both providing funding to establish the network and agreeing to co-ordinate it jointly with the ECO Secretariat. INIC is the Iranian representative on the network.

5.3.3 South-Eastern Asia

5.3.3.1 Malaysia

Priority emerging technologies including nanotechnology and nano-biochips, nano-biosensors and photonics were identified under Malaysia's Second National Science and Technology Policy (STP II), launched in 2003. Other products and technologies were also specified: photovoltaic (PV) solar cells, Li-ion batteries, plant vaccines, and drug delivery systems.

The Malaysian National Nanotechnology Initiative (NNI) was established in 2006 to advance nanotechnology and related sciences by clustering local resources and knowledge of Malaysian researchers, industry and the government. The NNI paved way for the establishment in 2010 of the National Nanotechnology Directorate under the Ministry of Science, Technology and Innovation (MOSTI). The National Nanotechnology Directorate (NND)[249] facilitates nanotechnology development in Malaysia by acting as a central co-ordination agency.

To further support activity on these priority areas, the National Innovation Council of Malaysia in 2011 identified the need for a national organisation for nanotechnology commercialisation. NanoMalaysia[250] was created in 2011 as a company under the Ministry of Science, Technology and Innovation (MOSTI). It is responsible for commercialisation of nanotechnology research and development; industrialisation of nanotechnology; facilitation of investments in nanotechnology; and human capital development in nanotechnology. NanoMalaysia identified as key economic clusters as jumpstart sectors of nanotechnology the following: electronics, devices and systems; food and agricultural; energy and environment; and wellness, medical and healthcare. Also in 2011, the Top down Nanotechnology Research Grant (NanoFund) was introduced and NanoMalaysia Centres of Excellence created.

5.3.3.2 The Philippines[251]

Nanotechnology was first identified as a priority area in the Philippines in 2009 when the Department of Science and Technology (DOST) formed a multidisciplinary group to create a roadmap for the development of nanotechnology in the country. The Nanotechnology Roadmap for the Philippines had four major programmes: nano-based technologies and materials for Environment (water and waste, water purification, nano-based engineering / industrial materials); nanosensors and nano-diagnostics (food-detection of contaminants, agriculture & forestry-detection of diseases, and health-Filipino ethnicity-based nano-diagnostics); nano-metrology for ICT and semiconductor; nanostructure solar energy devices and storage[252].

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[246] http://nanostandard.ir/index.php?lang=2
[247] http://www.isiri.com/
[248] http://statnano.com/strategicplans/1
[249] http://www.mosti.gov.my/en/about-us/divisions-departments/national-nanotechnology-directorate-division-nnd/
[250] http://www.nanomalaysia.com.my/index.php?p=aboutus&c=whoweare
[251] http://www.techmonitor.net/tm/images/d/d1/10jan_feb_sf3.pdf
[252] http://nanotech.apctt.org/countryreports/Philippines%20Country%20Report.pdf

5.3.3.3 Singapore

With the aim of transitioning to a knowledge-based economy, Singapore has relied, since the early 1990s, on its five-year basic plans for science and technology (S&T). Foresight and technology scanning were key components of the process by which the 2010 plan[253] was developed. Thirteen technology scanning panels were established, including one on 'Exploiting Nanotechnologies'. There were also panels on environmental technologies, materials and infrastructure, manufacturing, intelligent systems, semiconductors, energy, broadband, information storage, the grid, information management, engineering science in medicine, and frontiers in chemicals.

In the 2010 strategy document, the connection is made between the S&T Plan and the Manufacturing 2018 Plan Intelligent National Plans of Singapore's Economic Development Board[254], and the Roadmap (ITR5) of the Infocomm Development Authority[255]. It links nanotechnology research and development to industrial development and supports collaboration between industry, research institutes and universities. The aim is for an enhancement of applied research in nanotechnology to enable industrial clusters including ICT, electronics, precision machinery, transportation machinery, engineering, chemicals, food, and environmental. The Plan also indicates nanotechnology is fundamental and horizontal to these clusters.

The main funding agency for nanoscience and nanotechnology (NST) in Singapore is the Agency for Science, Technology & Research (A*STAR)[256]. A*STAR's Nanotechnology Initiative started in 2001 with the target of building on existing capabilities to develop specific areas of NST research always with applications and potential use by industry as a goal. In 2003, A*Star established the Institute of Bioengineering and Nanotechnology (IBN) which research activities are focused on green chemistry and energy, as well as nanomedicine, synthetic biosystems, biodevices & diagnostics[257].

In 2010, A*Star's SIMTech launched the Nanotechnology in Manufacturing Initiative (NiMI) to foster collaborative efforts between research and industry, developing industrial capability and enhancing competitiveness.

Nanotechnology is one of six areas at the heart of clinical and translational research supported under the Biomedical Research Council and is also a key area for the Science and Engineering Research Council (SERC).

5.3.3.4 Thailand

Thailand has been active in nanotechnology since at least 2003 when it established NANOTEC[258] as the leading national agency for nanotechnology development. It operates under the jurisdiction of the National Science and Technology Development Agency (NSTDA) and the Ministry of Science and Technology (MOST), one of four such agencies. The guiding aims of NANOTEC are to contribute to society; increase Thailand's competitiveness; and improve the quality of life and the environment of the people of Thailand through research and development in nanoscience and nanotechnology. NANOTEC undertakes and supports research, development, design and engineering in nanotechnology, and the transfer of the resulting technology to industry and the marketplace. In 2013, the Central Laboratory of NANOTEC consisted of twelve units located at the Thailand Science Park. These covered areas including nano-characterisation; engineering and manufacturing characterisation; integrated nano-systems, nanomaterials for energy and catalysis, hybrid nanostructures and nanocomposites; nanoscale simulation; and functional nanomaterials and interfaces.

In 2012, the National Nanotechnology Policy Framework (2012-2021)[259] and the Nanosafety and Ethics Strategic Plan (2012-2016)[260] were approved by government for implementation by the Ministry of Science and Technology, and relevant agencies. The Framework has three primary goals:

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253 https://www.mti.gov.sg/ResearchRoom/Pages/Science-and-Technology-Plan-2010.aspx
254 www.edb.gov.sg
255 www.ida.gov.sg
256 www.a-star.edu.sg/
257 http://www.ibn.a-star.edu.sg/about_ibn_6.php?expandable=0
258 http://www.nanotec.or.th/th/wp-content/uploads/2013/05/NANOTEC-brochure11.pdf
259 http://www.nanotec.or.th/en/wp-content/uploads/2012/02/The-National-Nanotechnology-Policy-framework-exe-sum.pdf
260 http://www.nanotec.or.th/en/

- Utilising nanotechnology to develop materials, products, and equipment in order to enhance the quality of life, wellness, and environment;
- Improving agricultural technology and manufacturing industry that meet the demand of the market through nanotechnology; and
- Becoming ASEAN's leader in nanotechnology research and education.

The overall strategic direction of the Framework encompasses four target clusters, which all directly or indirectly have a relationship with the environment: 1) energy and environment; 2) health and medicine; 3) food and agriculture; and 4) manufacturing industry. Eight industry sectors have been identified, partly overlapping with the clusters: energy and environment; health and medicine; food and agriculture; automotive; textile; electronics; (petro)chemicals and SMEs/community. It aims to achieve its goals through actions in human resources, research and development, infrastructure development, management (of quality, safety and standards) and technology transfer. The policy framework also identifies specific products, such as nanosensors manufactured from both bio and non-bio materials such as gas detectors and monitors used in environmental fields.

The cluster of energy environment is developed further into a strategic intent: nanotechnology for energy security and environmental conservation. Examples of environmental applications are insulation made from nanomaterials, nanotechnology for fuel cell production, the application of nanotechnology in water toxicity detectors and nanotechnology that helps reduce greenhouse gas emissions.

The aim[261] of the Nanosafety and Ethics Strategic Plan is to:

- establish and implement knowledge management in nanosafety and ethics and nano-products;
- develop and reinforce measures and monitoring mechanisms and enforcement;
- strengthen and promote public engagement activities.

NANOTEC, as a research funding agency, stimulates in-house researchers and funding applicants to include aspects of safety in all nanomaterial R&D grant proposals. For example, nanoparticle-coated fabrics under development were subject to wash-water contamination tests. Nano-titanium dioxide (TiO2) coated fish tanks were tested for toxicity to fish. Skin creams containing titanium dioxide nanoparticles were also tested for skin penetration through a model (pig) skin. Ecotoxicity of nanosilver in waste water was also tested. More comprehensive nanomaterial safety data resulting from Nano Safety and Risk Assessment Laboratory (SRA) of NANOTEC which specifically addresses on two main areas regarding safety investigation of nanomaterials: Human health and the Environment. Currently, the effects of three nanomaterials, Silver (Ag), Titanium Dioxide (TiO_2), and gold (Au), have been investigated.

5.3.4 Western Asia

5.3.4.1 Israel

The first nanotechnology policy initiative in Israel was the establishment of the Israel Nanotechnology Initiative (INNI)[262] in 2002 as a shared action of the Forum for National Infrastructures for Research & Development (TELEM)[263] and the ministry for the economy (now called the Ministry for Industry, Trade and Labour)[264]. INNI's mission is "to make nanotechnology the next wave of successful industry in Israel by creating an engine for global leadership". To achieve this, actions have been taken on scientific research in nanoscience and nanotechnology (NST); on increasing public-private collaboration on NST; on speeding up commercialisation of NST; and on leveraging funding from both public and private sources to support NST in Israel. INNI is closely linked to the national system with its Director appointed by the Chief Scientist at the Ministry, and its Board operating out of the MAGNET Programme[265] at the Office of the Chief Scientist.

Since the identification of nanoscience and nanotechnology (NST) as a national priority area in 2007,

[261] http://www.nanotec.or.th/en/?page_id=9279
[262] http://www.nanoisrael.org/
[263] http://www.trdf.co.il/eng/About/
[264] http://www.economy.gov.il/English/Pages/default.aspx
[265] http://www.moital.gov.il/NR/exeres/111E3D45-56E4-4752-BD27-F544B171B19A.htm
The Magnet programme supports companies and academics to form consortia to research precompetitive generic technologies. Direct funding is up to 66% of the cost of the project with no obligation to repay royalties.

the areas that have been targeted have included research infrastructure; training Israeli scientists in NST; attracting foreign researchers to work in Israeli institutions; increasing collaboration in NST and publication output of the highest international standard; fostering public-private partnerships; and knowledge transfer and commercialisation of NST. Investment has been c. USD 20 million (EUR 15.5 million[266]) per annum for basic NST equipment plus another almost USD 10 million (EUR 8 million[267]) per annum for new infrastructure and facilities.[268] The aim has been to create a sustainable basis for NST within the universities via training, recruitment and the provision of facilities on the basis that, without a strong research base, direct investment in technology will not be able to generate the required returns in terms of technology development and deployment.

In addition, the Triangle Donation Matching (TDM) programme[269] was launched under the INNI in 2006, a five-year national programme to support NST research infrastructure in six universities in Israel. A total of USD 250 million (EUR 198 million[270]) has been invested by Israeli Universities, private donors and the Israeli government to recruit leading nano-scientists and acquire equipment, facilities and laboratories for six nano-centres at the universities. The first impact was seen at Technion, Israel's Institute of Technology[271, 272], in 2005 (before the official launch of the programme), the other five research universities receiving support in 2006. These six participating each have their own Focal Technology Area (FTA); related to environment are nanostructured oxides for quantum conversion of solar energy (low cost, high efficiency solar conversion, self-window cleaning and light management); functional coatings; and functional detectors and imagers.

One of INNI's research areas is Nanowater, for the development of nano-membranes, nano-filtration and other nanotechnologies used in water remediation. This supports Israel's research and industrial strength in filtration and membrane research. Recent developments in global clean water markets have prompted several new initiatives that combine Israel's agricultural and industrial water treatment expertise with academic research experience in nanotechnology.

To help academics and industry to access the facilities of the six Israeli nano centres, the INNI has made available a national nano infrastructure catalogue[273]. The catalogue of equipment includes pricing for the use of the equipment and contact information. Industry users are supported by the university nano-centres to enable them to be effective in using their R&D equipment.

INNI also has introduced the Industry-Academia Matchmaking programme to make Israeli nanotechnology more visible to the industrial and investment communities and to promote Israel's NST research capabilities to potential partners. Experts help potential collaborators to meet, access expertise and access funding depending on their needs. They engage with key nanotechnology stakeholders in Israel and abroad, initiate and managing national and international networks in NST. They also gather statistics and market information on NST.

The websites and documents do not refer to environmental and safety related aspects of nanotechnology and materials, however Israel is a participant in the OECD's Working Party on Manufactured Nanomaterials (WPMN), which looks at the potential implications of manufactured nanomaterials for human health and environmental safety.

5.3.4.2 Saudi Arabia[274]

The King Abdul Aziz City for Science and Technology (KACST) was established in 1985 as the Kingdom's main agency for promoting research and development. In 2002, Saudi Arabia decided to build further on the work of KACST by putting in place a National Policy for Science and Technology (NPST) with plans to increase R&D funding to 1.6% of GDP. KACST was made responsible for implementing the policy which included five-year strategic plans (missions) in eleven research areas

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[266] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[267] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[268] Figures for funding under the programme to 2012.
[269] http://www.nanoisrael.org/category.aspx?id=1278
[270] Average yearly conversion rate, 2006 (*source*: www.wolframalpha.com)
[271] The Technion centre was co-funded by the Russel Berrie Foundation via a donation of USD 26 million which, together with funding from Technion itself, the Office of the Chief Scientist and the Ministry of Finance, made up to USD 78 million for the Russell Berrie Institute for Research in Nanotechnology.
[272] Israel Institute of Technology http://www.technion.ac.il/en/
[273] http://www.nanoisrael.org/category.aspx?id=13671
[274] A review of nanotechnology development in the Arab World, Bassam Alfeeli et al., Nanotechnology Review, 2013 (05/2013; 2(3):359-377)

prioritising areas including nanotechnology and information technology, electronics, photonics, advanced materials, as well as others: water, oil and gas, petrochemicals, biotechnology, space and aeronautics, energy and environment. The National Nanotechnology Programme (NNP) was established to deliver the plan.

During the implementation of the NNP, nanotechnology centres began to be established, such as the Centre of Excellence in Nanotechnology (CENT) established 2005 at the KFUPM[275]; and the CNT established in 2006 at the KAU[276]. These centres operated in the context of the multidisciplinary programme of Strategic Priorities for Nanotechnology 2008-2012, put in place by the Saudi Arabian Ministry of Economy and Planning in 2008.

Additional nanoscience and nanotechnology centres followed. The Centre of Excellence of Nano-manufacturing Applications (CENA) was established in 2009 at KACST (active in the area of fabrication of sensors) and the King Abdullah Institute for Nanotechnology (KAIN)[277] established in 2010 at the KSU in the Riyadh Techno Valley. The KAIN covers areas including energy, telecommunications, manufacturing and nanomaterials, medicine and pharmaceuticals, food and environment, and water treatment and desalination. Companies such as the energy company Saudi National Oil Company (established as an Arabian American Oil Company, known now as Saudi ARAMCO), and the Saudi Basic Industries Corporation (SABIC) are collaborating on nanotechnology research with the nanotechnology centres. There are more than 20 projects in the field of nanotechnology for these two organisations alone.

Environmental health and safety is not explicitly mentioned, but supported through research projects such as "Toxicity of Nanomaterials" funded by King Abulaziz City for Science and Technology.

5.3.4.3 Turkey

Nanotechnology was one of eight strategic fields of research and technology identified in the Vision 2023 Technology Foresight Study prepared by the Turkish Supreme Council of Science and Technology (SCST) in 2002. The Foresight Study formed part of the development of the National Science and Technology Policies 2003-2023 Strategy Document. In nanotechnology, seven thematic priority areas were selected: (i) nanomaterials; (ii) fuel cells and energy; (iii) nano-photonics, nano-electronics, nano-magnetism; (iv) nano-sized quantum information processing (v) nano-biotechnology; (vi) nano-characterisation; and (vii) nano-fabrication. Nanotechnology was also included as a priority technology field in the Development Programme prepared by State Planning Organisation (SPO) for the period 2007-2013.

Projects in nanotechnology are supported by the Scientific and Technological Research Council of Turkey (TUBITAK) and the Ministry of Development (MoD) and, between 2007 and 2014, it is estimated[278] that nanotechnology received State support of about one billion Turkish Lira, or c. USD 500 million (EUR 367 million[279]). Over 20 nanotechnology research centres, departments and graduate schools have been established including NanoTam[280] and Unam[281] at Bilkent University Sabanci University Nanotechnology Research and Application Center (SUNUM)[282] (with a focus on renewable energy systems and energy applications); and the Micro and Nanotechnology Department at the Middle East Technical University[283].

5.4 Oceania

5.4.1.1 Australia

The National Nanotechnology Strategy (NNS) was put in place in 2007 by the Australian Department of Innovation, Industry, Science and Research as a dedicated strategy for nanotechnology, 2007 to 2009. The Australian Office of Nanotechnology was established to co-ordinate the strategy and

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[275] King Fahd University of Petroleum and Minerals, Riyadh
[276] King Abdul Aziz University, Jeddah
[277] http://nano.ksu.edu.sa/en
[278] http://www.issi2015.org/files/downloads/all-papers/0720.pdf
[279] Average yearly conversion rate, 2007-2014 (*source*: www.wolframalpha.com)
[280] http://www.nanotam.bilkent.edu.tr/eng/main.html
[281] http://unam.bilkent.edu.tr/?page_id=576
[282] http://sunum.sabanciuniv.edu/
[283] http://mnt.metu.edu.tr/

ensure a whole-of-government approach to nanotechnology issues. A Public Awareness and Engagement Programme formed part of the NNS.

In 2009-2010, the NNS was replaced with a National Enabling Technology Strategy (NETS), a comprehensive national framework for the safe and responsible development of novel technologies (including nanotechnology and biotechnology). With funding over four years of AUS 38.2 million (EUR 28.3 million[284]), the strategy aimed to ensure good management and regulation of enabling technologies in order to maximise community confidence and community benefits from the commercialisation and use of new technology. Public engagement has remained an important topic in Australia for nanotechnology and other novel technologies.

In 2012, the National Nanotechnology Research Strategy[285] was prepared by the Australian Academy of Science, using funding received from the National Enabling Technologies Policy Section in the Department of Industry, Innovation, Science, Research and Tertiary Education. It highlighted, inter alia, the importance of developing clean energy solutions (with *Nanostructured materials for clean energy* highlighted among the selected areas of research, as well as nanoporous membranes and fuel cells).

The Research Strategy takes as its starting point the need to remain at the forefront of nanotechnology research while at the same time reaping the benefits in developing products and applications to address challenges in areas such as environment, sustainable energy and water supplies. In addressing environmental concerns that are specific to its needs, Australia has a particular focus on nanomaterials. These include waste, environmental remediation and recycling, and water and air purification. In the waste area, research is focused on zero emission products, nutrient and precious metal recovery, elimination of toxic waste from the environment, and developing novel sensing technology to monitor contamination. There is also specific research into ‘waste to energy’ and ‘waste to product’ technologies. These include:

- conversion of waste to nanocomposites;
- zero emission design for the pulp and paper industry;
- bioremediation to generate value-added by-products;
- (nano)membranes for environmental remediation; and
- new green processes for bio-derived or re-usable polymers.

In addition, there are programmes in adsorbent nanomaterials for carbon capture and separation technology as well as membrane systems for selectivity of CO_2 sequestration. In the water and air purification area, significant nanomaterials research involves gold photocatalysts to eliminate organic contaminants and other airborne pollutants, development of novel nanomaterials and membranes to purify water, and the use of photocatalysts for both water and air purification.

More generally, the Strategy set out a vision for Australia to become a world leader in a nanotechnology-driven economy with a strong nanotechnology research base and the means to assist industry to revolutionise its portfolio through nanotechnology, for greater competiveness and to address the grand challenges most relevant to Australia. The Strategy highlighted the importance of infrastructure, interdisciplinary research, international engagement, the translation of research and the growth of SMEs.

Australia also operates a network to link research facilities across the country, the Australian Nanotechnology Network[286]. The Network was established by bringing together four seed funding networks. It comprises about 1,000 active researchers from universities, institutes and government research organisations, half of whom are students. Its aims are to promote collaboration, increase multidisciplinary awareness and collaboration, foster forums for postgraduate and early career researchers, increase and improve awareness of nanotechnology infrastructure, and promote international links.

[284] Average yearly conversion rate, 2010-2013 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-aud.en.html)
[285] https://www.science.org.au/publications/national-nanotechnology-research-strategy
[286] http://www.ausnano.net/index.php?page=home

5.4.1.2 New Zealand

Nanotechnology strategies in New Zealand began by taking a networking approach and were led by the MacDiarmid Institute for Advanced Materials and Nanotechnology[287]. The Institute, formed in 2002, is a partnership between five Universities and two Crown Research Institutes in Auckland, Palmerston North, Wellington, Christchurch and Dunedin. It was awarded USD 23.2 million (EUR 19 million[288]) funding for 2003-2006 from the Ministry of Education and, in early 2006, developed a "Nanotechnology Initiative for New Zealand"[289] identifying where capability in nanotechnology could be developed in the country. The Initiative identified six programmes for nanoscience and nanotechnology research: nanomaterials for industry; nanotechnology for energy; nano-photonics, nano-electronics and nano-devices; nano- and micro-fluidics; bio-nanotechnologies; and social impacts of nanotechnology.

Also in 2006, the New Zealand government released a Nanoscience and Nanotechnologies Roadmap (2006-2015)[290]. Highlighting international and national research, the Roadmap placed nanotechnology amongst government's strategic priorities, setting high level directions for nanotechnology-related research and policy in New Zealand. As well as underpinning economic transformation and contribute to sustainable development and well-being, the objective is that nanoscience and nanotechnologies should be developed and managed responsibly.

Nanoscience and nanotechnologies are expected to contribute to New Zealand's existing industries, of which primary production is the most significant. This involves substantive improvements in productivity, product value and environmental sustainability in this sector (and associated industries such as the food and beverage and wood processing sectors). To deal with any potential risks of nanotechnologies and materials, one of the strategies directions is for further research into risk assessment and updating the regulatory framework.

The Ministry of Science and Innovation Statement of Intent 2011-14 highlighted two high-level priorities – growing the economy and building a healthier environment and society. In addition to the traditional resource sectors of New Zealand, it sought to build capability in knowledge-intensive activities, such as high-technology manufacturing and the services sector. Six priority areas were identified including energy and minerals, high-value manufacturing and services, health and society, as well as biological sciences, hazards and infrastructure, and the environment[291].

5.5 Africa

5.5.1.1 South Africa

Since 2002, the Republic of South Africa has launched several national nanotechnology initiatives to strengthen national capabilities in this field. Relevant steps have included:

- In 2002, the formation of the South African Nanotechnology Initiative (SANi)[292] with membership comprising academics, researchers, engineers, private sector companies, and research councils;
- In 2003, the launch of South Africa's Advanced Manufacturing Technology Strategy (AMTS)[293] by the Department of Science and Technology (DST);
- In 2005, the publication of the National Strategy on Nanotechnology (NSN)[294] by the DST. The strategy focuses on four areas:
  - establishing characterisation centres (national multi-user facilities);
  - creating research and innovation networks (to enhance collaboration: inter-disciplinary, national and internationally);
  - building human capacity (development of skilled personnel); and
  - setting up flagship projects (to demonstrate the benefits of nanotechnology towards enhancing the quality of life, and spurring economic growth).

A further key initiative of the strategy is the analysis and introduction of legislative instruments to

[287] http://www.macdiarmid.ac.nz/
[288] Average yearly conversion rate, 2003-2006 (*source*: www.wolframalpha.com)
[289] http://www.macdiarmid.ac.nz/a-nanotechnology-initiative-for-new-zealand/
[290] http://statnano.com/strategicplans/13
[291] http://www.mbie.govt.nz/
[292] http://www.sani.org.za/
[293] http://www.esastap.org.za/download/natstrat_advmanu_mar2005.pdf
[294] http://chrtem.nmmu.ac.za/file/35e56e36b6ab3a98fac6fc0c31ee7008/dstnanotech18012006.pdf

ensure that nanotechnology is applied according to international best practice in industrial and environmental safety standards. This is to ensure that nanotechnology research is conducted within an ethically sound framework and is rigorously subjected to international best practice in norms and standards such as peer reviews and other objective accountability instruments. Environmental impact assessment studies are deemed compulsory in instances where nanotechnology activity could have far-reaching socio-economic on people and their environment.

South Africa launched its first nanotechnology innovation centres in 2007 at the CSIR[295] and MINTEK[296]. Each centre has developed collaborative research programmes, often with other national institutions. These include programmes in designing and modelling of novel nano-structured materials, at the CSIR-National Centre for Nano-structured Materials (NCNSM)[297], and work on the application of nanotechnologies in the fields of water, health, mining and minerals at MINTEK.

In addition to engaging with European researchers through Framework Programmes, South Africa has established international collaboration mechanisms with other developing countries, e.g. the India–Brazil-South Africa (IBSA) partnership[298] enables joint projects and mobility[299] between S&T departments in those countries.

The next section reports on publishing activity in nanotechnology and environment.

[295] http://www.csir.co.za/
[296] http://www.nic.ac.za/
[297] http://ls-ncnsm.csir.co.za/
[298] http://www.ibsa-trilateral.org/
[299] http://www.ibsa-trilateral.org/about-ibsa/areas-of-cooperation/people-to-people

6 PUBLICATIONS IN NANOTECHNOLOGY AND ENVIRONMENT

6.1 Overview

In the period 2000 to 2014, almost 45,000 publications were identified as being related to both nanotechnology and environment. This volume of publications is equivalent to around 2.5% of all of the output for nanoscience and nanotechnology (NST), which amounted to about 1.8 million[300] publications between 2000 and 2014.

The table below shows the publication output (number of publications = npub) between 2000 and 2014. More than 15,000 publications on nanotechnology and environment were produced in the EU 28 & EFTA countries (which includes here just Switzerland and Norway), around 35% of the total world nanotechnology environment publications in the time period 2000-2014.

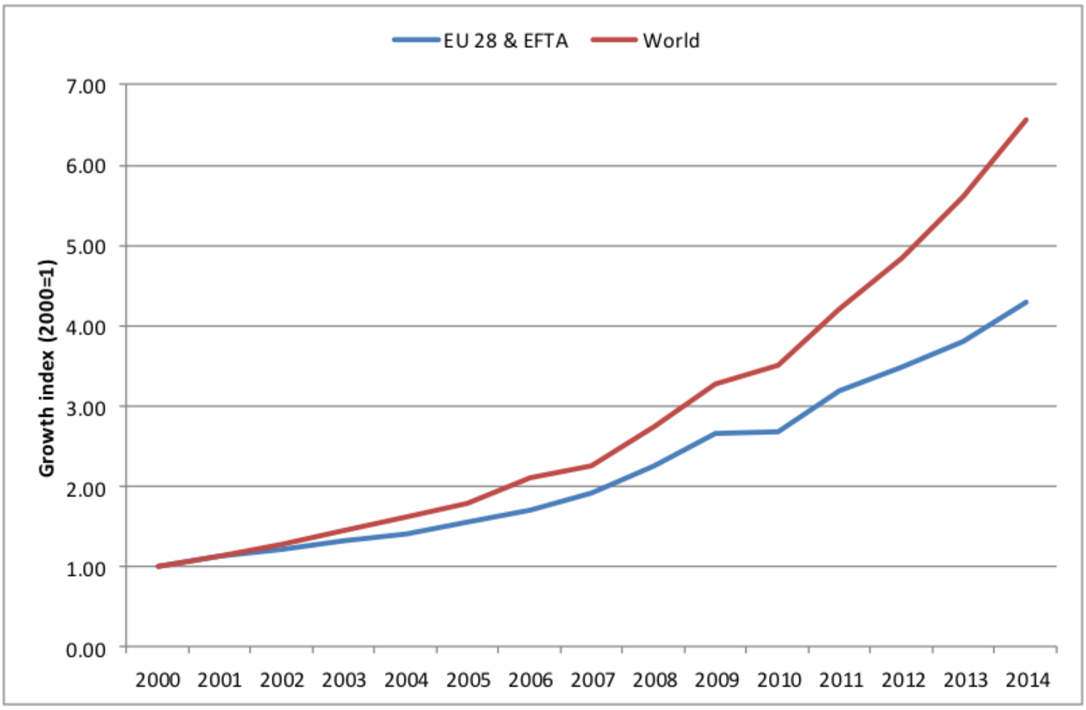
Table 6-1: Annual NST publication output for environment worldwide and in the EU28&EFTA, 2000-2014

Year	World	EU 28 & EFTA	
	npub	npub	%
2000	1,030	460	44.66%
2001	1,165	515	44.21%
2002	1,307	553	42.31%
2003	1,482	603	40.69%
2004	1,667	641	38.45%
2005	1,842	717	38.93%
2006	2,160	784	36.30%
2007	2,316	876	37.82%
2008	2,816	1,040	36.93%
2009	3,370	1,225	36.35%
2010	3,610	1,235	34.21%
2011	4,333	1,468	33.88%
2012	4,979	1,600	32.13%
2013	5,782	1,747	30.21%
2014	6,770	1,970	29.10%
TOTAL	44,629	15,434	34.58%

Source: Derived from Web of Science

There has been a strong growth in nanotechnology environment publications as indexed to the year 2000. For the world it means a six fold increase; for EU28 & EFTA, there has been almost a four-fold growth during the period to 2014.

300 http://www.vosviewer.com/Publications



Source: Derived from Web of Science
Indexed to year 2000=1

Figure 6-1: Annual NST publication output on environment, worldwide and EU28&EFTA, 2000-2014

The EU28 & EFTA proportion of world output on environment and nanotechnology has decreased gradually over time, as shown below, from 45% to 30%. This is mainly caused by a steep increase of Asian output.

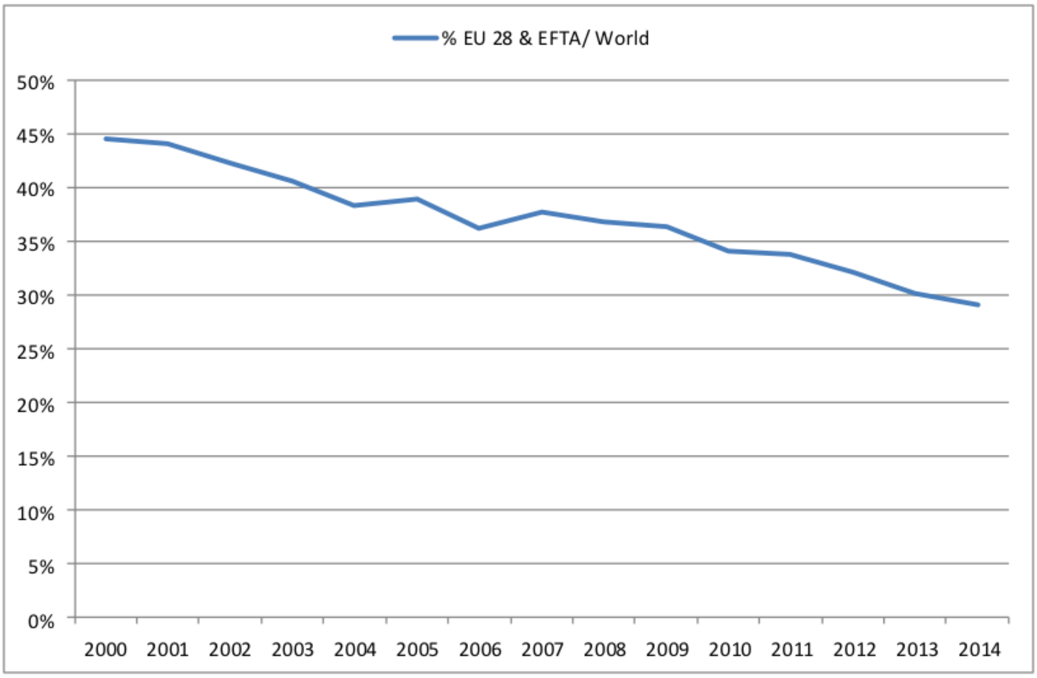


Figure 6-2: EU28&EFTA NST environment publications as a percentage of World total, 2000-2014

The table below shows the journals in which researchers in this sector most frequently published their results.

Table 6-2: Most common journals for NST environment publications (npub), 2000-2014

Rank	Journal	npub
1	Desalination	1,834
2	Atmospheric Environment	1,413
3	Journal of Hazardous Materials	1,387
4	Environmental Science & Technology	1,107
5	Journal of Membrane Science	1,037
6	Water Research	825
7	Desalination and Water Treatment	807
8	Chemical Engineering Journal	801
9	Atmospheric Chemistry and Physics	594
10	Chemosphere	590

6.2 Activity by region and country

The most prolific region for nanotechnology environment publications in 2014 (the most recent year for data collection) was Asia followed by EU28 & EFTA and North America.

Table 6-3: Most prolific regions for nanotechnology environment publications, 2014

Region	npub
Asia	3,225
EU 28 plus EFTA	1,970
North America	1,360
Middle East	414
Oceania	285

Source: Derived from Web of Science

The most prolific country for nanotechnology environment publications globally in 2014 was the People's Republic of China (PRC), followed by the US, India, South Korea, Spain, France and the United Kingdom.

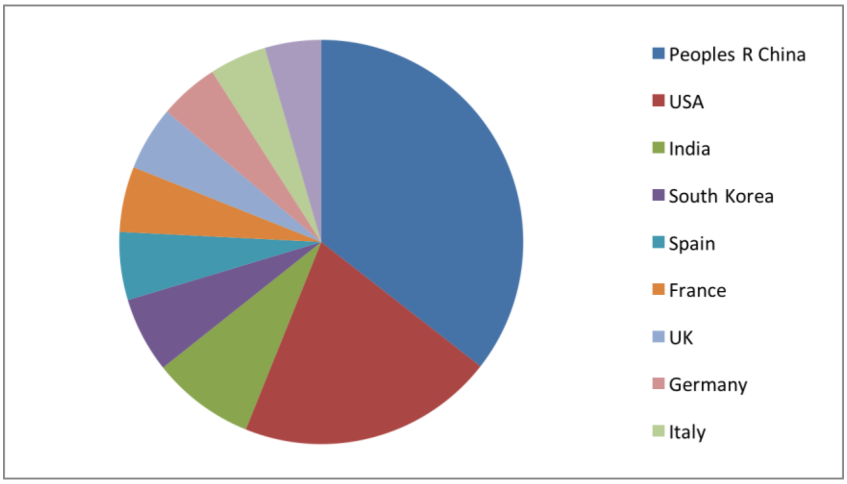


Figure 6-3: Top ten publishing countries showing their relative performance, 2014

Table 6-4: Number of nanotechnology environment publications by country (top 20), 2014

Country	Region	npub
PRC	Asia	2,052
USA	North America	1,186
India	Asia	475
South Korea	Asia	348
Spain	EU28 & EFTA	314
France	EU28 & EFTA	302
UK	EU28 & EFTA	296
Germany	EU28 & EFTA	275
Italy	EU28 & EFTA	264
Australia	Oceania	260
Canada	North America	205
Japan	Asia	204
Brazil	South & Central America	170
Saudi Arabia	Middle East	169
Poland	EU28 & EFTA	131
Singapore	Asia	126
Malaysia	Asia	120
Netherlands	EU28 & EFTA	118
Turkey	Middle East	117
Switzerland	EU28 & EFTA	106

Source: Derived from Web of Science

In the EU28 & EFTA, Spain generated the largest number of publications in 2014, followed by France, the United Kingdom, Germany and Italy, as shown below.

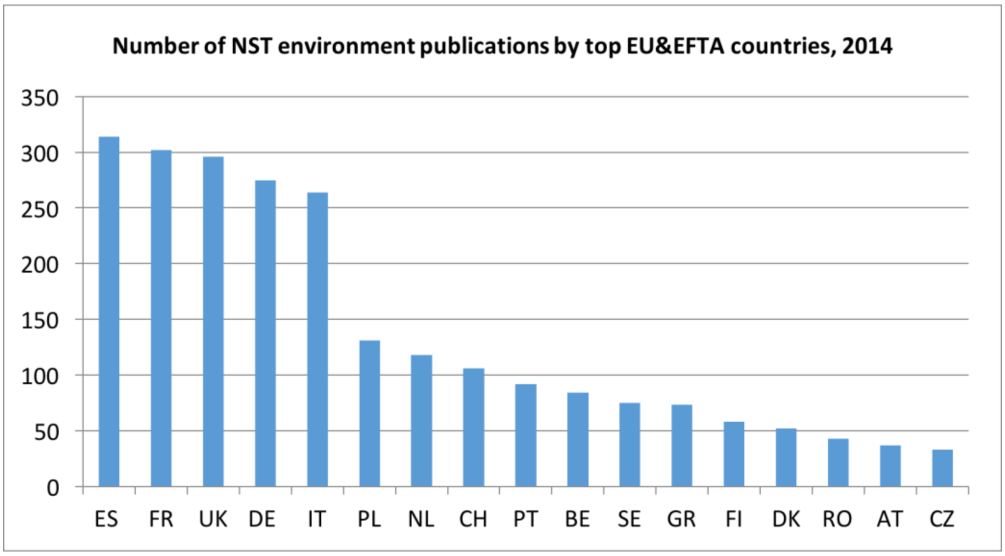


Figure 6-4: Number of NST environment publications for EU28 and EFTA countries, top 20, 2014
Data for the top NST environment publishing countries only

6.3 Activity by organisation type

The most active organisations in NST environment publications in 2014 are shown in the table below. The higher education organisations with the most nanotechnology environment publications globally in 2014 were mainly Chinese.

Table 6-5: Publications in nanotechnology environment for higher education and other research organisations, 2014

Country		University/ Research Institute	npub
1	PRC	Chinese Academy of Sciences	221
2	PRC	Tsinghua University	91
3	Singapore	National University of Singapore	67
4	PRC	Tongji University	66
5	PRC	Zhejiang University	61
6	PRC	Nanjing University	57
7	PRC	Wuhan University	55
7	Saudi Arabia	King Abdulaziz University	55
9	USA	University of California	53
10	Singapore	Nanyang Technical University	49
10	PRC	Shandon Institute of Light Industry	49
12	PRC	Beijing University	48
13	PRC	Harbin Institute of Technology	46
14	PRC	University of Science and Technology of China	45
15	PRC	Tianjin University	42
16	South Korea	Hanyang University	41
17	USA	University of California Berkeley and Berkeley National Laboratory	40
18	PRC	South China University of Technology	39
19	India	Indian Institute of Technology	38

Source: Derived from Web of Science

The higher education organisations (EU28 & EFTA) with the most nanotechnology environment publications globally in 2014 were Delft University of Technology, University of Barcelona and ETHZ, as shown in the table below of the top ten NST publishing organisations for nanotechnology environment publications.

Table 6-6: Number of NST environment publications by EU28&EFTA organisations (top ten), 2014

University/Research Institute		Country	npub
1	Delft University of Technology	NL	32
2	University of Barcelona	ES	30
3	ETH Zürich Swiss Federal Institute of Technology	CH	28
4	University of Aveiro	PT	27
4	Katholieke Universiteit Leuven	BE	27
6	UMIST[301]	UK	26
7	Polytechnic University of Valencia	ES	23
7	University of Porto	PT	23
7	University Complutense of Madrid	ES	23
8	Imperial College London	UK	22
8	CEA	FR	22
8	Wageningen University and Research Centre	NL	22

Source: Derived from Web of Science

The companies with the most nanotechnology environment publications globally in 2014 were Aerodyne and PetroChina, as shown in the table of the top publishing companies below.

Table 6-7: Number of NST environment publications by company (top 8), 2014

Company	npub
Aerodyne Research Inc.	9
PetroChina Company Ltd	6
ENVIRON International Corporation	5
Samsung Engineering Company	5
MWH Global	4

Source: Derived from Web of Science

The next section goes on to look at the patenting activity in nanotechnology and environment, over time, by country of applicant, by applicant organisation and by patents granted.

[301] University of Manchester, Institute of Science and Technology

7 PATENTING IN NANOTECHNOLOGY AND ENVIRONMENT

7.1 Overview

This section looks at the patenting activity in nanotechnology and environment by patent filings and patents granted over the time period 1993-2011 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (environment, in this case)[302]. The patent family to which the patents belonged was identified and all the patents in the patent families were retrieved.

The search was made for patents registered at the USPTO (US Patent and Trademark Office), EPO (European Patent Office) and WIPO (World Intellectual Property Organisation) thereby identifying USPTO, EPO and PCT applications. PCT[303] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[304] that are members of the treaty.

7.2 Number and evolution over time of nanotechnology environment patent families

Using the above methodology, 45,127 (simple) nanotechnology patent families[305, 306] of granted patent and patent applications were found in the period 1993-2011[307]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[308].

In the same period, the number of environment-related patent families identified among the nanotechnology patents is 523, 1.15% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EP and USA do not sum to 100%. The highest percentage of nanotechnology and environment applications is in the USA (88.5%) while the figures corresponding to PCT (59.5%) and EPO (41.1%) are considerably lower.

[302] Thus all patent documents including at least one of the keywords (in title or abstract) was found but only when the patent was classified as being related to at least one of the sectorial IPC codes. There are therefore other patents that are relevant for the transport sector, but do not belong to the classification of the transport patent families since they are not specifically related to the transport sector only but also to other sectors and applications (e.g. in the case of paints and coatings).

[303] http://www.wipo.int/pct/en/

[304] By filing one international patent application under the PCT, applicants can simultaneously seek protection for an invention in 148 countries throughout the world. http://www.wipo.int/pct/en/pct_contracting_states.html

[305] The definition of simple family is used, where all documents having exactly the same priority or combination of priorities belong to one patent family (http://www.epo.org/searching/essentials/patent-families/definitions.html). The patent families include at least one PCT, EPO or USPTO patent application.

[306] A patent family is defined by WIPO (the World Intellectual Property Organisation) as a set of patent applications inter-related by either priority claims or PCT national phase entries, normally containing the same subject matter. http://www.wipo.int/.

[307] This year refers to the oldest year of the priority patents.

[308] While patents can be filed in individual patent offices, many inventors choose to file applications under the Patent Classification Treaty (PCT). All WIPO applications are PCT applications.

Table 7-1: Absolute numbers and percentages of patents on nanotechnology and environment (1993-2011)

Environment NT applications	Absolute number	Percentage
Total patent families	523	100%
PCT applications	311	59.5%
EP applications	215	41.1%
USA applications	463	88.5%

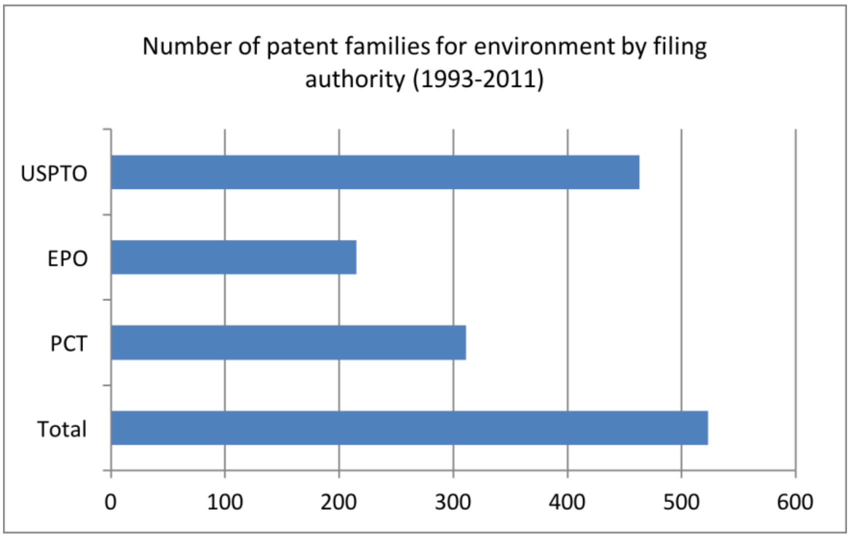


Figure 7-1: Number of patent families by filing authority (PCT, EPO, and USPTO)

The figure below shows the evolution over time of patent applications to WIPO (PCT), the EPO or USPTO as measured by the percentage of patent families.

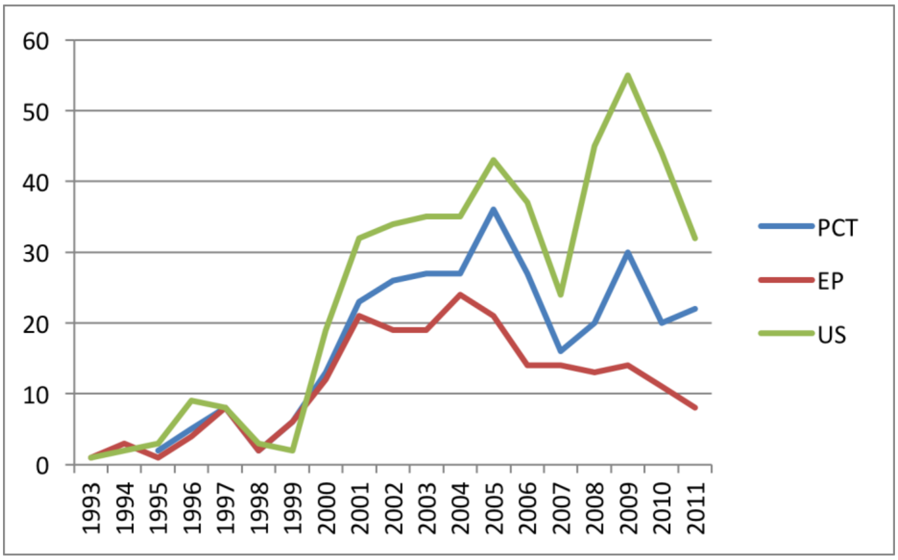


Figure 7-2: Evolution over time of WIPO (PCT), EPO and USPTO environment nanotechnology patenting

In this figure, it can be observed that the filings at EPO, USPTO and WIPO follow a somewhat similar pattern, with a significant increase in the filing from the year 2000 until midway the decade. From 2004 onwards filing at the EPO started to decline for the rest of the period. However, US and PCT filings grew again towards the end of the decade after the sharp drop in the filings in 2007.

7.3 Activity by filing country and region

By looking at PCT applications, it is possible to obtain an indication of the relative patenting activity of countries and regions. The top twelve patent authorities through which PCT applications were filed are shown in the table, each of them with four or more filings. The USA is by far the most prolific, followed by Japan and Europe (EPO). The sum of the figures for the European national patent offices in this table and the EPO is just 55, roughly 1/3 of the US filings.

Table 7-2: Number of nanotechnology environment patent families by PCT receiving authority

Receiving Authority	No. of Patent Families (1993-2011)
United States	151
Japan	38
European Patent Office (EPO)	32
International Bureau (WIPO)	15
France	10
United Kingdom	9
Israel	9
South Korea	8
China	6
Belgium	4
India	4
Singapore	4

7.4 Activity by country of applicant

PATENT APPLICATIONS

Within the group of 523 environment-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in 21.8% of them while there is participation from the rest of the world in 80.1% of cases.

Table 7-3: Origin of patent applicants, EU/EFTA and Rest of world (1993-2011)

	EU28 & EFTA	Rest of World
Number of nanotechnology and environment patent families	114	419
Percentage of nanotechnology and environment patent families	21.8%	80.1%

Applicants may file patents with more than one patent authority, e.g. at the USPTO and at the EPO. The table below shows the data for the top 25 countries of applicants, as well as indicating the percentage of patent families for each. EU28 and EFTA countries are marked in bold. As patents may be filed in more than one patent authority (i.e. PCT, US and EP applications), the percentages can sum to more than 100%.

By far the highest number of patent families is found where the country of the applicant is the US (244), followed by Japan already with a considerably lower amount of patents (80). The European countries which account for a higher number of patents are Germany (29), France (21), Spain (15) and United Kingdom (15), all of them among the top 10 countries in number of patent families.

Table 7-4: Patent families by country of applicant, numbers and percentages (1993-2011)

	Country of applicant	No. of Patent Families	PCT	US	EP
1	United States	244	65.6%	98%	33.6%
2	Japan	80	53.8%	87.5%	45%
3	South Korea	35	22.9%	88.6%	25.7%
4	**Germany**	**29**	**72.4%**	**69%**	**75.9%**
5	**France**	**21**	**76.2%**	**85.7%**	**71.4%**
6	China	19	57.9%	84.2%	31.6%
7	**Spain**	**15**	**80%**	**73.3%**	**73.3%**
8	**United Kingdom**	**15**	**86.7%**	**66.7%**	**53.3%**
9	Taiwan (Chinese Taipei)	12	0%	100%	16.7%
10	Israel	11	81.8%	90.9%	63.6%
11	India	10	70%	70%	20%
12	Canada	9	44.4%	88.9%	11.1%
13	**Belgium**	**8**	**87.5%**	**75%**	**75%**
14	Switzerland	8	75%	75%	50%
15	**Netherlands**	**7**	**57.1%**	**100%**	**85.7%**
16	**Italy**	**7**	**57.1%**	**57.1%**	**28.6%**
17	**Austria**	**5**	**40%**	**60%**	**80%**
18	Singapore	5	100%	80%	40%
19	**Finland**	**4**	**100%**	**75%**	**100%**
20	**Ireland**	**4**	**75%**	**50%**	**50%**

Almost all of patents by US applicants are filed with the USPTO while roughly 65% are filed as PCTs. Only one third of the patents by US applicants are filed at the EPO.

Among the European applicants, the differences in the percentage of filings among the different patent authorities are not large. In some cases, like France, there is a slight preference for the USPTO while the UK has a preference for the PCT route.

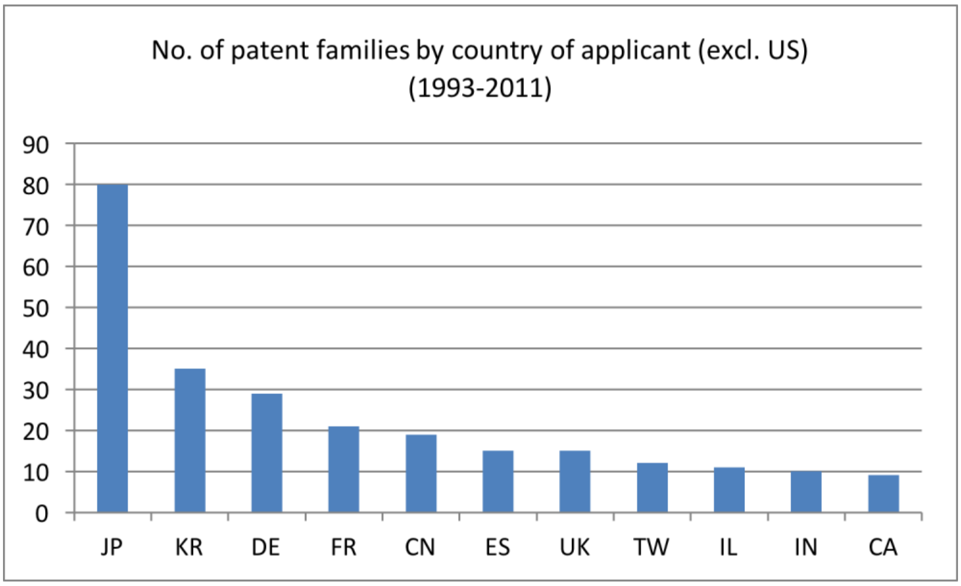


Figure 7-3: Number of patent families by country of applicant (excluding the US)(1993-2011)

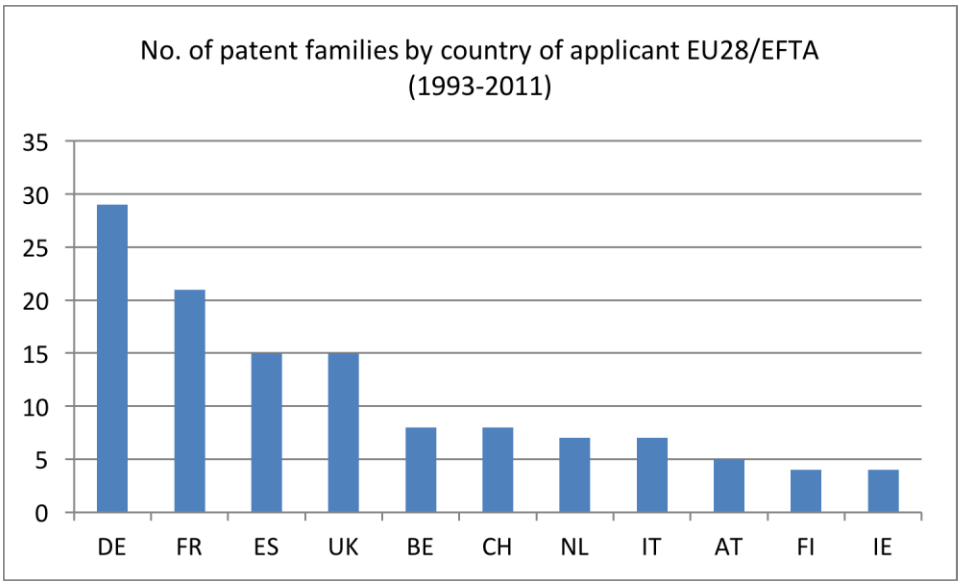


Figure 7-4: Number of patent families by country of applicant EU28/EFTA (1993-2011)

Table 7-5: Patent family by country of applicant for EU28/EFTA (1993-2011)

World ranking	Country of applicant	No. of Patent Families	PCT	US	EP
4	Germany	29	72.4%	69%	75.9%
5	France	21	76.2%	85.7%	71.4%
7	Spain	15	80%	73.3%	73.3%
8	United Kingdom	15	86.7%	66.7%	53.3%
13	Belgium	8	87.5%	75%	75%
14	Switzerland	8	75%	75%	50%
15	Netherlands	7	57.1%	100%	85.7%
16	Italy	7	57.1%	57.1%	28.6%
17	Austria	5	40%	60%	80%
19	Finland	4	100%	75%	100%
20	Ireland	4	75%	50%	50%

Looking at the non-EU/EFTA and non-US countries of applicants, the filing shows a preference, among the patent authorities considered in this study, to filing most at the USPTO.

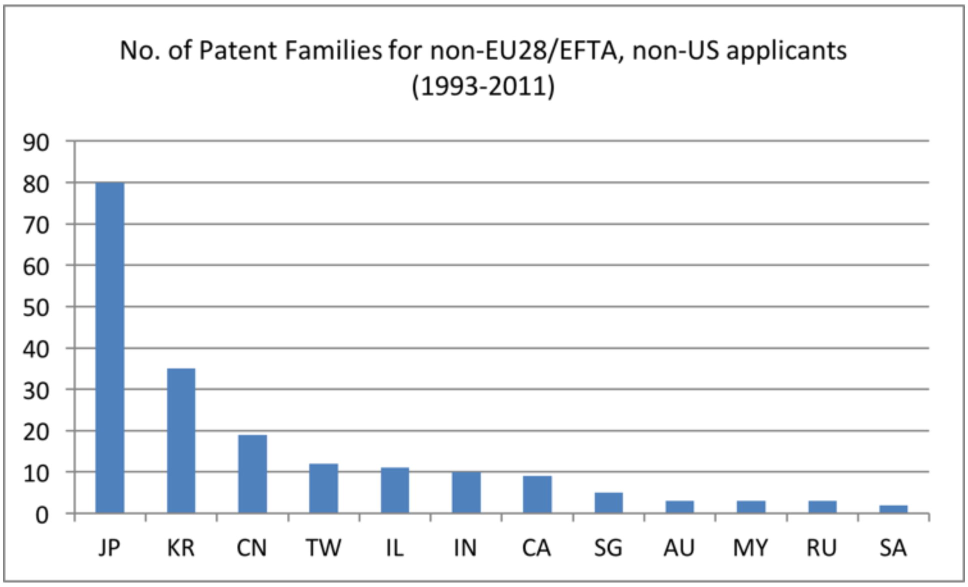


Figure 7-5: Number of patent families by country of applicant for non-EU28/EFTA, non-US

GRANTED PATENTS

The country from the EU and EFTA performing most strongly in patents granted by the EPO is Germany, followed by France. Also, these two countries, together with Spain, have the most patents granted by the USPTO.

Table 7-6: Country of applicant and number of patents granted at EPO and USPTO

	Country of applicant	No. of Patents Granted (1993-2011)	
		EPO	USPTO
1	Germany	10	12
2	France	4	9
3	Austria	2	1
4	Belgium	1	4
5	Finland	1	0
6	Italy	1	2
7	Norway	1	0
8	Spain	1	9
9	Sweden	1	1
10	Switzerland	1	1
11	United Kingdom	0	2
12	Ireland	0	1

For some countries like France, Belgium and Spain, the number of patents granted by the USPTO is substantially larger than by the EPO.

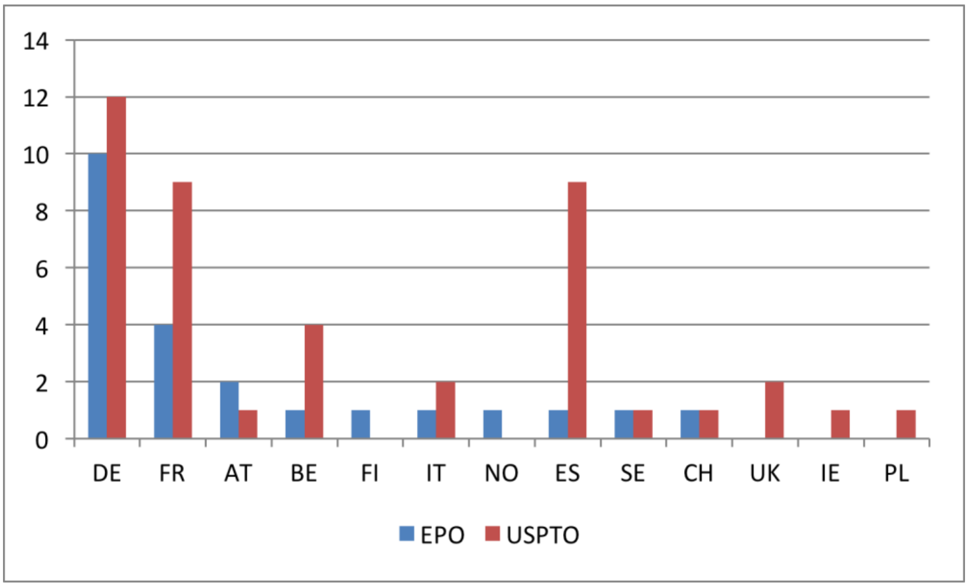


Figure 7-6: Granted patents by country of applicant for EU28/EFTA

The table below shows again the amount of patent families per country in the third column, and the amount of families with granted patents in the seventh column. In both cases, the top two countries are the same, Germany and France, with the United Kingdom also in the top five in both.

Table 7-7: Comparison of patent filings and patents granted by country of applicant (1993-2011)

	Country of applicant	No. of Patent Families			Country of applicant	No. of Patents Granted
1	DE	29		1	DE	17
2	FR	21		2	FR	12
3	UK	15		3	ES	9
4	ES	15		4	BE	5
5	CH	8		5	UK	2
6	BE	8		6	IT	2
7	NL	7		7	AT	2
8	IT	7		8	CH	1
9	AT	5		9	FI	1
10	IE	4		10	IE	1
11	FI	4		11	PL	1
12	PL	2		12	NL	0

A very approximate estimate can be made of relative success in patenting between countries of applicants by comparing the number of patent families and the number of patents granted[309]. This

[309] It should be noted that the data do not apply to the same filings as the patents applied for in 1993-2011 will not be the same as the patents granted in 1993-2011, albeit that some overlap can be expected.

shows a high success rate for Belgium, Spain, Germany and France.

Table 7-8: Estimate of relative patenting success by country of applicant

	Country of applicant	Granted/ Applied %
6	BE	62.5%
4	ES	60%
1	DE	58.6%
2	FR	57.1%
12	PL	50%
9	AT	40%
8	IT	28.6%
11	FI	25%
10	IE	25%
3	UK	13.3%

When considering the country of applicant and the country of inventor as seen in patent family data, it is clear that inventions are most often patented in the country in which they are invented (see table below). However, it is not uncommon to have inventions that are patented outside of the country in which they originate.

Table 7-9: Country of applicant and country of inventor table for cross-comparison

INVT APPL	CN	FR	DE	ES	IL	JP	KR	TW	UK	US
CN	19		1				3			3
FR		21	1						1	1
DE	1	1	29			1				4
ES				15						
IL					11					
JP			1			78	1		1	6
KR	3					1	35			
TW								12		
UK		1				1			13	4
US	4	2	5		1	4	1		6	237

7.5 Patenting activity by organisation type

7.5.1 Universities and public research organisations

PATENT APPLICATIONS

Among the top ten universities and public research organisations (PROs) with the highest number of patent families (with percentages for PCT, US and EP applications), five are in the United States. The EU28 is represented by two organisations, one in Spain and one in France.

Looking at the top 15 performing universities and PROs for patent families, five out of 15 are from outside the US, two being from the EU28 or EFTA (from France and Spain). The tables below show the top universities and PROs by number of patent families, followed by the top non-US universities and PROs.

Table 7-10: Number of patent families for top fifteen universities and PROs (1993-2011)

Rank	Country	Organisation	No. of patent families	PCT	US	EP
1	ES	Universidad de Sevilla	9	66.7%	88.9%	66.7%
2	US	University of California	8	75%	50%	12.5%
3	FR	CNRS[310]	6	66.7%	83.3%	50%
4	US	University of Arkansas	5	40%	100%	40%
5	US	Idaho Research Foundation Inc.	4	50%	75%	25%
6	US	Rice University	4	25%	75%	0%
7	KR	KIST[311]	4	0%	75%	25%
8	KR	Gwangju Institute of Science & Technology	4	0%	50%	0%
9	IL	Technion R&D Foundation Ltd	3	66.7%	66.7%	33.3%
10	US	Auburn University	3	33.3%	66.7%	0%
11	US	Michigan State University	3	66.7%	66.7%	33.3%
12	US	Uchicago Argonne LLC	3	0%	100%	0%
13	US	Washington State University	3	33.3%	100%	33.3%
14	US	Stevens Institute of Technology	3	66.7%	100%	0%
15	US	University of Delaware	2	100%	50%	0%

The table below shows the top performing universities and PROs for patent families in EU28/EFTA countries. Only French and Spanish organisations are among the top 30 applicants worldwide (the ranking being shown in the first column).

[310] Centre National de la Recherche Scientifique
[311] Korea Institute of Science & Technology

Table 7-11: Number of patent families in the top EU28/EFTA universities and PROs (1993-2011)

World rank	Country	Organisation	No. of Patent families	PCT	US	EP
1	ES	Universidad de Sevilla	9	66.7%	88.9%	66.7%
3	FR	CNRS	6	66.7%	83.3%	50%
25	ES	CSIC	2	100%	50%	50%
26	FR	CEA	2	50%	100%	50%

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted between 1993 and 2011. Only a few PROs have granted patents by the EPO, and two of them are from the EU28/EFTA countries (from Germany and Spain).

Table 7-12: Universities / research organisations granted patents, by EPO patents

Rank	Country	Organisation	EP	US
1	DE	Fraunhofer Society	1	0
2	ES	Universidad de Sevilla	1	8
3	KR	Electronics and Telecommunications Research Institute (ETRI)	1	0
4	USA	Princeton University	1	1
5	USA	University of Arkansas	1	3
6	IN	Indian Institutes of Technology	1	1

Ranking by the number of USPTO patents granted between 1993 and 2011, nine of the top 12 universities and research organisations are in the US and only two in the EU28/EFTA.

Table 7-13: Universities/research organisations granted patents, by USPTO patents

Rank	Country	Organisation	US	EP
1	ES	Universidad de Sevilla	8	1
2	US	University of Arkansas	3	1
3	US	Stevens Institute of Technology	3	0
4	FR	CNRS	3	0
5	US	Uchicago Argonne LLC	3	0
6	US	University of California	3	0
7	KR	Korea Institute of Science & Technology (KIST)	2	0
8	US	Auburn University	2	0
9	US	Brown University	2	0
10	US	Kansas State University Research Foundation	2	0
11	US	Tufts University	2	0
12	US	University of Houston	2	0

7.5.2 Activity of companies

PATENT APPLICATIONS

The top ten companies with the highest number of patent families (with percentages for PCT, US and EP applications), belong to five different countries. Germany and France are the only EU28 countries that feature in the table, marked in bold. It should be noted that some may be holding companies rather than research companies or manufacturers.

Table 7-14: Number of patent families for top ten companies (1993-2011)

	Country	Company	No. of patent families	PCT	US	EP
1	KR	Samsung SDI	10	0%	80%	40%
2	JP	Toyota	9	77.8%	66.7%	88.9%
3	FR	Rhodia	8	75%	50%	87.5%
4	DE	Bayer AG	6	83.3%	16.7%	16.7%
5	DE	BASF	5	40%	40%	40%
6	DE	Lanxess Deutschland GmbH	5	0%	80%	80%
7	JP	Toda Kogyo Corp	5	0%	100%	80%
8	US	KX Tech LLC	5	20%	40%	100%
9	US	Empire Tech Dev LLC	4	100%	75%	25%
10	US	Perry Equipment Corp	4	100%	75%	50%

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[312]. The first table shows the top ten when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In the first table, one company from France (Rhodia) and another from Germany (Lanxess) appear as the main companies in EPO patents.

Table 7-15: Companies granted USPTO and EPO patents (sorted by EPO patents)

Country	Company	EP	US
FR	Rhodia	4	3
DE	Lanxess Deutschland GMBH	4	4
US	Kx Tech LLC	3	2
JP	GSI Creos Corp	2	2
JP	Phild Co Ltd	2	2
JP	Toda Kogyo Corp	2	3
JP	Toyota	2	4
KR	Samsung SDI	2	7
US	3M	2	3
US	Seldon Tech LLC	2	1

[312] This data does not take account of there being multiple offices of one company. Where the name differs in the database, the companies are taken as being different.

Table 7-16: USPTO and EPO granted patents by company (sorted by US patents)

Country	Company	US	EP
KR	Samsung SDI	7	2
DE	Lanxess Deutschland GmbH	4	4
JP	Toyota	4	2
FR	Rhodia	3	4
JP	Toda Kogyo Corp	3	2
US	3M	3	2
US	Hyperion Catalysis Int. Inc.	3	1
JP	Nissan Motor Co Ltd	3	0
JP	Toshiba	3	0
US	Perry Equipment Corp	3	0

Interestingly, according to the number of patents granted by the USPTO, there are no US companies in the top five. There are four countries populating the top of the table, South Korea, Germany, Japan and France.

The next section looks at industry in the environmental sector.

8 INDUSTRY AND NANOTECHNOLOGY FOR ENVIRONMENT

8.1 Overview of the industry

In this section, primarily Eurostat statistics for the environmental goods and services sector (EGSS)[313] are used to provide an overview of industrial activity and employment. In addition, other sources of secondary data have been used (OECD, BCC report 2015) and these are not consistent with Eurostat. The differences result from the use of a number of methodologies to collect information and the lack of consistency of definitions. Thus, this section of the report is not intended to be a ratified and consistent reporting of industry figures for nanotechnology and industry. Rather, it contains information that may be of interest to the reader and gives an indication of the scale (or potential scale) of the industry.

Eurostat defines the environmental industry as producing goods and services for the purpose of preventing, reducing and eliminating pollution and any other degradation of the environment (environmental protection - EP) and preserving and maintaining the stock of natural resources and hence safeguarding against depletion (resource management - RM).

They distinguish between market and non-market EGSS. Market EGSS are those goods and services sold on the market. Non-market EGSS are those goods and services either supporting other activities (such as in-house waste management) or environmental services provided by government (such as supervision and control activities for managing natural resources). Market EGSS output is estimated at more than 80% of the total EGSS output.

The three tables below present the data on employment[314], gross value added[315] and production value[316] for the total environmental protection (EP) and resource management (RM) activities in the EU-28 countries. The total environmental protection and resource management activities employed 4.16 million people in the year 2013. This is an increase of more than a million employees compared to the year 2004[317]. The employment in the sector grew on average by almost 4% a year. The sector had a production value of EUR 697.5 billion in the year 2013 and a value added of EUR 271.5 billion. The value added grew annually by almost 6%.

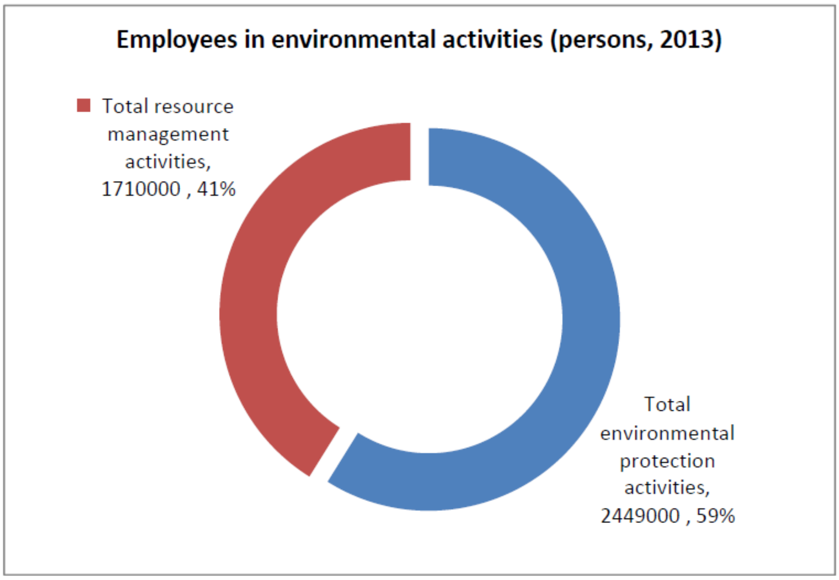
Table 8-1: Employment in the environmental sector

	Employment (thousands)									
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Total EP and RM activities, of which:	3,015	3,117	3,248	3,343	3,534	3,745	3,903	4,135	4,132	4,159
Total EP activities	2,106	2,144	2,181	2,209	2,267	2,345	2,385	2,409	2,425	2,449
Total RM activities	909	972	1,068	1,135	1,267	1,400	1,518	1,726	1,707	1,710

Source: Eurostat, EGSS statistics

59% of the employment in the environmental sector stems from environmental protection activities and 41% from resource management activities.

313 http://ec.europa.eu/eurostat/web/environment/environmental-goods-and-services-sector
314 The employment in environmental protection and resource management activities is measured by the full-time equivalent employment engaged in the production of the environmental output as defined above. The full-time equivalent is the number of full-time equivalent jobs, defined as total hours worked divided by average annual hours worked in full-time jobs.
315 Gross value added represents the contribution made by these activities towards gross domestic product. It is the difference between the value of the output and intermediate consumption (Source: Eurostat).
316 Production value measures the amount actually produced by the unit, based on sales, including changes in stocks and the resale of goods and services (Source: Eurostat).
317 Note that in this period the number of EU countries increased from 15 to 28. Also Eurostat on its site clarifies that data are provided by Member States on a voluntary basis and in accordance with their own definitions (*i.e.* not directly comparable) and they have data for 18 Member States.



Source: EGSS statistics, Eurostat

Figure 8-1: Distribution of employees in environmental activities

Table 8-2: Value added in the environmental sector

	Value added (EUR million)									
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Total EP and RM activities, of which:	166,039	177,235	192,166	206,572	220,015	220,146	242,467	262,635	267,873	271,476
Total EP activities	117,796	122,956	129,747	137,823	141,754	137,889	149,577	154,476	157,715	157,213
Total RM activities	48,243	54,280	62,419	68,750	78,260	82,258	92,890	108,158	110,159	114,263

Source: Eurostat, EGSS statistics

Table 8-3: Production value in the environmental sector

	Production value (EUR million)									
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Total EP and RM activities, of which:	393,439	428,661	478,579	520,582	570,514	552,468	615,753	678,864	689,113	697,455
Total EP activities	266,408	282,886	303,537	323,702	334,123	316,798	349,304	366,276	372,652	372,092
Total RM activities	127,031	145,775	175,042	196,880	236,391	235,670	266,449	312,588	316,461	325,363

Source: Eurostat, EGSS statistics

RESOURCE MANAGEMENT ACTIVITIES

For its data collection, Eurostat uses a classification of the following resource management activities: management of water; management of forest resources; management of wild flora and fauna; management of energy resources; management of minerals; research and development activities for resource management; and other resource management activities.

The impact of nanotechnology on resource management is primarily through monitoring these resources. Nano-sensors can, for example, be used to monitor the above-mentioned resources.

Nanotechnology has a more direct impact on the management of energy resources. The EGSS statistics only give data for the "production of energy from renewable sources" and "heat/energy saving and management" (see the table below). In 2013, these two sub-sectors employed more than 1.5 million people in the EU-28 countries. The production value was more than EUR 303 billion and the value added almost EUR 105 billion.

Table 8-4: Economic activity in management of energy resources

	Economic activity in management of energy resources (2013)		
	Production value (EUR million)	Value added (EUR million)	Employment (FTE)
Production of energy from renewable sources	180,458	57,858	715,000
Heat/energy saving and management	122,617	46,694	853,000

Source: EGSS statistics, Eurostat

ENVIRONMENTAL PROTECTION ACTIVITIES

Nanotechnology has a direct impact on environmental protection and remediation activities. The EGSS Statistics breaks the environmental protection activities down into NACE sub-categories (see the table below).

Table 8-5 : NACE codes for environmental protection activities

Code		Label	Nanotechnology applied
TOT_CEPA	Total environmental protection activities		
	CEPA1	Protection of ambient air and climate	X
	CEPA2	Wastewater management	X
	CEPA3	Waste management	
	CEPA4	Protection and remediation of soil, groundwater and surface water	X
	CEPA5	Noise and vibration abatement (excluding workplace protection	X
	CEPA6	Protection of biodiversity and landscapes	
	CEPA7	Protection against radiation (excluding external safety)	X
	CEPA8	Environmental research and development	X
	CEPA9	Other environmental protection activities	

As an example, according to 'Classification of Environmental Protection Activities and Expenditure (2000)'[318] wastewater management includes:

[318] http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=CEPA_2000&IntCurrentPage=1&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC

'…activities and measures aimed at the prevention of pollution of surface water through the reduction of the release of wastewater into inland surface water and seawater. It includes the collection and treatment of wastewater including monitoring and regulation activities.' [319]

Nanotechnology will not impact the collection of wastewater. A further division into the different activities of management and treatment of wastewater is, however, not made. The data for these sub-sectors are presented in the table below.

Table 8-6: Economic activity in environmental protection

	Employment (2013)	Value added (EUR million) (2013)	Production value (EUR million) (2013)
Protection of ambient air and climate	104,000	6,481	16,263
Wastewater management	589,000	40,752	95,923
Waste management	1,109,000	72,504	191,002
Protection and remediation of soil, groundwater and surface water	313,000	16,977	31,367
Noise and vibration abatement (excluding workplace protection)	23,000	1,398	2,882
Protection of biodiversity and landscapes	127,000	8,107	14,966
Protection against radiation (excluding external safety)	:	:	:
Environmental research and development	:	:	:
Other environmental protection activities	:	:	:

Source: Eurostat EGSS

Waste management is the biggest sector with an employment of 1.1 million people, a production value of EUR 191,002 million and a value added of EUR 72,504 million (see also the table below). Second biggest is wastewater management. This sub-sector employs 589,000 people, has a production value of EUR 95,923 million and a value added of EUR 40,752 million. Data are not available for some sub-categories.

[319] http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_NOM_DTL_VIEW&StrNom=CEPA_2000&StrLanguageCode=EN&IntPcKey=&IntKey=2999312&StrLayoutCode=HIERARCHIC&IntCurrentPage=1

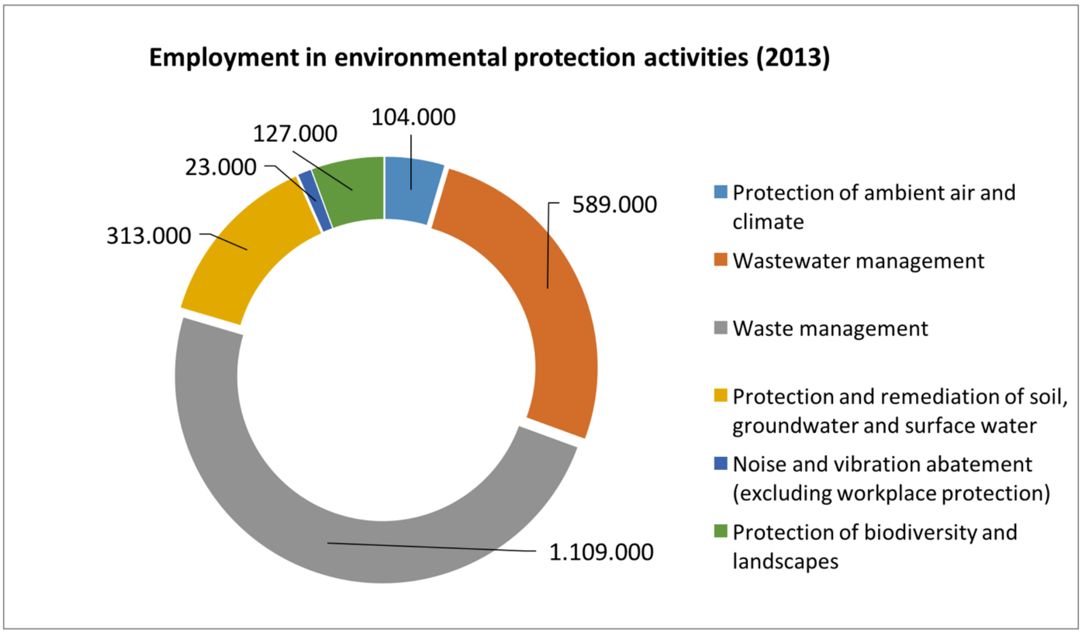


Figure 8-2: Distribution employment in environmental protection activities

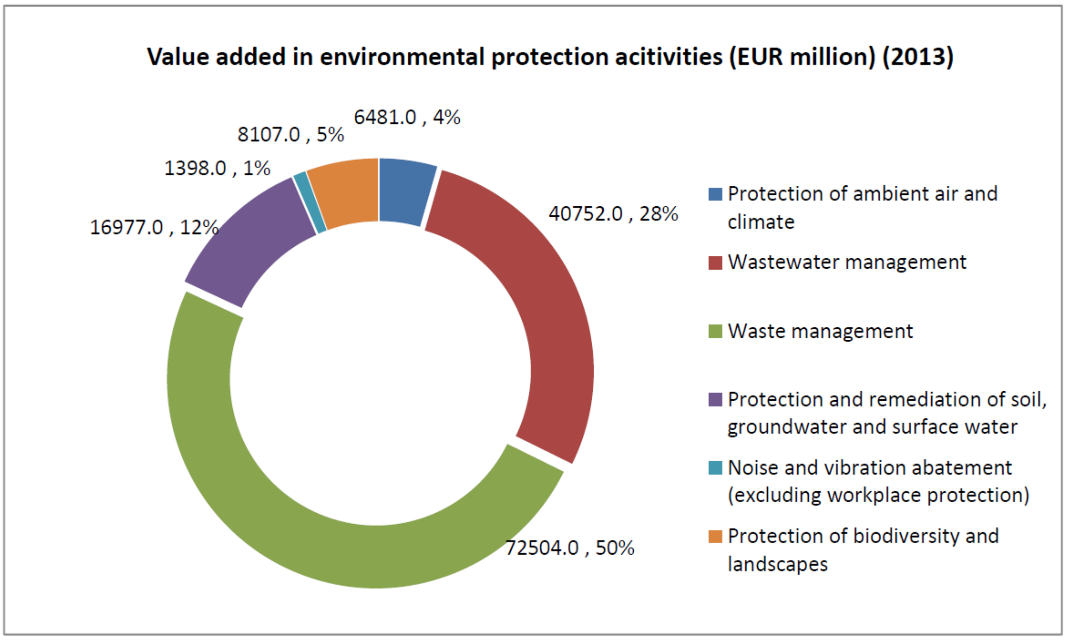


Figure 8-3: Distribution value added in environmental protection activities

Wastewater management, waste management and protection and remediation of soil, groundwater and surface water are also reflected in the data from the Structural Business Statistics (Eurostat). The table below gives an overview of the NACE codes that are related to these sub-sectors.

Table 8-7: NACE codes for water and soil management

Water quality and quality of soil			
E	Water supply; sewerage, waste management and remediation activities		
	E36	Water collection, treatment and supply	
	E37	Sewerage	
	E38	Waste collection, treatment and disposal activities; materials recovery	
		E381	Waste collection
		E382	Waste treatment and disposal
		E383	Materials recovery
	E39	Remediation activities and other waste management services	

Source: Eurostat, Structural Business Statistics

The table below presents the data for these NACE coded sub-sectors for the year 2014. In 2014, 75,678 companies were active in "Water supply; sewerage, waste management and remediation activities", these companies employed 1.45 million employees. They had a turnover of EUR 245,998 million, a production value of EUR 240,561 million and had a value added of EUR 97,500 million.

Table 8-8: Water supply, sewerage, waste management and remediation activities

	No. of enterprises (2014)	Turnover or gross premiums written (2014) (EUR millions)	Production value (2014) (EUR millions)	Value added at factor cost (2013) (EUR millions)	No. of persons employed (2014)
Water supply; sewerage, waste management and remediation activities, of which:	75,687	245,998	240,561	97,500	1,451,534
- Water collection, treatment and supply	14,200	65,000	67,800	34,000	396,614
- Sewerage	10,988	27,802	27,883	15,652	151,789
- Waste collection, treatment and disposal activities; materials recovery	47,275	148,771	140,817	46,634	874,953
- Remediation activities and other waste management services	3,500	:	5,200	1,394	34,019

Source: Eurostat, Structural Business Statistics

Nanotechnology especially has an effect on water purification, by improving filtration materials and improvement of the bacterial removal systems by adding, for example, carbon nano-clusters.

8.2 Investment and R&D in the environment

Most of the available data on R&D expenditures is specified by industrial sector. Data on R&D expenditures for environmental applications are not easy to acquire, because the environmental application is often part of research for other sectors. For example, the transport sector conducts research on the energy efficiency of vehicles.

The EU R&D Scoreboard 2015 ranked companies by their R&D level. The top 1,000 EU-companies are ranked according to their industry. Some industries can be identified which are most related to the environment:

- Alternative energy; and
- Gas, water & multi-utilities.

Six companies in the top 1,000 belonging to the alternative energy industry were responsible for a total of EUR 383 million R&D expenditure. Their research intensity lies in the range of 2.3% to 15.1%. Among the ten companies active in the sector gas, water and multi-utilities, four companies are primarily engaged in water technology, water and wastewater treatment, namely: Severn Trent, Suez Environment, Veolia Environment and BWT. These companies spend in total EUR 201.5 million on R&D activities, which amounts to a research intensity of 0.6%, 0.5%, 0.4% and 2.0% respectively.

The OECD's Business Enterprise R&D Statistics distinguishes between R&D on different socio-economic impact measurements. This data are, unfortunately, only available for a very limited number of European countries.

The section that follows considers nanotechnology products for the environment and global markets and trends.

9 PRODUCTS AND MARKETS FOR ENVIRONMENT THROUGH NANOTECHNOLOGY

9.1 Introduction

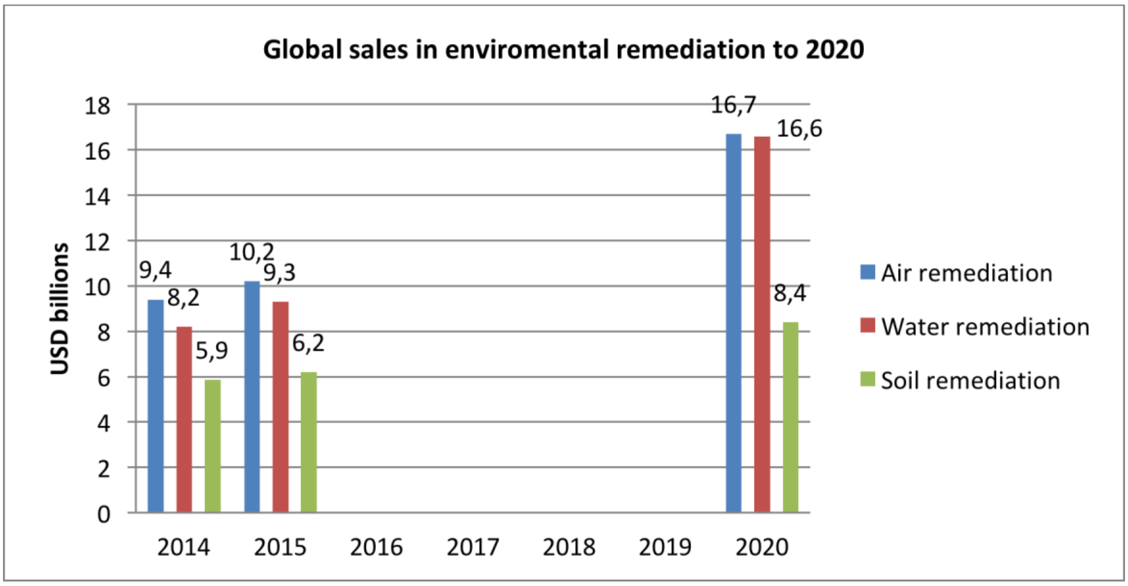
The commercial market for nanotechnology in the field of environment includes: soil remediation, water remediation, air remediation, and sensors.

Many companies identify themselves as being active in the area of nanotechnology. Where their product is generic with many applications in a wide range of sectors, one of which is environment, their product will often not appear as environment-specific. Here efforts have been made to identify only products that are environment-specific thereby increasing the relevance (but reducing the number) of products.

The next section looks at global markets and forecasts for environmental remediation products using nanotechnology.

9.2 Global markets and forecasts for environmental remediation products using nanotechnology

Global sales of nanotechnology products for air remediation applications accounted for nearly USD 9.4 billion in 2014. During the forecast period of 2015 through 2020, the market is expected to grow at a compound annual growth rate (CAGR) of 10.3%, to reach USD 16.7 billion in 2020. The nanotechnology market for water remediation applications totalled nearly USD 8.2 billion in 2014, and is expected to grow at a CAGR of 12.4% to reach USD 16.6 billion in 2020. Soil remediation applications accounted for nearly USD 5.9 billion in 2014 with forecast growth of CAGR 6.4% to reach USD 8.4 billion in 2020[320].



Source: BCC Research, 2015

Figure 9-1: Global market outlook for nanotechnology in environmental remediation to 2020

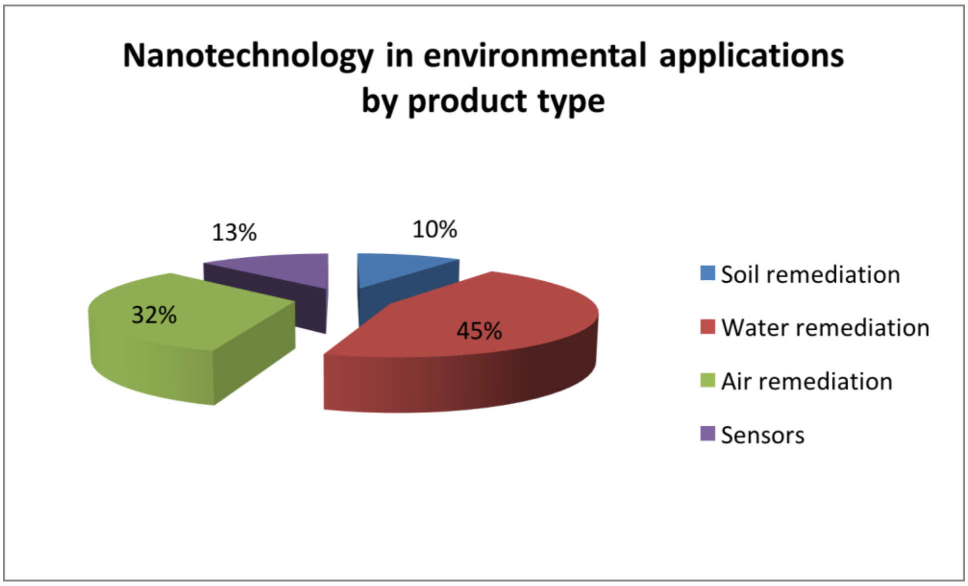
The section that follows explores these markets in greater detail, beginning in each case with the environmental applications and nanomaterials used in each market segment. This is followed by a description of the technology and products (including company examples) and concluded with market estimates and forecasts. Company snapshots and company case studies are included. In addition, where appropriate, information is presented on likely future products and markets.

[320] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.7

9.3 Commercialised products for environment through nanotechnology

9.3.1 Overview

To date, 40 products related to environmental remediation and using nanotechnology have been identified as being commercially available on the market. Almost half (45%) of those are in the area of water remediation; in particular filter systems and membranes are being used in the purification and remediation of water. Products in air remediation (33%) account for the second largest share as shown in the figure below. Products range from filter systems to photocatalytic coatings.



Source: JIIP, 2015

Figure 9-2: Nanotechnology in environmental applications by product type

9.3.2 Products for environment through nanotechnology, by application market

The application markets considered here are:

- Soil remediation;
- Air remediation;
- Water remediation; and
- Sensors.

9.3.2.1 Soil remediation

MARKET OVERVIEW

The soil remediation market is divided into three types of application: natural, incidental and engineered. Natural applications refer to the *in situ* use of nano-organic particles in remediation, such as bacteria. In incidental remediation, the contaminated soil is removed and stored and / or treated *ex situ*. In engineered applications, remediation is done *in situ* with the help of engineered nanomaterials. A further characterisation is the market for nanomaterials (or particles) used in soil remediation. The market size in terms of sales are described in this section, starting with natural, incidental and engineered applications.

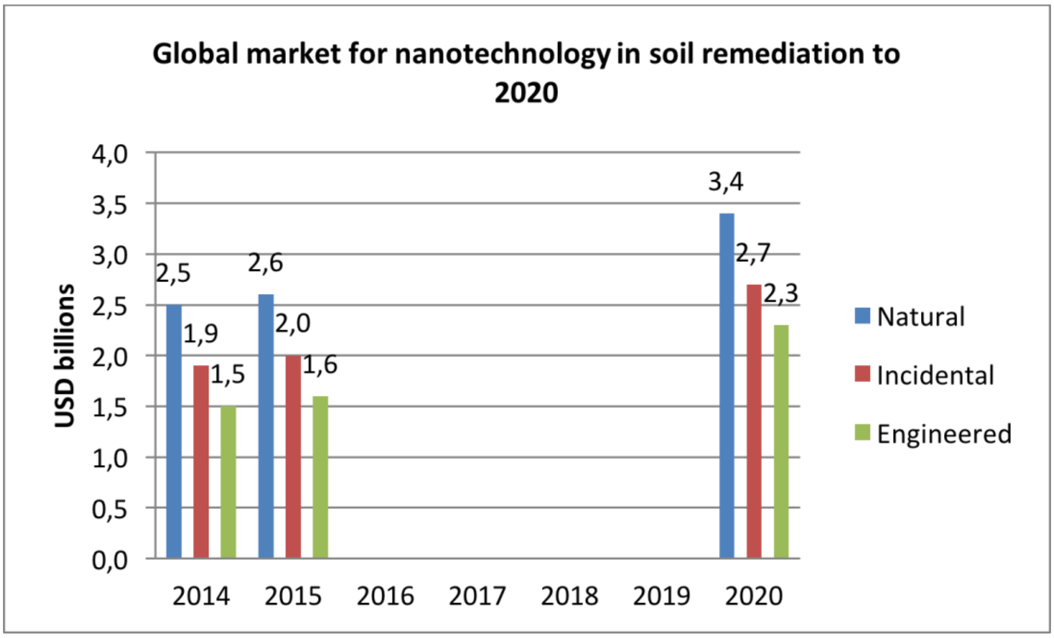
The nanotechnology market for *natural applications in soil remediation*[321] is forecast to increase to nearly USD 2.6 billion in 2015, up 5% from USD 2.4 billion in 2014, and further grow at a five-year CAGR of 5.8%, to reach USD 3.4 billion in 2020. Nano-organic particles, such as bacteria, have found use in soil remedial treatments.[322]

The nanotechnology market for *incidental applications in soil remediation* is expected to rise at a

[321] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.166
[322] Ibid

rate of 5.9% to nearly USD 2 billion in 2015, from USD 1.9 billion in 2014, and is expected to further increase at a five-year CAGR of 6.5%, to reach USD 2.7 billion in 2020. [323]

The nanotechnology market for *engineered applications in soil remediation* is forecast to increase 6.3% to USD 1.6 billion in 2015, from USD 1.5 billion in 2014. In addition, the category is expected to grow at a five-year CAGR of 7.2%, to reach nearly USD 2.3 billion in 2020. Recent developments of nano-wires comprising potassium manganese oxide can clean up oil and other organic pollutants, while making oil recovery possible.[324]

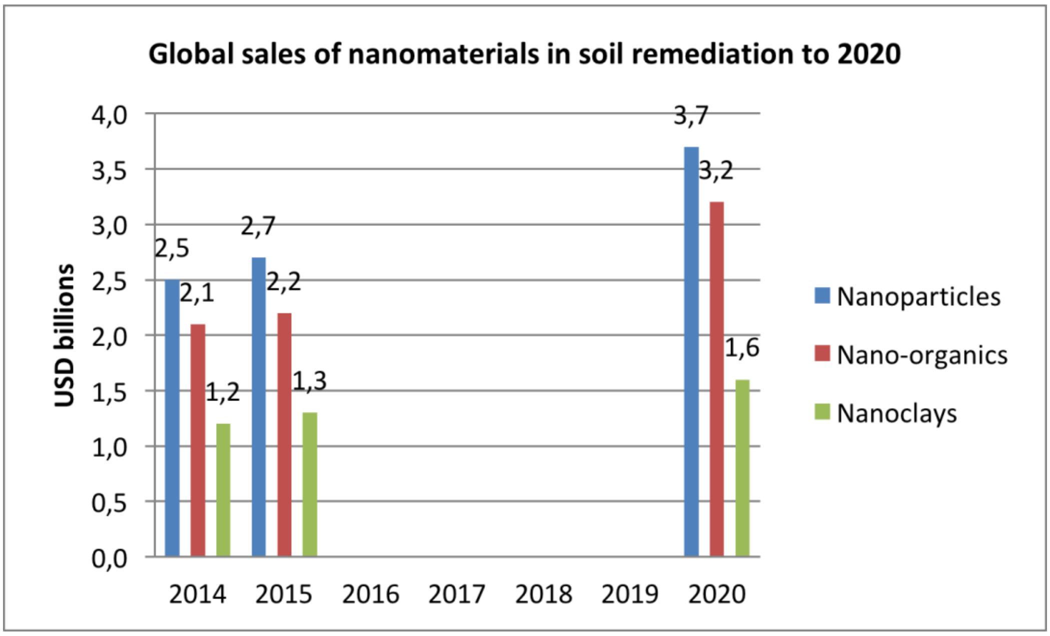


Source: BCC Research, 2015

Figure 9-3: Global market for nanotechnology in soil remediation to 2020

The nanotechnology market for nanoparticles (figure below) used in soil remediation is forecast to rise 6% to nearly USD 2.7 billion in 2015, from USD 2.5 billion in 2014, and see further growth at a five-year CAGR of 6.5%, to reach USD 3.6 billion in 2020[325].

[323] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.167
[324] Ibid
[325] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.172



Source: BCC Research, 2015

Figure 9-4: Global sales of nanomaterials in soil remediation to 2020

It is estimated that the nanotechnology market for nano-organics used in soil remediation will rise 5.6% to USD 2.2 billion in 2015, from USD 2.1 billion in 2014 and see more growth at a five-year CAGR of 7.1%, to reach USD 3.1 billion in 2020. The nanotechnology market for nanoclays used in soil remediation is forecast to increase to nearly USD 1.3 billion in 2015, up 4.8% from USD 1.2 billion in 2014. In addition, the category is expected to grow at a five-year CAGR of 5%, to reach USD 1.6 billion in 2020[326].

Product Overview

This section looks at specific applications, giving technology and product information.

Researchers from the Department of Chemistry, Warsaw University (Warsaw, Poland) have investigated the properties of carbon nanotubes (CNTs) and their potential application in soil remediation. CNTs exhibit highly absorbing properties and are excellent absorbers of various pollutants for example cadmium and lead ions and organic compounds such as chlorobenzene and herbicides. The scientists have shown the CNTs' absorbing capacity for these metals: copper (Cu), zinc (Zn), manganese (Mn), carbon monoxide (CO) and lead (Pb). The highest absorbing efficiency was obtained for Cu and the lowest for Mn, thus the CNTs has very high absorption rate for Cu metals and can be applied for purification of this metal[327].

In 2003, NanoScale Corp. (Kansas, USA) introduced FAST-ACT, a nanotechnology-based chemical hazard containment and neutralisation system. FAST-ACT is a proprietary formulation of nontoxic nanomaterials reportedly effective in neutralizing a wide range of toxic chemicals, including chemical warfare (CW) agents. In tests conducted by the U.S. Army and Battelle Memorial Institute, FAST-ACT removed over 99.6% of VX, GD and HD (nerve/mustard gas) CW agents from surfaces in under 90 seconds, converting them to safer by-products. FAST-ACT also neutralises acids and other commonly transported toxic chemicals, such as acidic/caustic gases, phosphorus/sulphur compounds and organic compounds. FAST-ACT was initially targeted at the Homeland Security market to provide emergency responders with effective chemical-hazard countermeasures. Because FAST-ACT is effective against such a wide range of chemical threats, emergency responders can use it when faced with a wide variety of known and unknown chemical hazards[328].

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[326] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.173
[327] https://www.researchgate.net/publication/257561791_Adsorption_of_heavy_metal_ions_with_carbon_nanotubes
[328] BCC Research (2014)

NANO IRON, s.r.o.[329] (Rajhrad, Czech Republic) is a company with its main focus on iron nanoparticles investigation and implementation for the various applications. The company has worked on implementation iron nanoparticles in in-situ technology for groundwater and stone environment purification from heavy metals, chlorinated hydrocarbons, radionuclides and other pollutants. This method is based on Fe^0 injection into groundwater by application wells. Small dimensions and suitable surface stabilisation allow the migration of injected nano-iron along the stone environment, where they redox reactions (oxidation-reduction) with contaminants dissolved in ground water.

A group of researchers from the School of Engineering & Applied Science at Washington University (St. Louis, USA) and the Central Arid Zone Research Institute (Jodhpur, India) tried to increase the mobility of native phosphorus in the soil. Researchers used biosynthesised zinc oxide nanoparticles obtained from the plant’s fungus. The application of nano-zinc oxide can decrease the usage of phosphorus (the fertiliser) by improving their activity approximately 80-90%. Zinc can also nourish the plants and improve their properties, for example, leaf protein, chlorophyll content, the height of stem or root volume. As a starting point, researchers have focused on introducing nano-zinc oxides into the mung bean plant, however the plan is to apply this technology to various crops, whenever phosphorus usage is high[330].

Researchers from Palacký University (Olomouc, Czech Republic)[331] have recently worked on iron nanoparticles for soil remediation applications. Nanoparticles modify the chemical and physical groundwater parameters and react to several kinds of contaminating reagents. Iron nanoparticles have the ability to break down pollutants or shift them from an extremely harmful form into less harmful solid states. This novel solution has demonstrated effective results in pilot remediation and practice in a real world situation, such as groundwater contaminated with chlorinated hydrocarbons and purification of industrial complexes[332].

Company snapshot: AMT&C Ltd

AMT&C Ltd is a recognized leader in the field of new magnetic materials and technologies. The company was founded in 1999 by Alexander Tishine and is headquartered in Troitsk (Russia). It is part of the AMT&C Group of 11 companies, which provide consulting services in applications of magnets and magnetic materials. The group is active in markets in South America, the former Soviet Union and Europe It has sales offices in the UK, Brazil, Germany, China and Ukraine and R&D and manufacturing in Moscow, Troitsk, Borovsk, St. Petersburg and Novosibirsk. AMT&C Group specialises in areas such as modern applied magnetism as magnetic separation, non-volatile shut-off gas valves, high performance permanent-magnet synchronous motors (PMSM), the treatment of cancer and precision controlled by a magnetic field desorption of targeted drugs, magnetic refrigeration, scientific instrumentation and methods of nanoscale and nanostructured materials manufacture. AMT&C Group holds 29 patents, certificates and licenses.

Related to the use of nanotechnology for environment, AMT&C Ltd conducts research and development in the field of liquid and solid foams containing magnetic submicron and nano-size particles. Such foams show magnetic properties and can be used for collection of oil or other hydrophobic pollution from water or solid surface. Solid magnetic foams also can be used for absorption and shielding of electromagnetic radiofrequency radiation.

http://www.amtc.org/en

[329] http://www.nanoiron.cz/en/ground-water-remediation
[330] https://source.wustl.edu/2016/04/nanoparticles-present-sustainable-way-grow-food-crops/
[331] http://www.upol.cz/nc/en/news/clanek/breakthrough-environmental-nanotechnologies-from-olomouc/
[332] https://source.wustl.edu/2016/04/nanoparticles-present-sustainable-way-grow-food-crops/

9.3.2.2 Air remediation

Market Overview

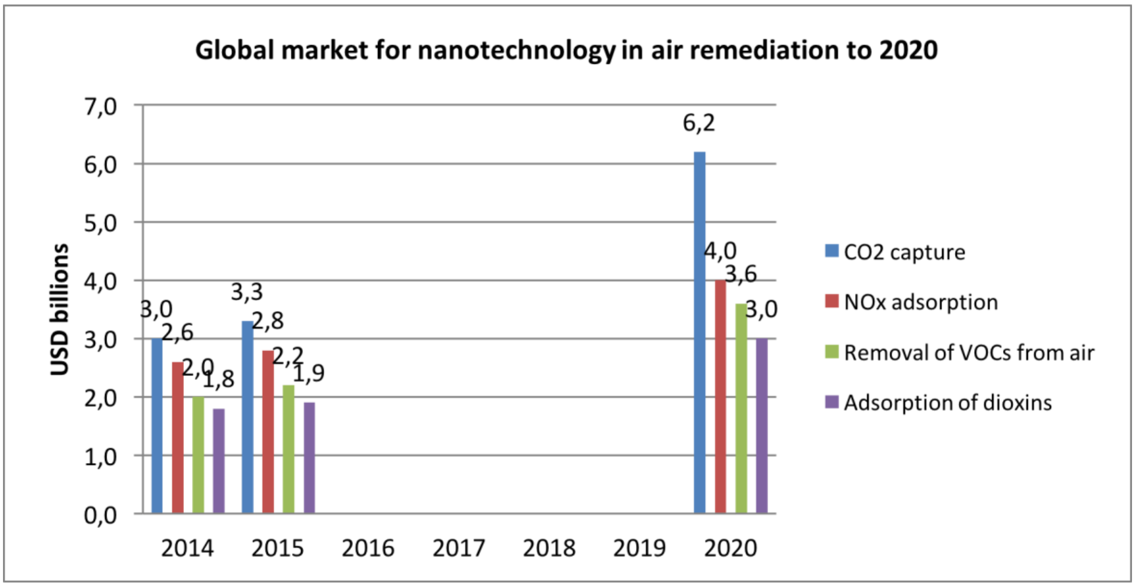
This section is split into markets by application and markets by material.

Markets by application

As shown in the figure below, the global market for nanotechnology in air remediation is divided into four application categories (in order of size of sales):

- CO_2 capture;
- NOx adsorption;
- Removal of VOCs from the air; and
- Adsorption of dioxins.

They are described in this section.



Source: BCC Research, 2014

Figure 9-5: Global market for nanotechnology in air remediation to 2019

CO_2 capture

The nanotechnology market for CO_2 capture is forecast to increase from nearly USD 3 billion in 2014 to USD 3.3 billion in 2015 at a year-on-year growth rate of 11.7%. In addition, the category is expected to grow at five-year CAGR of 13.1%, to reach around USD 6.2 billion in 2020[333].

NOx adsorption

The nanotechnology market for NOx adsorption is forecast to rise 7.3% to USD 2.8 billion in 2015, from USD 2.6 billion in the previous year. In addition, the category is expected to see 7.5% CAGR in the five-year period to reach USD 4 billion in 2020. New porous manganese oxide nanomaterials embedded with gold nanoparticles are being used for the effective removal of volatile organic compounds (VOCs) and nitrogen- and sulphur oxides from air at room temperature. These VOCs are potentially hazardous to human health and the environment[334].

Removal of VOCs from the air

The nanotechnology market for removal of VOCs from air is expected to rise 10% to USD 2.2 billion in 2015, from USD 2 billion in 2014, as well as see five-year CAGR of 10.4%, to reach USD 3.5 billion in 2020. Nanotechnology materials are being used to remove VOCs as well as nitrogen and sulphur oxides from air at room temperature, which in turn is driving the market for nanotechnology used

[333] Ibid
[334] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.163

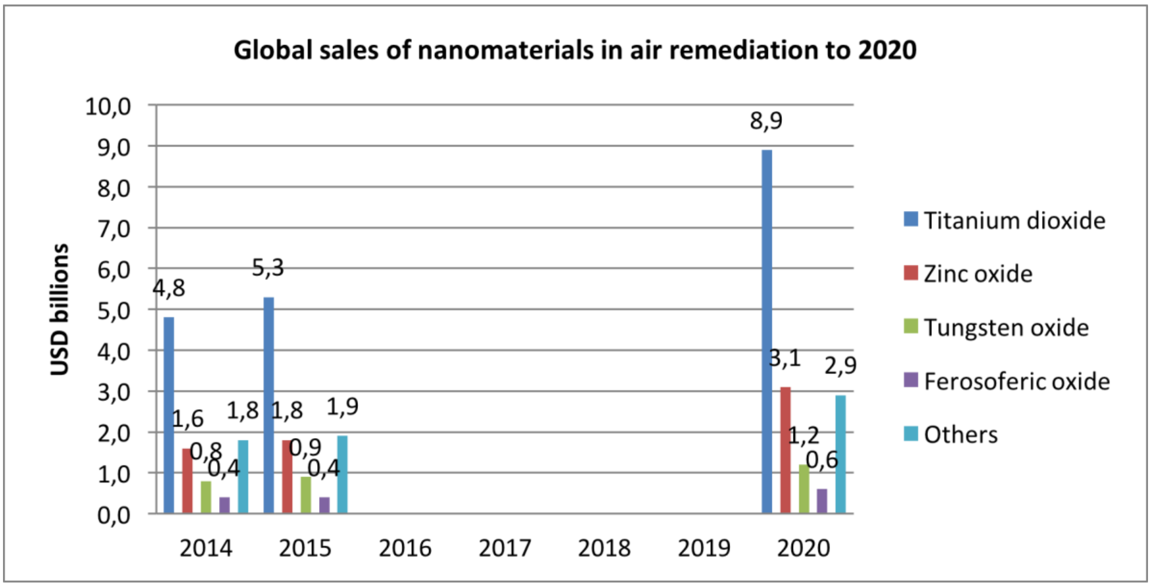
in air remediation[335].

ADSORPTION OF DIOXINS

The nanotechnology market for adsorption of dioxins is forecast to increase to USD 1.9 billion in 2015, up 7.5% from nearly USD 1.8 billion in 2014. In addition, the category is expected to grow at a five-year CAGR of 9.2%, to reach around USD 3 billion in 2020. Acetaldehyde, toluene, and hexane are the three major components of organic air pollution, which are effectively removed from air and degraded by the nano-catalyst.

MARKETS BY MATERIAL

Market sales data are also available for the following nanomaterials applied in air remediation: titanium dioxide, zinc oxide (ZnO), tungsten oxide, ferrosoferric oxide (Fe_3O_4) and remaining materials (classed as 'others'), as shown in the figure below.



Source: BCC Research, 2015

Figure 9-6: Global market for nanomaterials in air remediation to 2020

TITANIUM DIOXIDE

The nanotechnology market for titanium dioxide used in air remediation is expected to increase to around USD 5.3 billion in 2015, up 10.5% from USD 4.8 billion in 2014, and to further grow at 11.1% CAGR in the five-year period to reach USD 8.9 billion in 2020[336].

ZINC OXIDE

The nanotechnology market for zinc oxide used in air remediation is expected to reach nearly USD 1.8 billion in 2015, up 10.7% from USD 1.6 billion in 2014, and is projected to show further growth at 12.2% CAGR in the five-year period to reach USD 3.1 billion in 2020. Site-selective deposition (SSD) of metal oxide thin film has been developed to fabricate nano/microstructures of metal oxide such as TiO_2, Fe3O_4, ZnO, and yttrium oxide (Y2O_3), europium (Eu), etc. Several conceptual processes for SSD using self-assembled monolayers (SAMs) as templates were proposed, and nano/micro patterns of ceramic thin films were successfully fabricated. These different nano compounds are successfully being used for air remediation, which in turn is driving the market[337].

[335] Ibid
[336] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.168
[337] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.169

TUNGSTEN OXIDE

The nanotechnology market for tungsten oxide used in air remediation is expected to increase to USD 892.3 million in 2015, up 5.9% from USD 842.4 million in 2014, and is expected to further grow at a five-year CAGR of 6.3%, to reach USD 1.2 billion in 2020.

FERROSOFERRIC DIOXIDE

The nanotechnology market for ferrosoferric oxide used in air remediation is expected to rise 6.9% to USD 400.3 million in 2015, from USD 374.4 million in 2014. In addition, the category is expected to grow at a five-year CAGR of 7.3%, to reach USD 568.4 million in 2020[338].

OTHER COMPOUNDS

The nanotechnology market for other compounds used in air remediation is forecast to increase to USD 1.9 billion in 2015, rising 7.1% from nearly USD 1.8 billion in 2014, and to further grow at a five-year CAGR of 8.8%, to reach USD 2.9 billion in 2020. Catalysts work by speeding up chemical reactions that transform harmful vapours from cars and industrial plants into harmless gases. Catalysts currently in use include a nanofibre catalyst made of manganese oxide that removes VOCs from industrial smokestacks[339].

PRODUCT OVERVIEW

This section looks at specific products that are applications of nanotechnology. The information provided is on the technology, products and markets for:

A. Photocatalytic coatings;
B. Catalytic converters; and
C. Air filtration systems.

A PHOTOCATALYTIC COATINGS

Technology and products

When exposed to light certain semiconducting materials such as ‘photocatalysts’ trigger or accelerate chemical reactions resulting, for example, in a decomposition of organic molecules. Due to their large surface area, nano-sized catalyst particles show a significantly enhanced reactivity compared to larger particles or bulk material. Numerous materials are under examination; however, none appear to match the efficiency of titanium dioxide (TiO_2). Its application requires illumination in the ultraviolet or at the extreme blue edge of the visible spectrum[340].

These activated agents can oxidise and decompose many types of chemical substances including organic compounds, oil, ammonia, nitrogen oxide (NOx), hydrogen sulphide, and cigarette smoke and tar. Such photocatalytic reactions can be used to sanitise, treat or deodorise air, water, surfaces and fabrics[341].

A process for producing photocatalytic, self-cleaning coatings was developed by scientists at Singapore's A*STAR (Agency for Science, Technology and Research), and licensed to Haruna (S) Pte Ltd. The patented process produces a coating containing the nano-particle, titanium dioxide (TiO_2). When exposed to an ultraviolet light source, such as the sun, the coating's oxidative property decomposes organic substances such as microbes on its surface. In addition, the hydrophilic nature of the coating causes water that comes into contact with it to form an even layer, thereby allowing the dust and dirt that have accumulated on the surface to be washed away. These two properties of the coating create the "self-cleaning" effect[342].

Researchers from Wuhan Technical University (Wuhan, China) have developed self-cleaning concrete from titanium dioxide nanoparticles. In their study scientists claim to have developed a novel approach using the nano granular nature of hydration products and nanoparticles of TiO_2 photocatalyst properties. In the result, the surface of obtained concrete was coated by TiO_2 nanoparticles and Calcium Silicate Hydrates. This concrete is able to degrade methylene blue

338 Ibid
339 Ibid
340 Observatory Nano (2011), Nanocomposite Materials, BRIEFING No.10, p.1
341 BCC Research (2014), Nanotechnology, a realistic market assessment, p.64
342 http://phys.org/news/2008-11-photo-catalytic-coating-exteriors.html

effectively. This promising method can be applied as self-cleaning covering materials for building applications[343].

Green Earth Nano Science Inc**.** (Toronto, Canada) is a company that has commercialised a new photocatalyst solution called Gens Nano™. Gens Nano™ is a next generation of air purification technology, which can treat air pollutions caused by more than 85% of harmful gases such as car exhausts' NOx, formaldehyde, benzene, VOCs. At the presence of light, photocatalysts produce hydroxyl radicals and holes (h+), which react with organic materials and harmful gases to produce water and carbon dioxide. There is no extra pollution in the whole purification process. The nano photocatalyst reacts as catalyst in the chemical reaction so that its performance will maintain for a long time and it will never be consumed. and the company claims that its products are suitable for indoor use where UV light irradiation is weak.

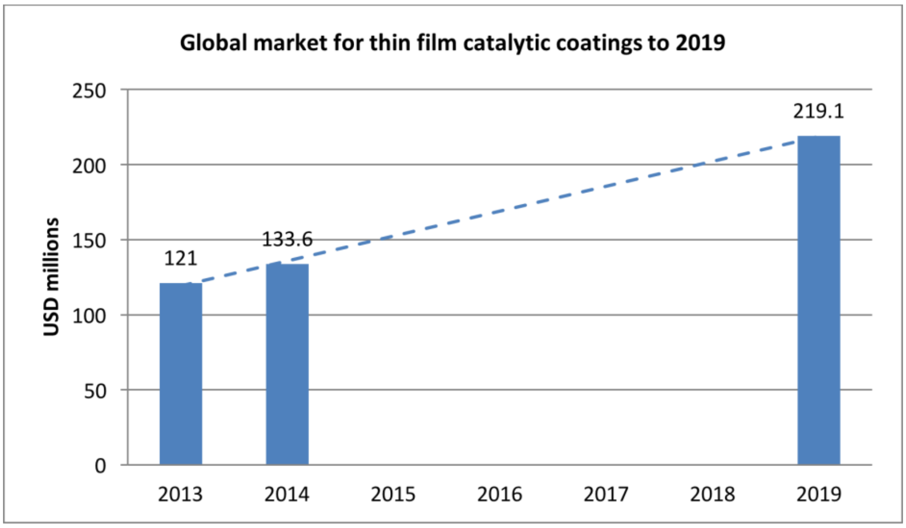
MAXIT Airfresh Plaster is a plaster which can be applied on ceilings and walls. Making use of nano sized TiO_2 particles in its formula and the so-called photocatalytic effect it eliminates unwanted odours, air pollutants and organic volatile compounds[344].

At least a dozen companies worldwide, including TOTO, Toshiba Lighting and Technology, Daikin Industries, Hitachi Metals, Mitsubishi Materials, Deutsche Steinzeug Cremer & Breuer AG, Nissan Motor Co., Matsushita Refrigeration, Airtech, Purifics Environmental Technologies, Matrix Photocatalytic, Lynntech and Kawasaki Heavy Industries, have introduced or are developing photocatalytic products[345].

Market data and forecasts

Nanoscale titanium dioxide thin films are used as photocatalytic coatings in a variety of products, ranging from anti-fogging mirrors, self-cleaning ceramic tiles and pollution-controlling construction materials. BCC Research estimated the total consumption of nanoscale TiO2 thin film materials in 2013 at 5,900 metric tons with a value of USD 121 million.

Reliable data on future trends in the production of mirrors, tiles and other articles that use these coatings are unavailable. The projections in the following figure are based on the assumption that the market will continue to grow at a CAGR of 10.4% from 2014 to 2019.



Source: BCC Research, 2014

Figure 9-7: Global market for thin film catalytic coatings to 2019

[343] http://www.sciencedirect.com/science/article/pii/S0959652614010543
[344] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.452.6825&rep=rep1&type=pdf
[345] BCC Research (2014), Nanotechnology, a realistic market assessment, p.65

Company case study: Green Earth Nano Science Inc. (GENS)

Green Earth Nano Science, Inc., (GENS) was established in 2008 in Toronto, Canada. It is directing its efforts to the investment, commercialisation, manufacturing and distribution of sustainable and environmentally benign technologies. These technologies are being used to address challenges associated with air and surface bio-contamination, including specialist attention to contamination caused by listeria, salmonella, E.coli, swine flu (H1N1), bird flu (H5N1), SARS, mould spores, etc.

The company started with the aid of private investments from the founders and is running on the profit which it generates. Currently a privately owned company, it has plans to go public by 2020. The company currently employs around 80 people, out of which 20 work in the R&D division.

The use of nanotechnology in building materials is estimated by the company as currently representing a market valued globally at USD 2 billion (EUR 1.8 billion) and it expects it to grow to around USD 7 billion (EUR 6.3 billion) by 2018 and around USD 10 billion (EUR 9 billion) by 2020. The market share of GENS is estimated by the company to be between 0.7% to 1% globally and around 1.5% to 2% of the North American market. With estimates of the total market for building materials standing at USD 890 billion (EUR 802 billion), this would indicate that the share of nanotechnology in the building materials market is around 0.2%.[346]

The company collaborates with researchers, scientists as well as technology companies, in order to adopt a swift go-to-market strategy. The company focuses on the commercialisation of proprietary technologies to achieve reductions in energy usage, greenhouse gas emissions, and air pollution, as well as protection of commercial and domestic buildings from pollution and bio-contamination. GENS' technologies are marketed under the product portfolio "Green 3D Shield". Green 3D Shield is the collective name for several innovative components, such as: self-cleaning, self-sanitising photocatalyst coatings, air purification coatings (NOx, formaldehyde, benzene, ammonia, ethylene gas, VOC's, purification), organic anti-pathogenic solution, air purification equipment and unique proprietary methodologies for infection control.

GENS offer its SolarStucco self-cleaning photocatalyst coating solution for building exteriors, delivering UV discoloration protection and preventing biological growth. It also supports road self-cleaning and purification of car exhausts. The company has two main products: Self-cleaning Sol Series and the Self-sanitising Sol Series[347]*.*

The revenue of the company already exceeds USD 100 million (EUR 90 million) with total revenue of USD 120 million in 2015 (EUR 108.1 million) and projected R&D expenditure of USD 10 million (EUR 9 million) in the same year. Both the products contributed a similar share of the revenue, i.e. 50%, in 2015. The company is targeting a revenue increase to USD 150 million (EUR 135.1 million) in 2016 by targeting an increase in sales of each of the two main products to at least USD 75 million (EUR 67.6 million). In order to achieve this, GENS plans to invest around USD 15 million (EUR 13.5 million) in R&D in 2016. The company aims to find partners globally in order to license its proprietary technology. Company profits were USD 12 million in 2015 (EUR 10.8 million) and USD 8 million in 2014 (EUR 6 million) and the company expects to generate a profit of USD 15 to 16 million in 2016 (EUR 13.5 to EUR 14.4 million).

The company has faced challenges in securing food safety certifications from the Canadian Food Inspection Agency before initiating its commercialisation activities. The certification is required when providing products or services to any entity in the food and beverage industry in Canada, including those for buildings or machineries used in the food contact area. The challenges were due to the long duration of the certification process which postponed the planned commercialisation dates. The company always aligned itself to have the necessary certifications required for commercialisation in North America such as exemption from the US Environmental Protection Agency (EPA) for their offerings such as organic disinfectants and nano-cleaners and coatings.

Some of the industries targeted by GENS for its Green 3D Shield products are government and

[346] http://www.e-cantonfair.com/special/news-how-much-do-you-know-about-global-building-materials-industry-in-2015-710.html

[347] http://www.greenearthnanoscience.com/products.php

commercial buildings and facilities, poultry and pork farms, food and beverage plants, healthcare facilities, businesses and homes. Green 3D Shield is sold directly or through a network of installers and applicators in various countries. GENS maintain a large network of distributors globally in order to reach out to existing and potential customers.

The company initiated strategic partnerships with various small scale companies in Europe and Asia in order to penetrate the market more effectively. One of the recent activities in its distribution network is the penetration of the Scandinavian region (Denmark, Sweden, Norway) and Germany through the Danish company CleanShield. CleanShield has an exclusive license distribution agreement for the distribution and application of GENS Nano & SolarStucco branded self-cleaning, anti-bacterial coatings and AgriHit branded organic disinfectants and sanitisers, natural bio degradable cleaners, natural foliar fertilisers & plant growth & health enhancers. Similarly, CleanShield has signed agreements with Gens Nano Sdn Bhd from Kuala Lumpur, Malaysia (for Asian countries), AIRnano s.r.o. for the Czech Republic, Gens Trading Ltd. and U.V. Nano Gens Ltd for Cyprus and V.M.BioTech s.r.o for Slovakia. The solutions offered by GENS can be adopted by the construction as well as the environmental applications sector.[348]

GENS applied its self-cleaning nano-coating technology in the exterior walls and concrete platforms of the soccer stadium in Vancouver, British Columbia, known as BC PLAYS. The authorities used to spend USD 0.38 million (EUR 0.34 million) per year on cleaning these surfaces, but after the application of this technology the cost has reduced to zero. This translates to a significant cost savings of USD 3.8 million (EUR 3.4 million) over 10 years.

The company has not been involved in any of the European Framework Programme projects but has expressed an interest in doing so. GENS would look at this opportunity as a means by which to expand into Europe, particularly into the Czech Republic, Denmark, Sweden, Norway and Germany. The company is also trying to find new distributors in Spain, France and Portugal. The company is satisfied with the existing regulatory, health & safety, and environmental standards in the US, Canada and Europe.

See http://www.greenearthnanoscience.com/index.php

B CATALYTIC CONVERTERS

Technology and products

A catalytic converter is a device used to reduce the toxicity of emissions from an internal combustion engine. It converts the harmful toxic combustion products and its by-products into less toxic substances[349].

Most present-day vehicles that run on petrol are fitted with a "three way" converter, so named because it converts the three main pollutants in automobile exhaust: an oxidising reaction converts carbon monoxide (CO) and un-burned hydrocarbons (HC), and a reduction reaction converts oxides of nitrogen (NOx) to produce carbon dioxide (CO_2), nitrogen (N_2), and water (H_2O).

The first widespread introduction of catalytic converters was in the United States, where 1975-model petrol-powered cars were so equipped to comply with tightening U.S. Environmental Protection Agency regulations on car exhaust emissions. These were "two-way" converters which combined carbon monoxide (CO) and unburned hydrocarbons (HC) to produce carbon dioxide (CO_2) and water (H_2O). Two-way catalytic converters of this type are now considered obsolete, having been supplanted except on lean burn engines by "three-way" converters which also reduce oxides of nitrogen[350].

Most catalytic converters contain a nanoscale thin film of platinum, palladium, and/or rhodium catalysts that turn harmful gases into less harmful substances. The nano-catalyst materials are

[348] http://www.greenearthnanoscience.com/press-releases.php

[349] Apostolescu et al. (2005), Selective catalytic reduction of nitrogen oxides by ammonia on iron oxide catalysts. Appl. Catal., B, 62(1-2), p.104

[350] Thakur, M., Saikhedkar, N. (2012), Reduction of Pollutant Emission from Two-wheeler Automobiles using Nano-particle as a Catalysts, Research Journal of Engineering Sciences Vol. 1(3), p.33

dispersed over a high-surface-area refractory aluminium oxide support structure. The refractory oxide support is designed to maximise the surface area and the thermal stability of the catalyst[351].

The nano-catalyst film is typically formed *in situ* via a chemical process involving the decomposition or reduction of salts impregnated on the oxide support material. The support structure itself is a nanoscale alumina thin film, fabricated by depositing a wash coat containing the oxide particles onto the carrier, followed by drying to form a porous coating. A three-way catalytic converter has a stainless steel body that contains catalytic material as a layer on a substrate (wash coat). The particles of the noble metal catalyst in the wash coat are nanoscale. Research is currently in progress to, amongst other things, minimise the amount of noble metal but with the same catalytic performance[352]. Alternatively, a chemical precipitation process in which the high surface area support particles are formed in situ from an aqueous solution may be used to fabricate the support. The technology described above is well established. In 2009, Mazda Motor Corp. of Japan introduced a "single nano-catalyst" technology that reduces the amount of platinum group metal (PGM) catalysts by as much as 70%. Mazda plans to introduce the new technology progressively to other models and markets and may eventually license the technology to other manufacturers[353].

Nanostellar[354] is a company located in Silicon Valley in California, USA, founded in 2004 by researchers from the NASA Ames Research Centre and Stanford University. The company is focused on developing new nanomaterial catalysts for use in chemical and fuel synthesis, energy efficiency, and emissions control. Nanostellar has launched its first product for emissions control in diesel vehicles. The emissions reduction was obtained due to the pioneering use of gold nanoparticles as a catalyst, called NS Gold™. The implementation of this particular catalyst allowed a reduction of emissions by 20%.

Company snapshot: Umicore SA - catalytic converters

Umicore is a global materials technology and recycling group, with more than 10,000 employees and a turnover of EUR 10.4 billion in 2015. Umicore generates the majority of its revenues from and dedicates most of its R&D efforts to clean technologies, such as emission control catalysts, materials for rechargeable batteries and recycling.

Umicore is one of the world's leading producers of catalysts used in automotive emission systems for light-duty and heavy-duty vehicles. Umicore's catalysts perform in a wide range of powertrains, including gasoline and diesel engines, natural gas, and alternative fuels, and are increasingly important in engines supporting mid- and full hybrid vehicles.

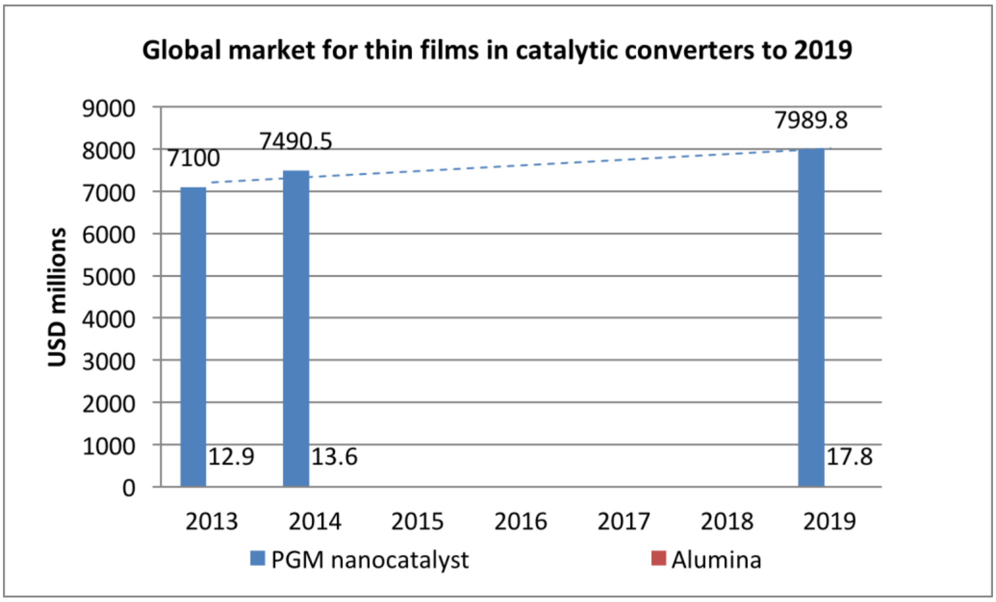
Umicore develops catalytically active after treatment solutions which transform pollutants into harmless gases before releasing them into the environment. The catalytically active materials consist of a combination of oxides and precious metals like platinum, palladium and rhodium incorporated into a porous structure which allows intimate contact with the exhaust gas. The composition and the structure enable the interaction with the exhaust gas and the chemical transformation into harmless compounds.

See http://www.umicore.com/en/industries/automotive/

Market data and forecasts[355]

Catalytic converters are used mainly in light motor vehicles, but also in non-vehicular emission control applications such as power lawn mowers and forklifts. These catalytic converters are a major market for platinum group nanocatalysts (i.e., platinum, palladium and rhodium) and nanoscale alumina, as shown in the figure below (note that for alumina the market figures are shown but the red bar is not visible due to the scale: the total market is USD 7,112 million of which the market for alumina is USD 12.9 million).

351 BCC Research (2014), Nanotechnology, a realistic market assessment, p.59
352 Federal Environment Agency of Germany (2010): Applications of Nanomaterials in Environmental Protection
353 http://www.mazda.com/en/innovation/technology/env/other/singlenano_tech/
354 https://www.nasa.gov/content/nanostellar/#.V4N4J6JUUXo
355 BCC Research (2014), Nanotechnology, a realistic market assessment, p.161



Source: BCC Research, 2014

Figure 9-8: Global market for thin films in catalytic converters to 2019

The overall weight ratio of alumina support materials to nanocatalysts used in catalytic converters is about 41:1. The total consumption of PGM nanocatalysts (new as well as recycled) was 235,440 metric tons in 2013. Thus, 5,742 metric tons of alumina were consumed in the production of catalytic converters (including non-vehicular converters) in 2013.

At an average price of USD 2,243 per metric ton, the value of these alumina support materials was USD 12.9 million in 2013. Based on projected trends in the number of vehicular and non-vehicular catalytic converters, consumption of alumina support materials is projected to reach USD 13.6 million in 2014 and USD 17.8 million in 2019.

C AIR FILTRATION SYSTEMS

Technology and products

Toxic gases pollute the air and are dangerous to the health of the population affected by these. Nanotechnology is capable of enhancing air purification of these toxic gases. For that particular application, CNTs can be used due to their hexagonal structure. There is a strong interaction between the surface of CNTs and dioxin hexagonal rings. Additionally, the entire porous wall surface of the CNTs interacts with dioxin molecules. Another benefit of using carbon nanotubes is its high oxidation resistance. Researchers from the Department of Textile Engineering Chemistry and Science at North Carolina State University have investigated the sheet efficiency of CNTs in air filters. Scientists report that CNTs can provide air purification with higher efficiency than conventional aerosol filters based on microfibres, because of their smaller pore size and higher surface area. Researchers have investigated both CNTs and microfibres. The implementation of CNTs dramatically improved the efficiency of filtration[356].

Donaldson Torit (Minneapolis, USA) develops nanofibre products and nanofibre filter media for applications where sub-micron fibre diameters, high filtration efficiency, high surface area and other unique material properties are useful. For many years, Donaldson has used its patented and patent-pending nanofibre filter media in Ultra-Web® filters for dust collection, Spider-Web® filters for gas turbine air filtration, and Donaldson Endurance™ air filters for heavy-duty engines[357].

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356 http://www.sciencedirect.com/science/article/pii/S0008622313007008
357 http://www2.donaldson.com/torit/en-us/pages/products/ultra-webmediatechnology.aspx

Company snapshot: Donaldson Filtration Systems

Donaldson Company, Inc. is a multinational company that manufactures and sells filtration systems and replacement parts worldwide. It was founded in 1915 and is based in Minneapolis, Minnesota.

The company has two product divisions: Engine Products and Industrial Products. The division Engine Products offers air filtration systems; exhaust and emissions systems; liquid filtration systems, including hydraulics, fuel, and lube systems; and replacement filters. It sells its products to original equipment manufacturers (OEM) in the construction, mining, agriculture, aerospace, defence, and truck markets; and to independent distributors, OEM dealer networks, private label accounts, and large equipment fleets. The division Industrial Products provides dust, fume, and mist collectors; compressed air purification systems; air filtration systems for gas turbines; polytetrafluoroethylene (PTFE) membrane-based products; and specialised air and gas filtration systems for applications, including computer hard disk drives and semiconductor manufacturing. This division sells its products to various industrial dealers, distributors, OEMs of gas-fired turbines, as well as OEMs and end-users requiring filtration solutions and replacement filters. Donaldson Company, Inc has been especially recognised for innovations made in air filter technology. Already in 2005, the company held more than 80 international patents covering nanofibre technologies for filtration.

In 2015 the company had a revenue of USD 2.4 billion (EUR 2.16 billion) and since 2008 annual spending on research and development has exceeded USD 40.6 million (EUR 36.48 million). It holds over 1,600 active US and international patents and operates a network of approximately 140 sales, manufacturing and distribution locations in 44 countries across the world with a team of over 13,000 employees. The company is a member of the S&P MidCap 400 Index and Donaldson shares are traded on the New York Stock Exchange under the symbol DCI.

https://www.donaldson.com/en

Market data and forecasts

No market data and projection on future sales are available for air filtration systems.

Company snapshot: Hollingsworth & Vose

Hollingsworth & Vose (H&V), an engineered paper and nonwovens company, manufactures and supplies materials for filtration, battery, and industrial applications to its international customer base in the Americas, Asia Pacific, Europe, Middle East and Africa. The company offers air and liquid filtration media products; lead acid and lithium primary battery separators; and industrial products in the areas of fibre nonwovens, clothing, engineered composite materials, home furnishings, and industrial nonwovens. It serves transportation, indoor air quality, industrial and manufacturing, heavy equipment, energy generation and storage, clothing and home furnishings, and aerospace industries. The company was founded in 1843 and is based in East Walpole, Massachusetts with regional offices in the USA, Mexico, Germany, the UK, China and India.

It has a heritage of investment in research and development as well as manufacturing processes, the continual diversification in types of paper enabling the company to grow. In 1890, the company made its first electrical insulating paper for Western Electric Company. In 1920, the gasket paper field was added to the company's list of specialties, and, in 1933, a new line of saturating papers started. The company's long experience in the production of technical and industrial papers enabled it to make highly specialised papers for the Navy, the Army Signal Corps, the Chemical Warfare Service, and other branches of the Armed Forces during the World War II, setting the foundation for H&V's HEPA air filter market expertise in 1941. In 1945, it became leader in manufacturing engine cellulosic and high efficiency microfibre glass filter media and pioneers in the development of wet-laid nonwovens used in home furnishings (1958). H&V developed diskette liner and became a major industry supplier (1982) and leading manufacturer of microfibre glass battery separators (1984), entering the high efficiency melt blown filter media market (1991). This was followed by the development of a chemisorptive product and process technology (1998), nanofibre coating technology

(1999), a commercialised Advanced Cure Resin (ACR) family of binders (2003), the introduction of pool and spa filter media (2005) and eventually to an advanced nanofibre technology (2008).

Hollingsworth & Vose has manufacturing facilities, and research and development laboratories in Corvallis, Oregon; Greenwich, New York; Floyd, Virginia; Hawkinsville, Georgia; West Groton, Massachusetts; Tlaxcala, Mexico; Bad Vilbel and Hatzfeld Germany; Kentmere and Winchcombe, United Kingdom; and Jiangsu, China.

Hollingsworth & Vose operates through four business divisions—High Efficiency and Specialty Filtration (HESF), Engineered Composite Materials (ECM) and Industrial Specialties (IS), Battery Separators and Engine and Industrial Filtration. The HESF division was enhanced through the acquisition of Hepworth Air Filtration, Kentmere, UK, in March 2000 and the Papierfabrik Binzer in Hatzfeld, Germany. Renamed Hollingsworth & Vose Air Filtration (HVAF), the acquisitions have broadened H&V's product offerings and capabilities in the respiratory protective equipment, medical, cabin air, furnace filter, appliance and industrial air filtration markets. HVAF products are sold in the US and Europe, and the integration of the company's resources have strengthened HESF internationally.

In 2015, Hollingsworth & Vose's nonwovens sales amounted to USD 375 million. By the end of 2015 the company employed 3,000 people. Continued growth is expected thanks to innovative air filter products like NanoWave synthetic media. Demand has increased across all segments but especially so in the HVAC, life sciences, and fuel/water areas, high efficiency and specialty filtration. Increasingly stringent indoor air quality standards continue to drive demand for higher particulate efficiency media in HVAC.

The company has recently announced several capacity expansions and acquisitions to help propel growth in the future. NanoWave is an extended surface area, multilayer filtration media for HVAC applications. Using nano and coarse fibre layers, NanoWave delivers 2.4 times the surface area of normal flat sheet media. The woven nanofibre layer allows for maximum mechanical efficiency with very low resistance while more than doubling dust-holding capacity compared to standard synthetic media. This patented technology is increasingly preferred for HVAC in hospitals, airports, automotive and pharmaceutical production facilities as well as in large retail stores. The company claims that product performance is widely recognised and lifecycle cost of HVAC systems employing NanoWave is superior to competitive media.

Hollingsworth & Vose has – with financial support from the German Federal Ministry of Education and Research (BMBF) – developed filter materials with a new type of architecture. This work has been done in co-operative research between the Philipps-University Marburg (Marburg, Germany) and the filter manufacturer. The technological base is a nano-fabric made of fibres with an average diameter of 200 nanometres or smaller. The Nanoweb® filter, the development of which emerged from the collaboration, is based on a thin layer of fibres on a carrier material. The nanofibre lattice determines the filter fineness. The advantage of this filter medium is a small overall pressure loss with simultaneous high intake capacity of the separated particles. Filter replacement intervals are increased and the energy required to flow through the filter is significantly reduced. The plastic nanofibres are manufactured using the electrospin process. The filter can be used for different filtering purposes; the market value is estimated at several hundred million euro.

To secure its competitive edge and to protect its ongoing innovation partnerships, Hollingsworth & Vose regularly reviews its patent portfolio considering costs and future benefit, and pursues a market-oriented patent strategy. As of the end of 2015, the Group possessed of 32 patents.

http://www.hollingsworth-vose.com/

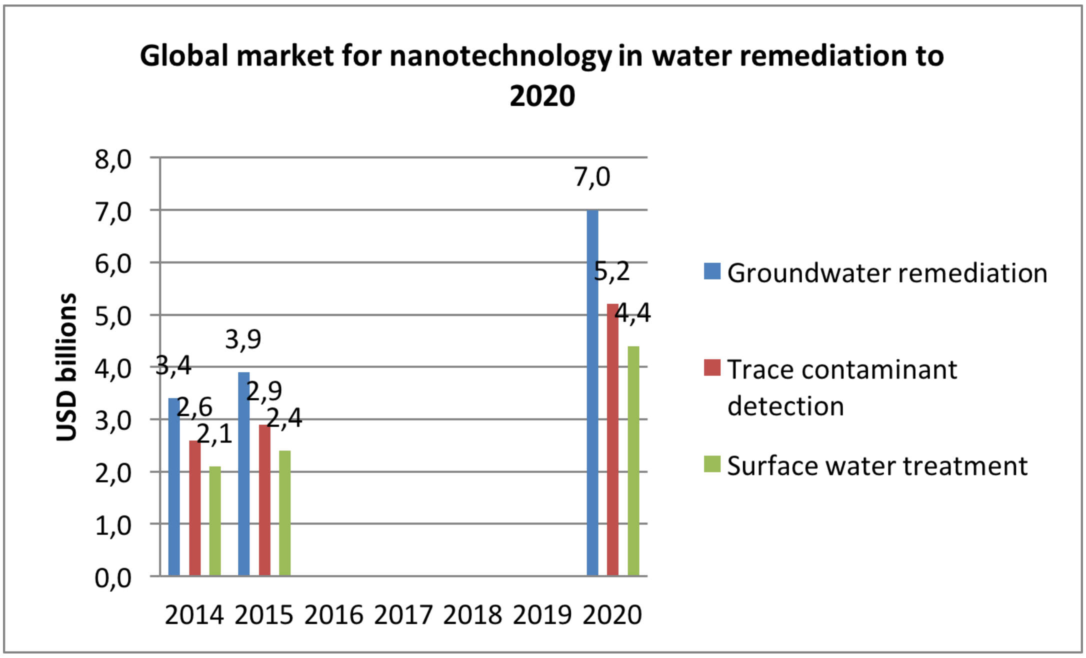
9.3.2.3 Water remediation

MARKET OVERVIEW

This section is split into markets by application and markets by material.

MARKETS BY APPLICATION

The global market for ground water remediation has three main segments: ground water remediation, trace contaminant detection and surface water treatment. The market size and forecast growth rate for each of those segments is shown in the figure below.



Source: BCC Research, 2015

Figure 9-9: Global market for nanotechnology in water remediation to 2020

Groundwater remediation

It is forecast that the nanotechnology market for groundwater remediation applications will increase to USD 3.9 billion in 2015, from USD 3.4 billion in 2014, and further rise at 12.4% CAGR over the five-year period to reach USD 7 billion in 2020[358].

Trace contaminant detection

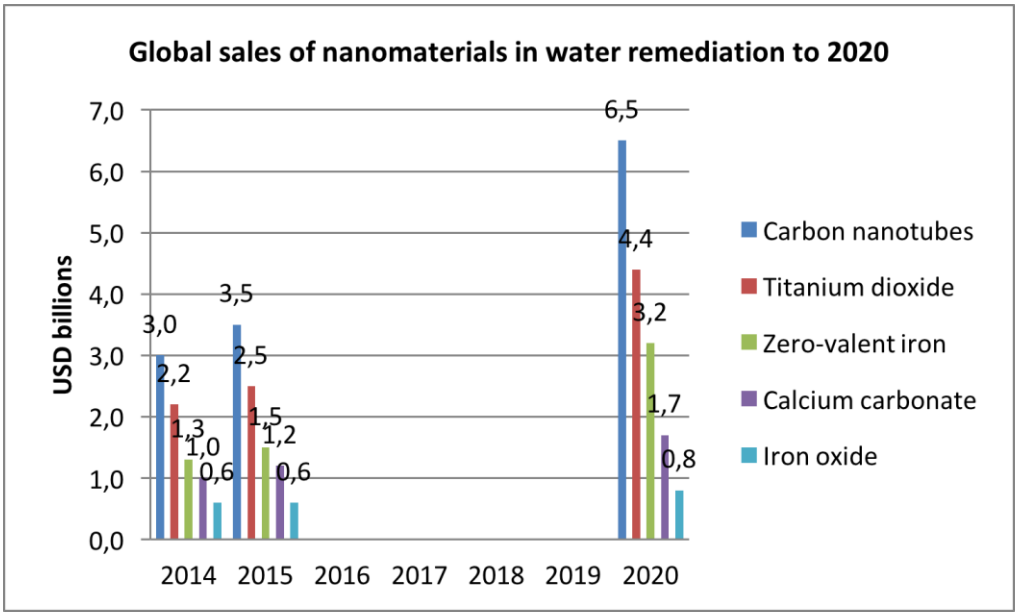
Trace contaminant detection is expected to increase 11.5% to USD 2.9 billion in 2015, from USD 2.6 billion in 2014, and further rise at five-year CAGR of 12.1%, to reach nearly USD 5.2 billion in 2020[359].

Surface water treatment

The nanotechnology market for surface water treatment is forecast to rise to USD 2.4 billion in 2015, up 14.1% from USD 2.1 billion. In addition, the category is expected to grow at five-year CAGR of 12.6% to reach USD 4.4 billion in 2020.

In terms of nanomaterials the most important markets are those for carbon nanotubes (CNTs), titanium dioxide, zero-valent iron, calcium carbonate and iron oxide (see figure below).

[358] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.164
[359] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.165



Source: BCC Research, 2015

Figure 9-10: Global market for nanomaterials in water remediation to 2020

MARKETS BY MATERIAL

Carbon nanotubes

The nanotechnology market for carbon nanotubes used in water remediation is expected to increase to USD 3.4 billion in 2015, up 14.1% from USD 3 billion in 2014. In addition, the category should see further growth at a five-year CAGR of 13.5%, to reach USD 6.5 billion in 2020. Sensors using carbon nanotube detection elements are capable of detecting a range of chemical vapours. These sensors work by reacting to the changes in the resistance of a carbon nanotube in the presence of a chemical vapour[360].

Titanium dioxide

It is estimated that the nanotechnology market for titanium dioxide used in water remediation will rise 13.8% to USD 2.5 billion in 2015, from USD 2.2 billion in 2014, and will grow further at five-year CAGR of 11.6%, to reach nearly USD 4.4 billion in 2020[361].

Zero-valent iron

The nanotechnology market for zero-valent iron used in water remediation is expected to reach USD 1.5 billion in 2015, up 16.8% from USD 1.3 billion in 2014 and increase by 16.1% CAGR in the five-year period to USD 3.2 billion in 2020[362].

Calcium carbonate

The nanotechnology market for calcium carbonate used in water remediation is expected to increase 9.3% to nearly USD 1.2 billion in 2015, from USD 1.1 billion in 2014, and see further growth at 8.4% CAGR to reach USD 1.7 billion in 2020. Different types of water remediation processes that utilise calcium carbonate include reverse osmosis, nano-filtration, ultra-filtration and micro-filtration.

Iron oxide

The nanotechnology market for iron oxide used in water remediation is expected to increase to USD 623.3 million in 2015, up 8.7% from USD 573.3 million in 2014. In addition, the category is expected to grow at a five-year CAGR of 5.2%, to reach USD 801.7 million in 2020.

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[360] Ibid
[361] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.171
[362] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market, p.170

PRODUCT OVERVIEW

This section looks at specific applications as follows, giving technology, product and market information:

A. Filtration systems based on nanoparticles;
B. Nano-porous membranes;
C. Water filtration based on carbon nanotubes;
D. Nano-structured water desalination membranes; and
E. Water filtration with nano-composites.

A AIR FILTRATION SYSTEMS

Technology and products

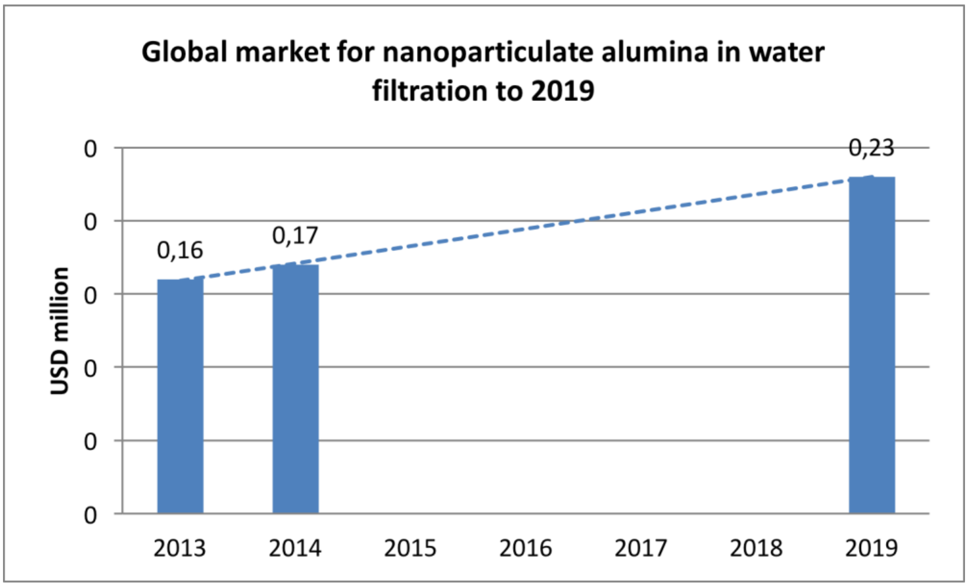
Protein that contains iron, called ferritin, is able to regulate the creation of mineralised structures. Ferritin forms the cage-like protein network. In the network cavity, iron molecules transform into ferrihydrite nanoparticles. Developers have worked on the ability of the ferritins to remediate harmful metals and organic compounds under the UV or solar radiation. The ferritins are more stable than traditional iron catalyst, because ferritins do not react in photo-reduction. The group of scientists from the Netherlands and Saudi Arabia has compared the characteristics of ferritins and their treatment against arsenate and phosphate pollutants. Ferritin has been demonstrated to be an excellent solution for fast phosphate and arsenate transformation from water solution to obtain concentrations of pollutants at pico-molar level. Due to this low concentration level, ferritins are an excellent tool in industrial biofouling to overcome the phosphate and arsenate limitations in terms of drinking water[363].

Argonide's (Sanford, USA) NanoCeram® patented filter media features a thermally-bonded blend of microglass fibres and cellulose infused with nano-alumina fibres in a non-woven matrix that creates an electropositively charged depth filter media. According to the company, all NanoCeram® filters, when assembled into a pleated cartridge, provide a unique combination of efficiency, capacity, flow rate & low pressure drop at levels unmatched in today's filtration marketplace. In addition, all NanoCeram® filter cartridges are assembled using only FDA-compliant materials. All cartridges are engineered and designed to satisfy the most difficult requirements in water treatment. By using the scientific principle of electropositive attraction/capture, NanoCeram®'s NASA-derived technology leads to a rapid and highly efficient adsorption of virtually all particle sizes. NanoCeram®'s media has a high capacity for particles as large as tens of microns or as small as a few nanometres. Each NanoCeram® filter cartridge exhibits a rating of 0.2µ – a rating typically associated with microporous membranes. Yet NanoCeram® flow rates are hundreds of times greater than such membranes[364].

Market data and forecasts

The consumption of nano-particulate alumina for ultrafiltration applications has been estimated at approximately USD 160,000 in 2013. The ultrafiltration market as a whole is projected to grow at a CAGR of between 6% and 6.5% through the end of the decade. At this rate, consumption of nano-particulate alumina ultrafiltration media should approach USD 230,000 by 2019[365].

[363] http://www.sciencedirect.com/science/article/pii/S0043135415001359
[364] http://www.argonide.com/nanoceram/
[365] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.126



Source: BCC Research, 2014

Figure 9-11: Global market for nano-particulate alumina in water filtration to 2019

B NANO-POROUS MEMBRANES

Technology and products

Koch Membrane Systems Inc.[366] (Wilmington, USA), was established in 1963 and is a developer and manufacturer of nano-based membranes for nano-filtration processes. One of the membranes offered by Koch Membrane Systems is TFCS®. It removes sulphate and hardness from seawater. Additionally, it removes colour and organics from ground water, thereby softening and de-ashing it. The primary market for such nano-filtration membranes is for the water desalination market. However, the technology can be used for the filiation of various industrial fluids depending on the composition of the filter membranes.

Générale des Eaux of France put the first nano-filtration plant for drinking water into operation at Mery-sur-Oise, north of Paris, in 2000. The plant uses polymer membranes with pores less than 1 nm in diameter, a technology developed in collaboration with Dow Chemical Co. (Midland, USA). Dow markets this technology under the name Filmtec[367]. The Filmtec NF 200B membrane permits the treatment of large quantities of water at low energy costs and also ensures the removal of pesticides, organic matter, related chlorine by-products and transmission of sufficient calcium to meet the water quality standard. The nano-filtration membrane, like reverse osmosis, provides an efficient barrier to micro-organisms no matter what their size. The variable operating conditions for this membrane are entirely compatible with the treatment of large water flows from polluted rivers at seasonally changing temperatures[368].

Market data and forecasts[369]

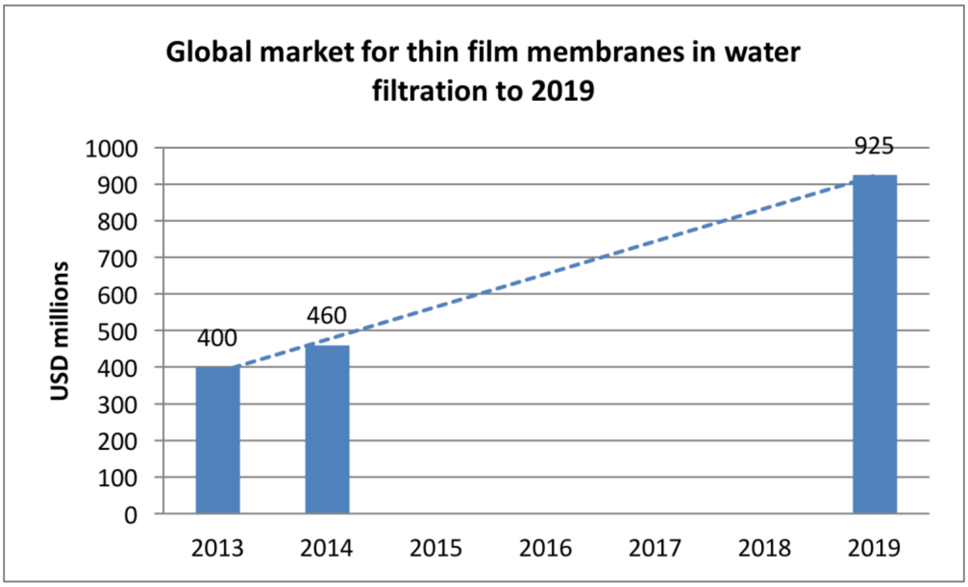
Nano-porous thin film membranes include membranes used in water filtration applications (e.g., Dow Chemical's Filmtec) and refinery separation membranes. The latter are not yet on the market in significant quantities but are expected to be commercialised before 2019.

Dow does not disclose sales data on Filmtec nano-porous polymer filtration media, but 2013 sales were estimated to have been around USD 400 million. Burgeoning global demand for potable water

[366] http://www.kochmembrane.com/Membrane-Products/Spiral/Reverse-Osmosis/Fluid-Systems-TFC-RO-Series.aspx
[367] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.61
[368] http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_003b/0901b8038003bb09.pdf?filepath=liquidseps/pdfs/noreg/016-00017.pdf&fromPage=GetDoc
[369] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.151

forms the background against which the market for nano-porous filtration membranes should be assessed. The following published statistics illustrate the magnitude of the potential market for devices such as Dow's Filmtec membranes: 1.4 billion people have no direct access to potable water. Some 80 countries, with 40% of the world's total population, are unable to ensure an adequate water supply for their citizens. Global demand for potable water is expected to increase by over 80% over the next 30 years.

Historically, sales of Filmtec membranes have been growing at a rate of about 15% per year, reflecting the growth in demand for potable water. At this rate, sales should reach USD 460 million in 2014 and USD 925 million by 2019.



Source: BCC Research, 2014

Figure 9-12: Global market for thin film membranes in water filtration to 2019

C WATER FILTRATION BASED ON CARBON NANOTUBES

Technology and products

Seldon Water (Johannesburg, South Africa) has developed an innovative technology for water purification applications. Their product Nanomesh™ is built of fused nano-structures of non-woven material that is manufactured in a scalable process using functionalised CNTs, activated carbon, and nanofibres within base sheet material. Using the immense surface area made by a carbon nanotube-based Nanomesh, this combines a large filtration area and excellent adsorption capability. This results in a facile, flow-through filter that brings maximum purification at low pressure loss[370].

Nanomesh is suitable for use in homes, offices, schools, clinics and other commercial environments. Nanomesh removes pathogens and contaminants such as viruses, bacteria, cysts and spores, delivering water that meets or exceeds the U.S. EPA Drinking Water Standard. The system delivers drinking water without the use of chemicals, heat or power, making it especially useful in developing countries, where it is most needed. Seldon is developing a new-generation Nanomesh filter to reduce or remove non-biological harmful contaminants, such as lead and cadmium, organophosphates, disinfection by-products and radioactive contaminants such as cesium-137[371].

Market data and forecasts

No market data and projection on future sales are available for water filtration products based on carbon nanotubes.

[370] http://seldonwater.com/technology/
[371] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.48

D NANO-STRUCTURED WATER DESALINATION MEMBRANES

Technology and products

In 2010, Dais Analytic Corp. (Odessa, USA) signed a USD 48 million contract to supply its NanoClear water treatment technology to China. This was the first major commercial sale of the NanoClear technology.

NanoClear uses a proprietary nanostructured polymer membrane that rejects dissolved solids, organics and biologics while allowing the permeation of water molecules from one face of the membrane to the other. Warm water at atmospheric pressure impinges on one face of the membrane, while the other face of the membrane is held at a pressure less than atmospheric. Water vapour absorbed by the membrane permeates across into the vacuum where a regenerative blower directs it onto a cold surface, where it condenses into ultraclean water.

Company snapshot: Dais Analytic

Dais Analytic Corp. is a nanotechnology company providing applications for heating & cooling, water treatment and energy storage. Their formation goes back to 1993 as Dais Corporation, but it was not until 1999 that the company was incorporated as a nanotechnology polymer materials and processes company when they purchased the assets of Analytic Power Corporation. It is located in the Tampa Bay area of Florida, U.S.A and counts with 25 employees. The revenue of the company in 2014 was USD 1.90m and came primarily from the sale of ConsERV™ cores and Aqualyte membranes. In the last 4 years their net income has been negative (-USD 1.5m in 2014). For the years ended December 31, 2014 and 2013, the company incurred research and development costs of approximately USD 763,100 and USD 676,100, respectively.

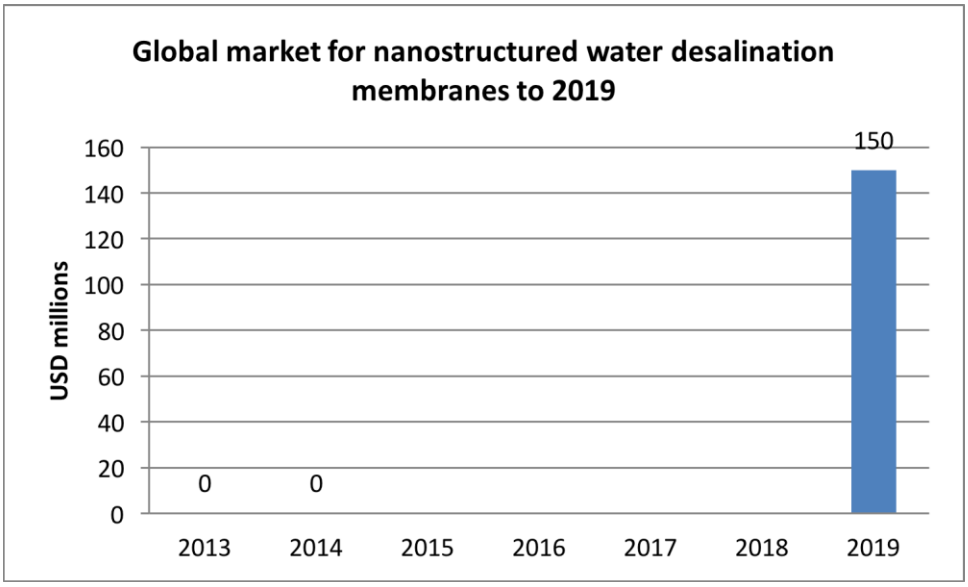
The first commercial product of the company was the energy recovery ventilator ConsERV™. Nowadays Dais Analytic Corp. includes a number of products in their portfolio such as NanoAir™ HVAC products for heating, ventilation, and air conditioning, NanoClear™ clean water systems for water treatment and desalination and NanoCap™ ultracapacitors for energy storage in a battery form. The company owns eleven US and one Chinese patent and has a substantial international impact in applied nanotechnology within the energy and water industries.

http://www.daisanalytic.com/

Market data and forecasts[372]

Dais Analytic Corp.'s 2013 Annual Report describes its water purification technology as developmental. However, BCC Research anticipates that sales of such membranes could grow to as much as USD 150 million by 2019. The latter figure is based on sales of Dow Filmtec nano-porous thin film polymer filtration media for portable water plants in 2005, five years after the Filmtec technology was introduced to the market.

[372] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.174



Source: BCC Research, 2014

Figure 9-13: Global market for nanostructured water desalination membranes to 2019

E WATER FILTRATION WITH NANOCOMPOSITES

Technology and products

Polymer nanoparticles, due to their expanded structure, exhibit both hydrophobic and hydrophilic properties based on the same principle as micelle structures. After water treatment a polymer will form a cell with several nanometres diameter inside a hydrophobic unit and a hydrophilic part outside. These polymer nanoparticles can be applied as surfactants in hydrophobic organic pollutants remediation, using the pump and treatment technology. The usage of polymer nanoparticles in purification systems is still in the research stage and needs future investigation regarding utilisation of these particular nanoparticles.

Researchers from the Department of Chemistry, Lahore University of Management Sciences (Lahore, Pakistan) have investigated the usage of magnetic functionalised polymer brush nanoparticles for mercury (Hg) ions removal from water. The group has used poly-AEMA·HCl (poly(2-aminoethyl methacrylate hydrochloride) polymer chain and Fe_3O_4 magnetic nanoparticles. This magnetic functionalised polymer brush enabled the total removal of mercury ions from water solutions. Usage of these polymer nanoparticles led to improvement of efficiency and kinetics of remediation[373].

Pardam (Pardubice, Czech Republic) has developed an innovative line of polymer (NnF MBRANE®) and ceramic (NnF CERAM®) nanofibrous materials, obtained by centrifugal spinning for various applications. Nanofibres are available in the form of powder, membrane, and a cotton-like structure. Centrifugal spinning allows the replacement of acidic solvents by water, which makes the technology environmentally friendly and also increases production capacity. As Jan Buk, Member of the Executive Board, Pardam company says[374], nanofibres can have an excellent impact on the water filtration process. Using the nanofibres in the filtration membrane can treat the metallic pollutants and various bacteria. For example polyacrylonitrile (PAN) and polyvinyl alcohol (PVA) nanofibres[375] with silver nanoparticles exhibits excellent antimicrobial reactivity. Investigations of these nano-fibrous polymers showed excellent antimicrobial activity of PVA-silver nanofibres within nontoxic and biodegradable properties of synthetic PVA.

LG NanoH2O[376] (Los Angeles, USA) has developed a nanocomposite technology designed to increase the efficiency of membrane-based water desalination and other purification systems by increasing

[373] http://www.ncbi.nlm.nih.gov/pubmed/23570443
[374] Interview with Mr Jan Buk, Member of the Executive Board, Pardam, June 22 2016 (http://www.pardam.cz/)
[375] http://www.ncbi.nlm.nih.gov/pubmed/25627790
[376] NanoH2O was acquired by LG Chem in 2014

water throughput at a given pressure[377]. LG NanoH2O manufactures seawater and brackish water reverse osmosis (RO) membranes that lower the cost of desalination. Based on breakthrough nanostructured materials and industry-proven polymer technology, LG NanoH2O's RO membranes dramatically improve desalination energy efficiency and productivity. Standard 61 certified by NSF International for the production of drinking water, these membranes deliver best-in-class flux and rejection, and are available in standard 8-inch (20 cm) diameter elements that fit easily into new and existing desalination plants, purifying water from a broad range of sources with improved productivity and water quality. More than 400 commercial sites in over 50 countries have installed LG NanoH2O's RO membranes for their desalination systems[378].

Market data and forecasts

LG NanoH2O's QuantumFlux nanocomposite water desalination membranes entered the market in 2011 and have since been installed in over 100 plants around the world. By 2019, LG NanoH2O's membranes will compete with Dais Analytics' NanoClear nanostructured polymer membranes (see above) and other non-nano technologies for a share of the reverse osmosis/nano-filtration membrane market, which is estimated to grow to as much as USD 1.5 billion per year by 2019. Sales of LG NanoH2O's nanocomposite membranes are expected by some forecasters to rival sales of NanoClear (i.e., USD 150 million) by 2019[379]. (See also previous section on water desalination membranes).

Company snapshot: Tersus Environmental LLC

Tersus Environmental develops and markets advanced technologies for the remediation of soil and groundwater. The company is headquartered in Cheyenne, Wyoming (US). Its product portfolio specialises in enhanced anaerobic bioremediation, and offers solutions for the bioremediation of halogenated straight-chain and aromatic hydrocarbons, perchlorate, explosives such as aromatic nitrates, energetic munitions residuals, nitrates, acids, radionuclides, oxidized metals, and other contaminants.

The company also provides technical support, training, and business development for technology leaders in the field of in situ soil and groundwater remediation.

Regarding nanotechnology, Tersus Environmental commercialises emulsified nano zero-valent iron (eZVI) (a NASA developed and patented technology). This product is a modified form of bare nano-iron with improved transportability and targetability for the remediation of organic-solvents in soil and groundwater.

http://www.tersusenv.com/en/

9.3.2.4 Sensors

Products and technology

A SENSORS BASED ON NANOPARTICLES

In 2003, scientists at California Institute of Technology (Caltech) (Pasadena, USA) patented a nanoparticle-based chemical "electronic nose". Caltech's electronic nose consists of an array of 20 electrically conducting carbon black loaded polymers, all fitted within a small space. The carbon black gives the sensors conducting properties; the polymer matrix provides sensitivity to vapour bound compounds (odorants). Odorant caused swelling of the polymer decreases the number of conducting pathways through the carbon black percolation network, increasing its resistivity. The change in resistivity is linearly related to the concentration of the various odorants. Each of the sensors is broadly tuned to a given region in solubility space. By combining the responses of all sensors with principal component analysis Caltech's electronic nose is capable of resolving specific odorants form complex mixtures, and provide an indication of their concentration at levels superior than the human nose. Combined with robotics the electronic nose is capable of imparting directional

[377] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.88
[378] http://www.desalination.biz/59757/d/LG-NanoH2O-Inc
[379] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.180

control to a robot even in the presence of a mild wind. Search and target acquisition strategies have been modelled after the behaviour of rats in control laboratory experiments.[380].

Earlier, media reports had indicated that Sony is working on an electronic nose device as part of a collaborative project with the Max Planck Institute. According to the reports, the "E-Nose" will use nanoparticles. The sensor, which has been used to distinguish among different types of coffee by their aroma, is expected to have applications in the robotic industry. The latter is apparently the same as or similar to the device patented by Sony in 2002 (U.S. Patent No. 6458327, "Electronic device, especially chemical sensor, comprising a nanoparticle structure")[381].

Researchers at the Louisiana State University (Baton Rouge, USA) have studied polyaniline nanowires for use as chemi-resistive sensors. These polyaniline nanowires have a unique chemical backbone structures. Some of the attributes which enable the adoption of nanowires in the chemical sensing industry include high sensitivity and fast response while preserving simplicity and high density. Other reasons why polyaniline nanowires are potential nano-sensors is the presence of a small cross-sectional area that maximises the current response. Due to the axial arrangement of the nanowires these also help create a change in conductance. The team of researchers have tested the nanowire for use in label-free detection of analytes with accurate sensitivity and real time monitoring[382].

A team at the University of Brescia (Brescia, Italy) has developed metal oxide nanowires for use in chemical sensors. Metal oxide is preferred as chemical sensors due to variation in electrical conductivity with the composition of the surrounding gas atmosphere. Titanium dioxide and zinc oxide are some of the metal oxides which are successfully used as chemical sensors. Some attributes which these metals impart include high selectivity and unique stability that has not been obtained in any other nanomaterial used yet. The lowering of crystallite size significantly enhances the sensing efficiency. In these chemical sensors the conduction is governed only by the few thermal activated carriers. As the nanomaterial comes in direct contact with the gas sample to be monitored, a non-activated carrier results in high sensor conductance and better sensing. Some of the properties which enable metal nano-oxides to perform over other traditional chemical sensors include very large surface-to-volume ratio, dimensions comparable to the extension of surface charge region and superior stability owing to the high crystallinity[383].

A team at the University of Massachusetts (Amherst, USA) developed gold nanoparticles for use in both chemical and biological sensing. Gold nanoparticles (AuNPs) are made into scaffolds and fabricated into nano sensors. These nanoparticles possess unique chemical properties which make them ideal materials for biological nanosensors. Gold nanoparticles can be manufactured easily and this enables large scale manufacturing of such sensors. Gold nanoparticles have better optoelectronic properties in comparison to many other nanoparticles, even nanowires which make these ideal candidates for biological or chemical sensing[384].

Sensigent Inc. (Dover, USA) has developed a chemical sensing technology that consists of nanosensors made for small molecule sensing such as gases, acids, bases and many other compounds. Sensigent uses proprietary materials such as nanocomposites, conducting polymers, metallic and non-metallic nanoparticles to develop the chemical nanosensors. For example Sensigent's nanocomposite sensor technology is particularly sensitive to volatile organic compounds (VOCs) over a wide range of vapour pressures and concentrations. The sensors are compact and reliable and are used in arrays. The life of these sensors has been guaranteed by the company for 10 years without any maintenance or need for replacement. The sensors function in a broad range of challenging industrial environments and applications[385].

INanoBio LLC (Tempe, USA) has developed the FDEC FET nano-sensor in collaboration with Arizona State University. The novel nano sensor technology is highly selective and capable of exponential capacitive transduction for ultra-high sensitivity molecular detection. INanoBio LLC has strictly protected their technology but mention that the nano-sensor can be used for both chemical as well

[380] http://www.wag.caltech.edu/home-pages/mario/enoseabs.htm
[381] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.43
[382] http://www.mdpi.com/2079-4991/3/3/498/htm
[383] http://www.sciencedirect.com/science/article/pii/S1369702110701267
[384] http://pubs.acs.org/doi/abs/10.1021/cr2001178
[385] http://www.sensigent.com/chemical.html

as biological sensing activities. Industries where these sensors would have a positive impact include health care diagnostics, industrial leak detection systems and security[386].

B SENSORS BASED ON CARBON NANOTUBES

Nanomix Inc. (Emeryville, USA) has developed a chemical sensing technology (called "Sensation") that integrates carbon nanotube sensing elements with CMOS technology on a silicon chip. Such sensor chips offer ultrahigh sensitivity in a small package and provide key cost and performance benefits vis-à-vis conventional chemical sensor technologies. Nanomix has commercialised several products that incorporate the Sensation technology, including respiratory monitors and industrial gas leak detectors[387].

A nano-sensor technology has been developed by researchers at NASA using single walled carbon nanotubes (SWNTs), combined with a silicon-based microfabrication and micromachining process. This technology provides a sensor array that can accommodate different nanostructures for specific applications with the advantages of high sensitivity, low power consumption, compactness, high yield and low cost. These current sensor development results have proved that the carbon nanotube sensors can offer very high sensitivity for NO_2 , ammonia, methane, acetone, benzene and toluene detection, with detection limits in the lower parts per million (ppm) to parts per billion (ppb) level and response time in seconds to minutes. Each sensor draws the power in microwatts to milliwatts. The size of the detector is designed to be 5 inch x 5 inch x 1 inch for 32 sensing elements detection system. The weight of this detector will be less than 2 kg[388].

Market data and forecasts

The market for nanosensors is at a nascent stage, with negligible sales in 2013 and 2014. It is estimated that the market could reach at least USD 60 million by 2019[389].

[386] http://www.inanobio.com/aboutus.php
[387] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.102
[388] http://www.nasa.gov/centers/ames/research/technology-onepagers/gas_detection.html
[389] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.194. (IAS027C MEMS: Biosensors and Nanosensors)

Company snapshot: NevadaNano

Founded in 2004 as a start-up that grew out of the University of Nevada, Reno (US), NevadaNano (Nevada Nanotech Systems, Inc.) develops and manufactures micro-electro-mechanical systems (MEMS)-based sensor modules and subsystems for a diverse array of commercial and government applications.

Early R&D was supported by DARPA, the DOD, and the Department of Homeland Security, but NevadaNano turned its focus to commercial applications. Specifically, NevadaNano specialises in a broad range of sensor applications. The core element of NevadaNano's sensor modules and systems is manufactured on a solid-state MEMS technology, offering small size, low cost, and high reliability. The sensing element is an array of MEMS structures that are not only self-activating and self-sensing, they are also self-cleaning and self-calibrating, thus enabling unattended deployment for extended periods. Using proprietary materials as well as unique sensing methods and analysis techniques, a single sensor configuration is able to detect hundreds of diverse types of vapours and particles. NevadaNano has grown from five to just over 20 employees, spending over USD 13 million (EUR 11.7 million) in R&D (2004-2014).

In 2014, NevadaNano and the University of Nevada were awarded US Army funding to develop a robotic flying vehicle that can be used for environmental health and safety monitoring of large areas. It is being developed to detect environmental threats in vapour form using interchangeable, on-board sensors. With real-time data collected and analysed by the sensors, it will be capable of swarming with other units during surveillance of a given area to, for example, localise and profile a contaminant source, such as toxic industrial chemicals and materials, semi-volatile and volatile organic compounds (pesticides, ammonia and explosives), and chemical or biological agents.

http://www.nevadanano.com/
http://www.nanowerk.com/news2/robotics/newsid=34680.php

The next section looks at the wider environment for nanotechnology in relation to the environment – regulation and standards, environmental health and safety issues, communication and public attitudes.

10 THE WIDER ENVIRONMENT FOR NANOTECHNOLOGY AND ENVIRONMENT

10.1 Regulation and standards for nanotechnology and environment

10.1.1 European Union regulations

The European Union regulatory framework for environmental protection covers the use of nanotechnologies in a number of acts. These have been designed by the Environment Directorate-General of the European Commission which has also dedicated specific efforts to the assessment of the regulatory framework on nanomaterials. Two regulatory reviews in 2008[390] and 2012[391], which may be followed by a third regulatory review in 2016, have assessed the role of different pieces of regulation and set targets for further steps.

REACH

The regulatory reviews have confirmed the overarching regulatory framework in place for chemical substances as the main act to regulate nanomaterials: *Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)*. *"There are no provisions in REACH referring explicitly to nanomaterials. However, nanomaterials are covered by the 'substance' definition in REACH",* states the 2008 Communication. In 2012, the Commission reiterated the statement and committed to modify the REACH annexes while inviting the European Chemicals Agency (ECHA) to develop further guidance regarding nanomaterials.

Since the summer of 2013, there has been ongoing work to adapt the Annexes of REACH to specifically cover nanomaterials; an impact assessment and a large consultation on this issue have been run by the European Commission but discussions are still ongoing. The rules of ECHA however prevent the modification of the regulation two years prior to the next round of registration which is set in June 2018. A modification of the REACH annexes is therefore very unlikely before that date. This rule also applies to guidance documents that the Agency provides to support registrants; in 2016, ECHA nevertheless announced that four guidance documents related to nanomaterials would be released in May 2017, one year prior to the next registration deadline. These are:

- Guidance on nanoforms;
- Guidance on information requirements for nanomaterials for human health;
- Guidance on information requirements for nanomaterials for the environment; and
- Guidance on read-across for nanoforms.

RECOMMENDATION ON THE DEFINITION OF A NANOMATERIAL

One of the milestones of the European regulatory framework for nanotechnologies is the *European Commission Recommendation on the Definition of a Nanomaterial (2011/696/EU).* This non-binding document has been used by other pieces of regulation that needed to define the term 'nanomaterial'.

The definition is the following:

" 'Nanomaterial' means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %."

Developed in 2011, this definition is undergoing a review process that should have been concluded in December 2014; an outcome of this review could be a revision of the definition. The process of review of this definition is still ongoing.

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[390] European Commission. 2008, *Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee - Regulatory aspects of nanomaterials [SEC(2008) 2036].* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0366:FIN:en:PDF

[391] European Commission. 2012, *Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee - Second Regulatory Review on Nanomaterials.* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0572:FIN:en:PDF

Biocidal product regulation

Nanomaterials are also covered in the Biocidal Product Regulation (BPR) (EU/528/2012). Applicable since 1 September 2013, it requires a dedicated risk assessment when a nanomaterial form of an active or non-active substance is used in a biocidal product. Such biocidal products must also be labelled and indicate the name the nanomaterial followed by the word "nano" in brackets. In addition, the simplified procedure for authorisation introduced in the BPR is not applicable for nanomaterials.

Other environmental regulations

While considering that 'all environmental regulation reviewed could be considered to address nanomaterials in principle', the second regulatory review states that classifications under the *Regulation for the Classification and Labelling and Packaging of Substances and Mixtures (CLP) EU/*1272/2008 are the main trigger of pollutant identification.

The Second Regulatory Review was supported by a *Review of Environmental Legislation for the Regulatory Control of Nanomaterials*[392]*.* Conducted in 2011 by the environmental consultancy Milieu, the study had a specific look at nanomaterials in environmental regulation; a thorough analysis of the following pieces of legislation was undertaken:

- Waste Framework Directive 2008/98/EC
- Decision 2000/532/EC on the List of Waste
- Directive 2000/53/EC on end-of-life vehicles
- Landfill Directive 1999/31/EC
- WEEE Directive 2002/96/EC
- Directive 2002/95/EC on RoHS
- Packaging and Packaging Waste Directive 1994/62/EC
- Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when the sewage sludge is used in agriculture (Sewage sludge Directive)
- Water Framework Directive 2000/60/EC
- Directive 2008/105/EC on EQS in the Field of Water Pollution
- Directive 2006/118/EC on the protection of groundwater against pollution and deterioration
- Urban Waste Water Directive 91/271/EEC
- Drinking Water Directive 98/83/EC
- Directive 96/82/EC on the control of major-accident hazards involving dangerous substances (Seveso II Directive)
- Air Quality Directive 2008/50/EC
- Regulation (EC) No 66/2010 on the EU Ecolabel

In principle, the consultants found that nanomaterials fall under these regulations. However, the report notes that only a few of the aforementioned acts list or precisely refer to these substances; these are:

- *The WEEE Directive 2002/96/EC,* this directive requires the European Commission to consider nanomaterials when reviewing Annex VII - Selective treatment for materials and components of waste electrical and electronic equipment referred to in Article 8(2) of the Directive. At the moment, nanomaterials have not been addressed in this annex.

- *The Directive 2002/95/EC on RoHS,* this directive revised in 2011 as the *Directive on the restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS2) - 2011/65/EU.* RoHS2 restricts the use of hazardous materials for electronic and electronical materials and mentions nanomaterials. In the absence of scientific evidence that nanomaterials have hazardous properties, the European institutions are invited to consider such substances during the process of reviewing Annex II – List of Restricted Substances. Between late 2012 and June 2014, Environment Agency Austria (Umweltbundesamt) had been tasked with writing up a methodology for the review of the List of Restricted Substances under RoHS2. This methodology does not prioritise nanomaterials, but assessors are still invited to be cautious when dealing with such substances.

- *The Regulation (EC) No 66/2010 on the EU Ecolabel* sets the rules for the award of the European environmental quality 'ecolabel'. It excludes products containing hazardous substances but has

[392] http://ec.europa.eu/environment/chemicals/nanotech/pdf/review_legislation.pdf

no rules regarding nanomaterials. However, in 2014, a decision by the European Commission excluded nanosilver from eligibility for the EU Ecolabel for rinse-off cosmetic products[393]. Other decisions[394] have added requirements for information regarding the state and physical form of substances used in the final product.

In addition, a specific study was commissioned by the EU to tackle the coherence of waste legislation[395]. Compiled in 2011 by Bio Intelligence Service, the study lists nano-waste as one of the waste streams with potentially inadequate coverage. The report also features a section dedicated to nanomaterials and considers that "adaptation of EU waste policy might be required in the future to take into account possible new risks identified".

While regulations covering cosmetic products, food contact materials and novel foods also target nanomaterials, these do not address environmental issues.

Nanomaterial registries

While the EU has been developing a regulatory framework for nanomaterials under REACH, some European Member States have sought to find additional ways to define and regulate nanotechnologies. In recent years, databases and reporting schemes for nanomaterials have been developed in Europe. Whilst these are not specific to the market sector covered by this report, they are still relevant to the regulation of nanotechnologies.

Under the Belgian Presidency of the European Union, in 2010, the EU has opened the discussion on a "harmonised database of nanomaterials"; it was followed by a 2012 letter to the European Commission calling for a European Reporting Scheme and signed by 10 EU Member States, plus Croatia. The European institutions are still weighing the pros and cons of such a reporting scheme; nevertheless, some EU Member States have been going forward.

Belgium

The Belgian FPS (Public Health, Food Chain Safety and Environment) has been working on a similar scheme: in February 2014, the Belgian Council of Ministers validated the Royal Decree regarding the Placement on the Market of Substances manufactured at the Nano-scale (*Koninklijk besluit betreffende het op de markt brengen van als nanodeeltjes geproduceerde stiffen* or *Arrêté royal relatif à la mise sur le marché des substances manufacturées à l'état nanoparticulaire*). The registration of substances began on 1 January 2016, while mixtures will have to be registered from 1 January 2017.

The definition of nanomaterials used is that of the EC Recommendation 2011/696/EU, but excluding naturally occurring and incidental nanomaterials, as well as pigments. Also excluded are nanomaterials which fall under other EU legislation (e.g. biocides, food products).

Denmark

Following a public consultation, the Danish Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register - BEK nr 644 came into force in June 2014. With this Order, the Ministry of the Environment creates a national mandatory database of nanomaterial-containing products that will register the first products for the year 2014 in the year 2015. The definition of nanomaterials included in the executive order follows the European Commission definition.

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[393] European Commission. 2014, *Commission Decision of 9 December 2014 establishing the ecological criteria for the award of the EU Ecolabel for rinse-off cosmetic products (notified under document C(2014) 9302).* Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.354.01.0047.01.ENG

[394] European Commission. 2012. *Commission Decision of 14 November 2012 establishing the ecological criteria for the award of the EU Ecolabel for Industrial and Institutional Automatic Dishwasher Detergents.* Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012D0720-20121201 and European Commission. 2012. *Commission Decision of 14 November 2012 establishing the ecological criteria for the award of the EU Ecolabel for Industrial and Institutional Laundry Detergents (notified under document C(2012) 8055).* Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012D0721-20121201

[395] Bio Intelligence Service, 2011, *Study on coherence of waste legislation – Final Report*, DG ENV. Available at: http://ec.europa.eu/environment/waste/studies/pdf/Coherence_waste_legislation.pdf

Certain activities or products are excluded from the registration requirement: nano-products sold between businesses and products that fall under specific regulations (e.g. food, feed, pharmaceuticals, medical devices, cosmetics, pesticides and waste). The following specific products in which nanomaterials are used are also excluded:

- Nano-sized products of substances in REACH Annex V
- Products where the material is not consciously produced in nano-size
- Products where the nanomaterial is in a fixed matrix
- Products where the nanomaterial is used as printing ink directly on the product or on labels on the product
- Textiles where the nanomaterial is used as printing ink or to colouring of the textile
- Paints and wood protection products containing titanium dioxide where the sole purpose for the titanium dioxide is to colour the product
- Products of rubber or rubber parts that contain the nanomaterials carbon black or silicon dioxide.
- Products imported for private use
- Products used for research and development.

FRANCE

As part of the electoral promises of the 2007 Presidential Elections, the 'Grenelle de l'Environnement', a large environmental debate was organised in France and resulted in major environmental acts: *Grenelle Acts (Lois Grenelle I & II)* which enacted the future creation of a mandatory reporting scheme for nanomaterials. France hence took steps towards setting up the first registration scheme for substances at the nano-scale in Europe; in 2012, the Decree[396] on the annual declaration on substances at nano-scale - 2012-232 was published; it came into force on 1 January 2013. It grants to the French Agency for Food Safety, the Environment and Labour (ANSES) the authority to collect "information from a production, distribution, import of nano-scale substances of 100 grams"*.* The French legislation refers to, and is applicable to, substances as defined in article 3 of EC Regulation no. 1907/2006 (REACH), that are intentionally produced at nanometre scale, containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for a minimum proportion of particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm. Furthermore: "in specific cases and where warranted by concerns for the environment, health, safety or competitiveness, this minimum proportion may be reduced".

A Joint Order (Ministerial Order of 6 August 2012) issued by the Ministers of environment, agriculture, health labour and industry states that "The minimum proportion of the number size distribution is specified to be 50%".

OTHER EU MEMBER STATES

Other EU Member States have been considering options for a registration scheme for nanomaterials. Sweden has given the mandate to its chemical agency (KEMI) to develop a reporting scheme; in the spring of 2016, KEMI declared that it aimed at establishing a Swedish registry in 2019 which would register manufactured and imported quantities during 2018. Italy is also considering setting up a similar system.

With these initiatives, EU Member States have been pushing the European Commission to act; the Second Regulatory Review on Nanomaterials of 2012 included an impact assessment of potential transparency measures which include approaches similar to the reporting schemes set in action in several Member States. The *Study to Assess the Impact of Possible Legislation to Increase Transparency on Nanomaterials on the Market* was led by consultancies Risk & Policy Analysis (RPA) and BiPRO; three reports were published to help the EC decide on an eventual EU-wide registry of nanomaterials. *Early in 2016, the European Commission has stated that it will not go forward with an EU-wide nanomaterial registry but would rather support the establishment of a knowledge base entitled the 'nanomaterials observatory' which would contain publically available information on nanomaterials and their use in Europe.*

The table below lists some key regulatory documents within the European Union as a whole and within Member States.

[396] Décret n° 2012-232 du 17 février 2012 relatif à la déclaration annuelle des substances à l'état nanoparticulaire pris en application de l'article L. 523-4 du code de l'environnement

Table 10-1: Overview of regulations for nanotechnology use in Europe

Status	Name of the document	Country/ Region	Scope	Nano-specific
Implemented	Regulation concerning REACH - 1907/2006(EC)	EU	Chemicals & Raw Materials	No, but 'substance' covers nanomaterials
Implemented	European Commission Recommendation on the Definition of a Nanomaterial	EU	Substances at the nanoscale	Yes
Implemented	Decree on the annual declaration on substances at nano-scale - 2012-232	France	Substances at the nano-scale	Yes
Implemented	Royal Decree regarding the Placement on the Market of Substances manufactured at the Nano-scale	Belgium	Substances manufactured at the nano-scale	Yes
Implemented	Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register – BEK no. 644	Denmark	Nanomaterials	Yes

10.1.2 Nanotechnology regulation in the rest of the world

Environmental protection is the main driver for the development of regulation directed to nanomaterials.

OTHER EUROPEAN COUNTRIES

NORWAY

Norway developed a register under its Pollution Control Authority (SFT). From 2013, chemical products must be registered in the Norwegian Product Register of Chemicals at the Norwegian Environment Agency, which includes chemicals that are classified as dangerous, and whose quantity produced in/imported to Norway and/or placed on the market each year is 100 kg or more. Registrants are required to provide information on chemicals containing "a substance in nano form" with a 'tickbox' system

If the chemical contains nanomaterials this must be declared in the registration, and information on any substance in nano form must be given for all mandatory declared chemicals, including the identity of the constituent that is in nano form. Only intentionally added nanomaterials need to be registered in the Norwegian Product Register of Chemicals, and the definition of nanomaterials follows the EC Recommendation 2011/696/EU.

SWITZERLAND

The Swiss Secretariat for Economic Affairs (SECO) published a guideline document for the compilation of safety data sheet for synthetic nanomaterials, with as definition:

"A material whose particle size distribution includes over 1% nanoparticles (1-100 nm) in an unbound state, either as an aggregate or as an agglomerate. Fullerenes, graphene flakes and single-wall carbon nanotubes are classed as nanomaterials even if they have dimensions of less than 1 nm. Should the particle size distribution not be known, then any material with an average grain size less than 500 nm will be classed as a nanomaterial"

The definition adopted, as explained in the guideline, is mainly based on the definitions of nanomaterial of the 2011/696/EU Recommendation1 and on the ISO definition CEN ISO/TS 27687.8 The differentiation between nano-particles, nano-fibres and nano-plates and the definition of agglomerates and aggregates (not cited here) are adopted from the ISO definition.

Two important aspects of this definition: the percentage used for the particle size distribution (1% versus 50% of the EC recommendation) and the 500 nm upper size limit to be used when the PSD is unknown. The adoption of 500 nm as upper size limit is justified by the following considerations: a) in size distributions of manufactured nanomaterials (MNM) with a maximum at 500 nm, a large fraction of the MNM can still be in the low nm range; b) potential nano-specific interaction with cells can occur for sizes < 300 nm.

legislation that may be applied to vehicles in Europe: the RoHS2 and WEEE directives enacting restrictions for the use of certain hazardous materials have been adapted in numerous countries outside of Europe (i.e. Argentina, China, Vietnam, the State of California, India etc.), but do not specifically target nanomaterials.

THE AMERICAS

UNITED STATES OF AMERICA

In the United States of America, the *Toxic Substances Control Act (TSCA)* is the main chemical regulation. The US Environmental Protection Agency (EPA) is in charge of adapting this regulation to nanoscale materials (the US authorities have decided not to write a binding definition of a nanomaterial). The latest regulatory initiative was taken by US EPA in April 2015 with the publication of a proposed rule for section 8 (a) of TSCA*.* This proposal would introduce reporting and recordkeeping requirements for nanoscale materials as well as a 135-days pre-notification requirement for the manufacturers of "chemical substances as discrete nanoscale materials". The inclusion of a new rule addressing nanomaterials under TSCA is intended to be promulgated in the fall of 2016.

CANADA

In Canada, Health Canada and Environment Canada require manufacturers and importers to register information on a selection of 206 substances at the nanoscale under the *Canadian Environmental Protection Act (CEPA 1999*). Health Canada published a "Policy Statement on Health Canada's Working Definition for Nanomaterials" (2011)[397].

OTHER

AUSTRALIA

The Australian National Industrial Chemicals Notification and Assessment Scheme (NICNAS) covers nanomaterials: nanoforms of substances in the Australian Inventory of Chemical Substances may be used and introduced in Australia while nanomaterials that are "new substances" are submitted to notification and assessment procedures. It is worth noting that the Australian regulations rely on a NICNAS working definition of "industrial nanomaterial" which reads as follows:

"…industrial materials intentionally produced, manufactured or engineered to have unique properties or specific composition at the nanoscale, that is a size range typically between 1 nm and 100 nm, and is either a nano-object (i.e. that is confined in one, two, or three dimensions at the nanoscale) or is nanostructured (i.e. having an internal or surface structure at the nanoscale)".

In 2016, NICNAS published a consultation on its reform initiative. The publication includes criteria for classifying materials as hazardous if it is a nanomaterial. This reform initiative also suggests that safety data sheets are provided to workers handling nanomaterials (even if they are not classified as hazardous substances) and that nanomaterials are labelled as *"caution: hazards unknown" or "caution: hazards not fully characterised"*.

SOUTH KOREA

The Republic of South Korea has established the "National Nano-safety Strategic Plan (2012/2016)".

[397] http://www.hc-sc.gc.ca/sr-sr/pubs/nano/pol-eng.php

The Ministry of Knowledge and Economy and the Korean Agency for Technology and Standards, published in 2011 a "Guidance on safety Management of Nano-based products", (Korean Agency for Technology and Science Public Notice No.2011-0108 of 12 May 2011).

Taiwan (Chinese Taipei)

Under the Council of Labour Affairs, Taiwan addresses nanomaterials within the context of Chemical Substance Nomination & Notification (2012)[398].

OECD

Efforts to regulate nanomaterials are harmonised globally at the Organisation for Economic Co-operation and Development (OECD). Under the Working Party on Manufactured Nanomaterials, the OECD has a testing programme on manufactured nanomaterials. The organisation promotes its system of Mutual Acceptance of Data and develops Guidelines for the Testing of Chemicals that specifically address endpoints adapted to nanomaterials.

10.1.3 Standards

ISO

At the International Organisation for Standardisation (ISO), environmental issues are addressed in the ISO 14000 family of standards, developed in ISO/TC 207 Environmental Management. Nevertheless, these do not directly address the use of nanotechnologies.

In its scope ISO/Technical Committee (TC) 229 Nanotechnologies includes the development of “standards for: […] science-based […] environmental practices”. Work package 3 of the TC specifically addresses Health, Safety and Environmental Aspects of Nanotechnologies. It has developed a number of technical specifications and technical reports addressing risks raised by nanomaterials for the environment and aiming at standardising test and toxicity assessment methods. For example, the technical committee has produced the following documents relevant to environmental protection:

- ISO/TR 13121:2011 Nanotechnologies — Nanomaterial risk evaluation.
- ISO/TR 16197:2014Nanotechnologies -- Compilation and description of toxicological screening methods for manufactured nanomaterials.
- ISO 29701:2010 Nanotechnologies -- Endotoxin test on nanomaterial samples for in vitro systems -- Limulus amebocyte lysate (LAL) test.

Work on environmental issues continues at ISO/TC 229. WG3 is currently working on an approved work item on *Nanotechnologies -- Considerations for the measurement of nano-objects, and their aggregates and agglomerates (NOAA)* in the environment and another one on *Nanotechnologies: Aquatic Toxicity Assessment of Nanomaterials in salt water lakes using Artemia sp.*

CEN

In Europe, the European Committee for Standardisation on nanotechnology (CEN/TC 352) mirrors the structure of ISO/TC 22: in WG3 - Health, safety and environmental aspects, the technical committee is currently developing a number of documents relevant to environmental protection, these are:

- CEN/TS (PWI 00352011) "Nanotechnologies – Guidelines for aspects of Life Cycle Assessment specific to nanomaterials"
- CEN/TS (PWI 00352012) "Nanotechnologies – Guidance on detection and identification of nano-objects in complex matrices"
- CEN/TS (PWI 00352013) "Nanotechnologies – Guidelines for determining protocols for the explosivity and flammability of powders containing nano-objects (for transport, handling and storage)"
- CEN/TS (PWI 00352014) "Nanotechnologies – Guidelines for the management and disposal of waste from the manufacturing and processing of manufactured nano-objects"
- CEN/TS (PWI 00352023) "Manufactured nanomaterials (MNMs) in the construction industry.

[398] This legislation was reformed in 2013 with the Toxic Chemical Substance Control Act (TCSCA) but, at the moment, it is not clear how nanomaterials will be affected

Guidelines for occupational risk management".

10.2 Environment, health and safety and nanotechnology

10.2.1 Introduction

Not much is known about exposure of humans to nanomaterials in the environment sector. CNT was identified for use in water filtration systems and nanosensors implemented to monitor environmental parameters. Also other nanomaterials (e.g. Ni, Pt, Au, Si, InP, GaN) are used in nanosensors. Nanosensors were evaluated as part of the ICT sector (see NanoData Landscape Compilation: ICT), and are therefore not further discussed here. Furthermore, nano-remediation was identified as an important environmental application. Various nanomaterials, such as nanoparticles, tubes, wires, fibres, function as adsorbents and catalysts and their composites with polymers are used for the detection and removal of gases (e.g. SO_2, CO, NO_x), chemical contaminants (e.g. arsenic, iron, manganese, nitrate, heavy metals), organic pollutants (aliphatic and aromatic hydrocarbons) and biological substances, such as viruses, bacteria, parasites and antibiotics[399]. Examples of nanomaterials applied are cobalt manganese oxide nanoparticles, synthesised *in situ* in pressurised reactors for the supercritical water oxidation process to clean waste water of organics; zero-valent iron in permeable reactive barriers and silver, iron, gold, iron oxides and titanium oxide in polymeric membranes to remove metals and other contaminants from wastewater; nanofibres (silica, dendrimers, CNTs) in nanofibre media and membranes used for filtration; nano-zeolites and dendrimers functionalised with inorganic nanoparticles, used as sorbents to remove heavy metals from wastewater[400]. Another nanomaterial used in remediation, is nano-calcium peroxide, which is applied in *in situ* chemical oxidation (ISCO) of contaminated ground water, sediment or soil in order to destroy the contaminants by converting them to innocuous compounds[401].

The basis for the evaluation was the "Stoffenmanager Nano" application[402] [403], a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios. This tool combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. "Stoffenmanager Nano" does not contemplate the dermal and oral routes of exposure. The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in production facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries[404]. The dermal route may be the main route of exposure for some substances or exposure situations, and cause local effects on the skin or systemic effects after absorption into the body[405]. However, nanoparticles as such are very unlikely to penetrate the skin[406], and consequently nano-specific systemic toxicity via the dermal route is improbable. Therefore, when evaluating nano-risks for the respiratory route, the most important aspects of occupational safety are covered.

Currently version 1 of Stoffenmanager Nano is being updated with recent data and insights. The hazard of six metal oxide nanoparticles has been reassessed and their hazard bands have been updated. This revision is based on more recent toxicity data to attribute the hazard bands according

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[399] Khin, M.M., Nair, A.S., Babu, V.J., Murugan, R., Ramakrishna, S., 2012. A review on nanomaterials for environmental remediation. Energy Environ. Sci. 5, 8075. doi:10.1039/c2ee21818f

[400] Ibid

[401] Khodaveisi, J., Banejad, H., Afkhami, A., Olyaie, E., Lashgari, S., Dashti, R., 2011. Synthesis of calcium peroxide nanoparticles as an innovative reagent for in situ chemical oxidation. J. Hazard. Mater. 192, 1437–40. doi:10.1016/j.jhazmat.2011.06.060

[402] Marquart, H., Heussen, H., Le Feber, M., Noy, D., Tielemans, E., Schinkel, J., West, J., Van Der Schaaf, D., 2008. 'Stoffenmanager', a web-based control banding tool using an exposure process model. Ann. Occup. Hyg. 52, 429-441

[403] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541

[404] ECHA, 2012. Chapter R.14: Occupational exposure estimation in: Anonymous Guidance on Information Requirements and Chemical Safety Assessment., Version: 2.1 ed. European Chemicals Agency, Helsinki, Finland.

[405] Ibid

[406] Watkinson, A.C., Bunge, A.L., Hadgraft, J., Lane, M.E., 2013. Nanoparticles do not penetrate human skin - A theoretical perspective. Pharm. Res. 30, 1943-1946

to the methodology described in the ISO guideline on the use of the control banding approach in occupational risk management of engineered nanomaterials[407] [408]. It has been published in a TNO-report[409]. Hazard bands for the nanoparticles listed in the table below are taken by preference from this report and, if not available in that report, from van Duuren-Stuurman et al. (2012). If a nanoparticle in the list has not been evaluated in either publication, data were collected from public literature to derive its hazard band, as described in the section on hazard assessment below.

10.2.2 Hazard assessment

In the ISO guidelines the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). In essence, it applies the toxicity classification rules of the Globally Harmonised System (GHS)[410] to establish the hazard band.

The table below lists the criteria to allocate hazard bands per toxicity endpoint.

[407] This approach is very similar to the Stoffenmanager version 1.0 approach.

[408] ISO, 2013. Nanotechnologies -- Occupational risk management applied to engineered nanomaterials -- Part 2: Use of the control banding approach, ISO/PDTS 1. ed. International Organisation for Standardisation, Geneva, Switzerland. doi:http://www.iso.org/iso/catalogue_detail.htm?csnumber=53375

[409] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles.

[410] UN, 2015. Globally Harmonized System of Classification and Labelling of Chemicals (GHS). United Nations, New York, USA and Geneva, Switzerland

Table 10-2: Allocation of hazard bands per toxicity endpoint to nanomaterials insoluble in water

Toxicity category	Hazard band				
	A No significant health hazard	B Slight Hazard	C Moderate Hazard	D Serious hazard	E Severe hazard
Acute toxicity: LC_{50} inhalation 4H (mg/m^3) (Aerosols/particles)	Low >5000	Acute tox 4 1000-5000	Acute tox 3 500-1000	Acute tox 1-2 <500	-
Severity of acute (life-threatening) effects		STOT SE 2-3; Asp. Tox 1	STOT SE 1	-	-
Respiratory Sensitization	Negative	-	-	-	Prevalent moderate to strong respiratory allergic reactions Resp. sens. 1
Mutagenicity/ genotoxicity	Negative	-	-	-	Muta 2, Muta 1A-1B
Irritant/ corrosiveness[a]	None to Irritant Eye Irrit.2: skin Irrit 2 EUH 066	-	Severe irritant skin/eyes Irritant to respiratory tract STOT SE 3: Eye Dam. 1 Corrosive Skin Cor. 1A-1B	-	-
Carcinogenicity in combination with mutagenicity[b]	Negative	Negative	Some evidence in animals Carc. 2	-	Confirmed in animals or humans. Carc. 1A-1B
Carcinogenicity without mutagenicity[b]	Negative	Negative	Some evidence in animals Carc. 2	Confirmed in animals or humans. Carc. 1A-1B	-
Developmental/ reproductive toxicity	Negative	Negative	Negative	Reprotoxic defects in animals and /or suspected or proved in humans Repr. 1A/B or 2	-
Likelihood of chronic effects Adverse effects per respiratory route (mg/m^3/6 h/day) (90 day chronic study with dusts/mists/ fumes)[d]	Unlikely No adverse effects seen at C < 200[e]	Unlikely No adverse effects seen at C < 200[e]	Possible, STOT RE 2 Adverse effects seen at 20 < C ≤ 200	Probable, STOT RE 1[c] Adverse effects seen at C ≤ 20	-

Details of the hazard bands derived for each material are given below.

CALCIUM PEROXIDE NANOPARTICLES

In contact with water, CaO_2 dissolves to form H_2O_2 and $Ca(OH)_2$, liberating a maximum of 0.47 g H_2O_2/g CaO_2 (Khodaveisi et al., 2011). The rate at which it decomposes is higher for nano-calcium peroxide than for micro-calcium peroxide[411]. No data on the toxicity of the nano-form have been found in public literature, and since it decomposes into soluble compounds in water, its hazard should be evaluated using Stoffenmanager for bulk compounds. Calcium peroxide is not classified for toxic hazards by the EU, but the majority of REACH registrants has classified it with Skin Irrit. 2 (H315), Eye Irrit. 2 (H319) and STOT SE 3 (H335). Based on the last classification calcium peroxide is allocated hazard band C.

Carbon nanotubes, single- and multi-walled (CNT)

Carbon nanotubes have often been demonstrated to have severe toxicity; however, this seems to be largely dependent on the dose, the degree of agglomeration and the route of administration. Differences in toxicity are also expected between single and multi-walled CNTs and are presumably dependent on their aspect ratio[412].

Upon inhalation, single walled carbon nanotubes (SWCNTs) have shown various chronic inflammatory responses in rat and mice, depending on type of exposure (inhalation, oral administration)[413] [414] [415]. For example, while no tumours were reported in the case of short to medium term pulmonary exposures to SWCNTs or MWCNTs in rodents, several studies have shown the potential for MWCNTs to act like the persistent fibres of asbestos, causing thoracic inflammation and fibrosis. Additionally, MWCNT have been shown to penetrate into the alveolar region of the lung and to cause inflammation. These biological events have been shown to lead to the cancer mesothelioma[416], although MWCNT have not been demonstrated to *de facto* cause mesotheliomas. Still the weight-of-evidence for certain types of MWCNT (e.g., those with high aspect ratios) is increasing. In conclusion, flexible, rigid, high-aspect-ratio MWCNT may cause cancer in a similar fashion to asbestos and may be as potent in this respect. [417]

Cobalt manganese oxide nanoparticles

These particles are formed *in situ* and react *in situ* in closed reactors and as such will not constitute a human safety issue and are therefore not further discussed here.

Cobalt-platinum nano-catalyst (Co Pt alloy)

No data on the toxicity of the alloy, be it in bulk or nano-form, have been found in public literature, hence it will be evaluated based on the properties of its constituent metals. The table below lists the classifications published by ECHA: cobalt has a globally harmonised classification and platinum only self-classifications. The most serious classification is that of cobalt for respiratory sensitisation code 1, on which basis the nanoparticle is attributed hazard band E.

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[411] Khodaveisi, J., Banejad, H., Afkhami, A., Olyaie, E., Lashgari, S., Dashti, R., 2011. Synthesis of calcium peroxide nanoparticles as an innovative reagent for in situ chemical oxidation. J. Hazard. Mater. 192, 1437–40. doi:10.1016/j.jhazmat.2011.06.060

[412] El-Ansary, A., Al-Daihan, S., Bacha, A.B., Kotb, M., 2013. Toxicity of novel nano-sized formulations used in medicine. Methods Mol. Biol.

[413] Ibid

[414] Zhao, J., Castranova, V., 2011. Toxicology of nanomaterials used in nanomedicine. J. Toxicol. Environ. Heal. - Part B Crit. Rev. 14, 593–632.

[415] Yildirimer, L., Thanh, N.T.K., Loizidou, M., Seifalian, A.M., 2011. Toxicological considerations of clinically applicable nanoparticles. Nano Today 6, 585–607.

[416] http://www.mesothelioma.com/mesothelioma/

[417] For more information and additional references, see the relevant annex to this report.

Figure 10-1: Classification of cobalt and platinum for human health hazards (ECHA)

Hazard class and code	Hazard statement code	Cobalt (GHS) classification?	Platinum (self-classification) # classified/total notifiers
Skin Sens. 1	H317	yes	56/317
Resp. Sens. 1	H334	yes	9/317
Skin Irr. 2	H315	no	1/317
Eye irr. 2	H319	no	1/317

Source: http://echa.europa.eu/information-on-chemicals/cl-inventory-database

Copper tungstate ($CuWO_4$)

No toxicity data on copper tungstate, be it in the bulk or nano-form, have been retrieved from public literature. Copper tungstate is virtually insoluble in water[418]. Nano-copper tungstate is used for its photocatalytic activity[419] and has a band gap energy of 3.5 eV[420]. In a number of respects it is comparable to titanium dioxide, namely it is also insoluble in water, is photocatalytic and has a similar band gap energy of 3.0 (rutile) or 3.2 eV (anatase)[421]. Therefore, tentatively and in view of the uncertainties of this read-across, copper tungstate is attributed one hazard band higher than titanium dioxide, i.e. band D.

Dendrimers

The most successful early dendrimeric constructs were synthesised using classical linear, random coil polymers, such as polyethylene glycol (PEG), N-(2-hydroxypropyl) methacrylamide (HPMA) copolymers, poly(glutamic acid) (PGA), poly(ethyleneimine) (PEI) and dextrin (a-1,4 polyglucose), while more recently polyamidoamine (PAMAM; Starburstk) dendrimers and poly propylenemine) (also called PPI, DAB; AstramolR) dendrimers have gained commercial success[422].

Many in vitro studies have shown toxic effects for almost all of dendrimeric nano-polymers, depending on particle size, shape, coating and many other factors[423] [424]. When they display clear toxicity, it is mostly associated with cationic dendrimers disrupting the cell membrane, e.g. the 5.0G PPI dendrimer has a 24h-EC_{50} for HEPG2 cells between appr. 10 and 1 µg/mL and a 72h-EC_{50} < 1 µg/mL (Jain, et al. 2010). At concentrations around 1 mg/mL, also clear haemolytic effects were observed in vitro (4 h incubation) with uncoated dendrimers, but not with coated ones (Jain, et al. 2010). Via the i.p route LD_{50} of 7.0 G PAMAM dendrimers is between 40 and 160 mg/kg in mice, while sub-chronic administration of 2.5 and 10 mg/kg bw did not result in mortality nor in renal damage. Based on the available data, no clear conclusion can be drawn with respect to dendrimer toxicity, but based on their membrane disruptive effects, it cannot be excluded that they may cause serious health effects, especially after respiratory exposure. Since there is no indication of mutagenic effects, and they also do not seem probably as these polymers destroy the cell membrane thus killing the cell, this nanoparticle is assigned the one but highest hazard band, D.

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[418] Grobler, S.R., Suri, S.K., 1980. Solubilities of the molybdates and tungstates of silver and copper(II) in water by ion-selective electrodes. J. Inorg. Nucl. Chem. 42, 51–53. doi:10.1016/0022-1902(80)80042-X
[419] Gouma, P.I., Lee, J., 2014. Photocatalytic nanomats clean up produced water from fracking. Transl. Mater. Res. 1, 25002.
[420] Jovanović, D.J., Validžić, I.L., Mitrić, M., Nedeljković, J.M., 2012. Synthesis and structural characterisation of nano-sized copper tungstate particles 59, 70–74
[421] Li, W., Bak, T., Atanacio, A., Nowotny, J., 2016. Photocatalytic properties of TiO2: Effect of niobium and oxygen activity on partial water oxidation 198, 243–253. doi:10.1016/j.apcatb.2016.05.044
[422] Duncan, R., Izzo, L., 2005. Dendrimer biocompatibility and toxicity. Adv. Drug Deliv. Rev. 57, 2215–2237.
[423] Ibid.
[424] Jain, K., Kesharwani, P., Gupta, U., Jain, N.K., 2010. Dendrimer toxicity: Let's meet the challenge. Int. J. Pharm. 394, 122–142.

FULLERENES (C60)

Classified by Stoffenmanager Nano in hazard band D[425].

GRAPHENE AND GRAPHENE OXIDE

Graphene is composed of sp2-hybridised carbon atoms arranged in a two-dimensional structure. The various forms of graphene include few-layer graphene, reduced graphene oxide, graphene nano-sheets and graphene oxide (GO)[426].

The UK government body, the Medicines and Healthcare Products Regulatory Agency (MHRA), and the US Food and Drug Administration (FDA) are now reviewing all forms of graphene and functionalised graphene oxide (GO) because of their poor solubility, high agglomeration, long-term retention, and relatively long circulation time in the blood[427].

Currently, limited information about the *in vitro* and *in vivo* toxicity of graphene is available[428]. The toxicity profiles of graphene and graphene oxide (GO) nanoparticles remain difficult to separate, since their characterisation, bulk and chemical composition are very similar at the nanometre length scale[429].

In vitro graphene has been demonstrated to be cytotoxic, be it overall to a lesser degree than carbon nanotubes (Seabra, et al. 2014). However, the reliability of this conclusion can be doubted since Seabra et al. stated that graphene showed an inverse dose-relationship, being more cytotoxic than carbon nanotubes at low concentrations. The only elaborate comparative study reported by Seabra et al., refers to genotoxicity towards human fibroblast cells. GO proved to be the most potent genotoxic agent compared to iron oxide (Fe304), titanium dioxide (Ti02), silicon dioxide (Si02), zinc oxide (ZnO), indium (In), tin (Sn), core—shell zinc sulphate-coated cadmium selenide (CdSe(3)ZnS), and carbon nanotubes.

GO has been shown to cause severe pulmonary distress in mice after inhalation causing excessive inflammation, while non-functionalised graphene[430]. Single intravenous (i.v.) injection of graphene oxide into mice accumulated in the lung resulting in pulmonary oedema and granuloma formation[431]. Furthermore, surface functionalised graphene (PEGylated) appears to be far less toxic: no toxic effects after single i.v. injection[432]. In mice, PEGylated GO materials showed no uptake via oral administration, indicating limited intestinal absorption of the material, with almost complete excretion. In contrast, upon intra-peritoneal (i.p.) injection in mice, PEGylated GO was found to accumulate in the liver and spleen[433].

The toxicity of graphene is dependent on the graphene surface (the chemical structure or the nature of the functionalised coatings), size, number of layers, cell type, administration route (for *in vivo*

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[425] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525–541. doi:10.1093/annhyg/mer113

[426] Seabra, A.B., Paula, A.J., De Lima, R., Alves, O.L., Durán, N., 2014. Nanotoxicity of graphene and graphene oxide. Chem. Res. Toxicol. 27, 159-168.

[427] Begum et al. 2011 cited in Nezakati, T., Cousins, B.G., Seifalian, A.M., 2014. Toxicology of chemically modified graphene-based materials for medical application. Arch. Toxicol. 88, 1987-2012.

[428] Seabra, A.B., Paula, A.J., De Lima, R., Alves, O.L., Durán, N., 2014. Nanotoxicity of graphene and graphene oxide. Chem. Res. Toxicol. 27, 159–168.

[429] Nezakati, T., Cousins, B.G., Seifalian, A.M., 2014. Toxicology of chemically modified graphene-based materials for medical application. Arch. Toxicol. 88, 1987–2012

[430] Duch, M.C., Budinger, G.R.S., Liang, Y.T., Soberanes, S., Urich, D., Chiarella, S.E., Campochiaro, L.A., Gonzalez, A., Chandel, N.S., Hersam, M.C., Mutlu, G.M., 2011. Minimizing oxidation and stable nanoscale dispersion improves the biocompatibility of graphene in the lung. Nano Letters 11, 5201-5207.

[431] Zhang, X., Yin, J., Peng, C., Hu, W., Zhu, Z., Li, W., Fan, C., Huang, Q., 2011. Distribution and biocompatibility studies of graphene oxide in mice after intravenous administration. Carbon 49, 986-995

[432] Yang, K., Wan, J., Zhang, S., Zhang, Y., Lee, S.-T., Liu, Z., 2011. In vivo pharmacokinetics, long-term biodistribution, and toxicology of pegylated graphene in mice. ACS Nano 5, 516–522.

[433] Yang, K., Gong, H., Shi, X., Wan, J., Zhang, Y., Liu, Z., 2013. In vivo biodistribution and toxicology of functionalised nano-graphene oxide in mice after oral and intraperitoneal administration. Biomaterials 34, 2787–95. doi:10.1016/j.biomaterials.2013.01.001 cited in Seabra, A.B., Paula, A.J., De Lima, R., Alves, O.L., Durán, N., 2014. Nanotoxicity of graphene and graphene oxide. Chem. Res. Toxicol. 27, 159–168.

experiments), dose, time of exposure, and synthesis methods[434]. Generalisations are therefore hard to make, but graphene nanostructures are not fibre-shaped and theoretically may be assumed to be safer than carbon nanotubes[435].

Based on the scarce available evidence, it cannot be excluded that some forms of graphene will be as potent a toxicant as carbon nanotubes. Therefore, graphene and graphene oxide are assigned to hazard band E.

IRON NANOPARTICLES

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm). Since the size distribution of the iron nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

IRON OXIDE NANOPARTICLES

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm). Since the size distribution of the iron oxide nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

GOLD NANOPARTICLES

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm). Since the size distribution of the gold nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

MICELLES

Micelles in aqueous environments are globular aggregates of amphipathic molecules with their hydrophobic tails facing inwards and their hydrophilic heads facing outwards[436]. In the environment nano-micelles may be used to clean polluted water from metals and organic pollutants[437]. There are many chemically different nano-micelles, that may differ in toxicity. However, most likely in the application envisaged here their toxicity may principally depend on the pollutants they sequester and concentrate inside themselves. Therefore, it is not feasible to derive a hazard band for nano-micelles in general without taking into account their chemical composition and the pollutants they are supposed to remove from the environment.

NANOCLAY

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm, and in band C for sizes >50 nm. Since the size distribution of the nanoclay nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

NANO-POROUS MATERIALS

The description of the role of nanotechnology for environmental purposes in chapter 2 mentions the use of nanocrystals to capture carbon dioxide. Sneddon et al. (2014) reviewed the use of nano-porous materials, amongst others materials with a crystalline structure, in carbon dioxide capture. None of these are already applied at an industrial scale and it is doubtful that they ever will be in view of their higher costs in comparison to the absorbent usually applied in the capture and subsequent geological storage of carbon dioxide[438]. Technically, metal-organic frameworks (MOFs) and mesoporous[439] silicas and ordered mesoporous activated carbon functionalised with amine groups are the most likely candidates for carbon dioxide capture. Since all these materials themselves are not nano-sized, but only contain nano-sized pores, their toxicological properties will be mainly determined by their bulk chemical properties. MOFs often contain toxic metals (e.g. Cu)

[434] Seabra, A.B., Paula, A.J., De Lima, R., Alves, O.L., Durán, N., 2014. Nanotoxicity of graphene and graphene oxide. Chem. Res. Toxicol. 27, 159–168.

[435] Ibid

[436] Stryer, L., 1988. Introduction to biological membranes, in: Biochemistry. W.H. Freeman and Company, New York, USA, pp. 280–312.

[437] Noh, S. Il, Shim, J.K., Kim, J.Y., 2008. New amphiphilic polymer nanoparticle-enhanced UF process for removal of organic pollutants and metal ions 14, 480–486. doi:10.1016/j.jiec.2008.02.007

[438] Sneddon, G., Greenaway, A., Yiu, H.H.P., 2014. The potential applications of nanoporous materials for the adsorption, separation, and catalytic conversion of carbon dioxide 4. doi:10.1002/aenm.201301873

[439] The designation "mesoporous" refers to nano-sized pores.

and/or heterocyclic or aromatic organic compounds, making it likely more hazardous than e.g. mesoporous silicas and activated carbon. However, the nature of amine compounds ligated to the silicas and activated carbon in order to confer carbon dioxide capturing properties to them, may introduce hazardous properties to these rather inert bulk chemicals. Concluding, based on the scant information available and great variety in materials applied, no realistic estimate of the hazard band to be attributed to nano-porous materials can be made.

NANO-COATED HYDROPHOBIC SAND

The description in this report of the role of nanotechnology for environmental purposes mentions nano-coated hydrophobic sand to create an artificial water table in the soil in order to address water scarcity. Since the sand will consist of macroscopic grains and is chemically inert, possible toxicological hazards of this material will depend on the nature of the nano-coating used and human exposure to it will largely depend on the ease with which it may get detached from the sand when coming in contact with the skin. Due to lack of information in these respects, no realistic estimate of the hazard band to be attributed to nano-coated hydrophobic sand can be made.

SILICON NANOWIRES

Silicon nanowires are high-aspect ratio filamentary crystals of silicon, which implicates these nanowires may cause asbestos-like toxicity upon inhalation[440]. Fibres may induce lung inflammation and fibrosis that progress over time after exposure and may eventually lead to tumour formation. Whether this process occurs will depend on the dimensions of the fibres (length and width), and their durability (bio-persistence). Particles less than 3 µm in width deposit more readily in the respirable region of the lung; long fibres with lengths greater than 15 µm frustrate phagocytosis and clearance by alveolar macrophages. Roberts et al. (2012) performed an in vivo experiment in rats to test whether silicon nanowires do cause asbestos-like toxicity. They found indications for the fibre paradigm being valid for these nanowires, but the evidence was not conclusive, a.o. because of the scarcity of long fibres ultimately reaching the alveoli. In view of the physical properties of the silicon nanowires and the fact that some evidence points to them following the fibre paradigm, hazard band E is attributed to them, in accordance with the Stoffenmanager Nano approach.

SILVER NANOPARTICLES

In an update on silver and some metal oxide nanoparticles hazard band D was attributed to nanosilver[441].

SINGLE ENZYME NANOPARTICLES (SENS)

The description of the role of nanotechnology for environmental purposes in chapter 2 mentions the use of SENs in water remediation. Immobilizing enzymes on nanoparticles will allow increased concentrations of the enzyme and convey a broader working pH and temperature range and a higher thermal stability. Many different nanoparticles may be used, like alumina nanoparticles, cellulose-coated magnetite nanoparticles, Fe_3O_4 nanoparticles, gold nanoparticles, poly-methyl methacrylate (PMMA) nanoparticles, polystyrene nanoparticles, silica coated nickel nanoparticles, silica nanoparticles, zeolite-gold nanoparticles and ZnO nanoparticles, as well as single and multi-walled carbon nanotubes and graphene oxide nanomaterials[442] [443]. Not only the nature of the nanoparticles employed but also that of the enzyme immobilised on it will determine the hazardous properties of single enzyme nanoparticles, since enzymes are bioactive compounds. Concluding, based on the scant information available and great variety in nanoparticles and enzymes applied, no realistic estimate of the hazard band to be attributed to SENs can be made.

TITANIUM DIOXIDE NANOPARTICLES

In an update on some metal oxide nanoparticles hazard band C was attributed to titanium dioxide

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[440] Roberts, J.R., Mercer, R.R., Chapman, R.S., Cohen, G.M., Bangsaruntip, S., Schwegler-Berry, D., Scabilloni, J.F., Castranova, V., Antonini, J.M., Leonard, S.S., 2012. Pulmonary toxicity, distribution, and clearance of intratracheally instilled silicon nanowires in rats 2012. doi:10.1155/2012/398302

[441] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles.

[442] Ansari, S.A., Husain, Q., 2012. Potential applications of enzymes immobilised on/in nano materials: A review. doi:10.1016/j.biotechadv.2011.09.005

[443] Campbell, A.S., Dong, C., Meng, F., Hardinger, J., Perhinschi, G., Wu, N., Dinu, C.Z., 2014. Enzyme catalytic efficiency: A function of bio-nano interface reactions 6, 5393–5403. doi:10.1021/am500773g

nanoparticles[444].

10.2.3 Exposure assessment

For the environmental applications where information on the application process or conditions is available, the nanomaterials are either present in a closed system or in a solid matrix (e.g. membrane, filter, grid). For such applications the exposure potential during the use phase is low (1). It may be assumed this is also the case for the other applications mentioned. However, a number of applications mentioned are still being investigated at the laboratory scale only, and consequently their exact use condition at an environmental scale are yet uncertain. Furthermore, during the production phase of these systems or matrices the exposure potential may be higher (3). Also during the end-of life phase, exposure is not expected to be very high, but somewhat higher than during the use phase (2).

10.2.4 Risk assessment

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table below. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures ort to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 10-3: Priority bands in the Stoffenmanager system

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Risks based on the hazard and exposure banding applied to the environmental sector are listed in the table below. Carbon nanotubes, dendrimers, graphene and graphene oxide have a high priority (1), indicating the need to apply exposure control methods or to assess the risks more precisely. All other materials have an intermediate priority, except calcium peroxide and titanium dioxide in the in-use phase, for which they have a low priority.

[444] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles.

Table 10-4: Priority bands for the nanotechnology environment sector

		Exposure band	
		In use exposure	End-of-life exposure
Nanoparticle	**Hazard Band**	1	2
Calcium peroxide	C	3	2
Carbon nanotubes, single- and multiwalled	E	1	1
Cobalt manganese oxide	n/a	n/a	n/a
Cobalt platinum catalyst	E	1	1
Copper tungstate (CuWO4)	D	2	2
Dendrimer	E	1	1
Fullerenes (C60)	D	2	2
Gold	D	2	2
Graphene and graphene oxide	E	1	1
Iron	D	2	2
Iron oxide	D	2	2
Micelles	n/a	n/a	n/a
Nanocoated hydrophobic sand	n/a	n/a	n/a
Nanoclay	D	2	2
Nanoporous materials	n/a	n/a	n/a
Silicon nanowires	E	1	1
Silver	D	2	2
Single enzyme nanoparticles (SENs)	n/a	n/a	n/a
Titanium dioxide (titani, rutile, anatase)	C	3	2

The next section looks at communications, public attitudes and societal issues.

10.3 Communication, public attitudes and societal issues

This section looks at nanotechnology and environment in printed and online media, and surveys

10.3.1 Printed and online media

A search on the web of terms related to nanotechnology and keywords related to environment [445] is summarised in the table below. News sites only were searched using the Google News search tool. A second search, using Google Scholar[446], was done in order to obtain an indication of where the interests of academics lie. The ratio of news web-pages to total web-pages for each search was much lower than the ratio of scholarly to general web-pages. While these data are approximate, they may be useful in identifying where the public can find the most information, relatively speaking, on a given nanotechnology and environmental topic. The number of news items is an indication of where the media perceive that the interest of the public lies.

Table 10-5: Frequency of articles on the web, in the news for nanotechnology environment topics

Category	Keyword	Web, 1000s	News, 1000s	News/Web %	Scholar 1000s	Scholar / Web, %
	Nanotechnology Environment	21,400	539	2.52%	737	3.44%
Pollution	Pollution	966	24.9	2.57%	2,180	225.67%
	Air pollution*	1,460	12	0.82%	2,320	158.90%
	Soil pollution*	381	3.7	0.97%	379	99.48%
	Water pollution*	944	10.8	1.14%	2,070	219.28%
	Atmospheric pollution*	249	7.7	3.09%	501	201.20%
Remediation	Remediation	432	2	0.46%	74.1	17.15%
	Air remediation	10,400	1.4	0.01%	60.6	0.58%
	Water remediation	450	1.7	0.38%	105	23.33%
	Soil remediation	372	1.3	0.35%	41.8	11.24%
	Bio remediation	637	1.7	0.27%	25.6	4.02%
Green nanotechnology	Green manufacturing	2,010	22.2	1.10%	242	12.04%
	Green chemistry	1030	18.2	1.77%	2,030	197.09%
Purification	Purification	1,710	7.1	0.41%	1,560	91.23%
	Water purification	849	5.4	0.64%	1,490	175.50%
	Soil purification	526	0.4	0.08%	79	15.02%
	Air purification	660	1.8	0.27%	1,170	177.27%

There are various journals that specialise in environmental related aspects of nanotechnology, both

[445] The search was carried out using the keywords in quotation marks, coupled with the term nano*, so all words beginning with nano are included.

[446] Google Scholar is an online database of many of the peer-reviewed online journals of Europe and the US, plus books and non-peer reviewed journals, containing an estimated 160 million documents in 2014 (Orduña-Malea, E.; Ayllón, J.M.; Martín-Martín, A.; Delgado López-Cózar, E. (2014). About the size of Google Scholar: playing the numbers. Granada: EC3 Working Papers, 18: 23 July 2014.)

regarding its environmental uses and also regarding Environmental Health & Safety.

Table 10-6: Journals specialised in environment-related aspects of nanotechnology

Name of the Journal	Publisher	ISSN	Website
Environmental Nanotechnology, Monitoring and Management	Elsevier	2215-1532	http://www.journals.elsevier.com/environmental-nanotechnology-monitoring-and-management
NanoImpact	Elsevier	2452-0748	http://www.journals.elsevier.com/nanoimpact/
Journal of Environmental Nanotechnology	IENT Publishers	2279-0748 (print) 2319-5541 (online)	http://www.journals.elsevier.com/environmental-nanotechnology-monitoring-and-management
Nanotoxicology	Informa Healthcare	1743-5390 (print) 1743-5404 (online)	http://informahealthcare.com/nan
Journal of Water and Environmental Nanotechnology	Iran Nanotechnology Initiative Council (INIC) and Iranian Environmental Mutagen Society	Not available	www.jwent.net/
Environmental Science: Nano	RSC Publishing	2051-8153 (print) 2051-8161 (online)	http://pubs.rsc.org/en/journals/journalissues/en
Nanotechnology for Environmental Engineering	Springer	2365-6379 (print) 2365-6387 (online)	http://www.springer.com/earth+sciences+and+geography/environmental+science+%26+engineering/journal/41204
Nanomaterials and the Environment	Versita	2299-1204	http://www.degruyter.com/view/j/nanome

Apart from these specialised journals, many general nanotechnology journals feature environment related articles and likewise general environmental journals feature nanotechnology related articles.

Examples of the first are 'ACS Nano'[447] and 'Journal of Nanomaterials'[448]; examples of the second are the journals 'Environmental Research'[449], 'Critical Reviews in Environmental Science and Technology'[450], and 'Environmental Science & Technology'[451].

More than 200 scientific journals regularly publish articles on nanotechnology[452]. For the academic community, the International Scientific Journal & Country Ranking (SJR) index provides a means of identifying which are perceived to be the most prestigious. The h-5 index is a measure of the number of highly cited articles, and is thus dependent on how many articles are published annually by the journal. The top five journals, as measured by the SJR index largely follows the metric of citations per document published, as shown in the table below.

Table 10-7: Bibliometric data for nanotechnology

Title of journal	SJR	h-5 index 2010-14	Total articles (3 years)	Citations per article (2 years)	Country
Nature Nanotechnology	19.8	203	711	27	UK
Advanced Materials	9	345	2860	18.4	DE
Nano Letters	9	341	3234	14.2	US
ACS Nano	7.1	202	3875	13.2	US
Nano Today	6.5	86	198	13.5	NL

Source: http://www.scimagojr.com/journalrank.php?category=2509

While it should be noted that many nanotechnology publications may not have a Facebook page, one indication of popularity of nanotechnology media can be seen in the figures for the number of "Likes" on Facebook:

Table 10-8: Facebook likes as a measure of interest in nanotechnology

Facebook page	Likes
Nanotechnology	99,000
Nanotechnology World Association	33,000
Nanotechnology Now	6,400
Nanotechnology Solutions	3,500
Nanowerk Media/News/Publishing	5,400
The International Nano Science Community	5,700
Nanobiotechnology	2,100

This information may be useful in targeting any information for the public in future over and above the EC's own web pages.

447 http://pubs.acs.org/journal/ancac3. For example, "Common Strategies and Technologies for the Ecosafety Assessment and Design of Nanomaterials Entering the Marine Environment", published in ACS Nano in 2014

448 http://www.hindawi.com/journals/jnm/. An example of an article published in Volume 2015, Article ID 851928 "Dominating Role of Ionic Strength in the Sedimentation of Nano-TiO2 in Aquatic Environments

449 Elsevier; a multidisciplinary journal of Environmental Sciences, Ecology, and Public Health http://www.journals.elsevier.com/environmental-research

450 Taylor & Francis http://www.tandfonline.com/action/journalInformation?show=aimsScope&journalCode=best20#.V4zrJpN97Vo

451 ACS Publications, http://pubs.acs.org/journal/esthag

452 http://www.nanowerk.com/nanotechnology/nanotechnology_periodicals.php

10.3.2 Surveys of the public

More rigorous measures of public awareness, attitudes and communication can be seen through surveys. Although not fully representative of the 'average' EU-citizen, the results provide some indications of trends in attitudes.

NanOpinion was an FP7 project, which ran from 2012 to 2014, focused on monitoring public opinion on nanotechnology in Europe[453]. An online hub, social media, education and information booths in public spaces and special events were used to develop a dialogue with the general public about nanotechnology. Over 1,500 questionnaires were completed in which participants answered questions designed to gauge their understanding and opinions of nanotechnology.

Analysis of the questionnaires revealed that Europeans in general have little understanding of nanotechnology but are generally interested in and positive about it. Respondents expected information on nanotechnology to be honest and balanced and wished there was more information available, particularly in the popular media. Across all educational backgrounds, they would be interested in buying products, including food containers, clothing and sun cream, containing nanomaterials. However, they would like to see nano-containing products labelled with detailed information and the testing and regulation of these products carried out by independent national or international bodies rather than profit-oriented companies. Their main policy recommendations were to promote consistent and detailed product labelling carried out by an independent body, to update teachers' knowledge of nanotechnology and to encourage more interdisciplinary STEM (science, technology, engineering and mathematics) curricula.

The objectives of NanoDiode, an FP7 project running from mid-2013 to mid-2016, is to develop a co-ordinated and innovative strategy to engage EU civil society in a dialogue about responsibility around nanotechnologies[454]. As part of their approach they reviewed the experiences and outputs of previous European projects on nanotechnology dialogue and outreach in order to identify best practices they could adopt for educational workshops and other activities[455]. The scope of NanoDiode is more ambitious than NanOpinion in as much as they aim to facilitate dialogue across all levels of the nanotechnology value chain, from the general public to policy makers. Through outreach, education and specific events they will involve a cross-section of researchers, industrialists, citizens, scientific advisers and policy makers with the aim of learning where and how society wish nanotechnologies to be applied. For example, they aim to bring groups of potential nanotechnology 'users' (industrial customers as well as consumers) together with researchers working on near-market products in order to facilitate discussions which could help steer the research towards social values and user needs.

In addition to these FP7 projects, two population surveys in Germany provide some data on the public's attitudes (Zimmer et al, 2009)[456], as well as a survey among young people conducted within the framework of the NANOYOU project (NANOYOU, 2010)[457] and a recent survey in the USA (Shipman, 2010)[458]. Work has also been undertaken by the OECD on public engagement with nanotechnology and a guide produced to assist policymakers in working with the public on issues related to nanotechnology (OECD, 2010)[459].

Relatively favourable situations may exist if citizens have concrete experiences with, or expectations towards specific applications; they tend to support applications "that are linked to a wider social

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[453] www.nanopinion.eu
[454] www.nanodiode.eu
[455] Analysing previous experiences and European projects on nanotechnology outreach and dialogue and identifying best practices, Daan Schuurbiers and De Proeffabriek, March 2014, (Accessed at http://www.proeffabriek.nl/uploads/media/NanoDiode_WP1_Best_Practices.pdf in November 2015)
[456] Zimmer, R., Hertel, R., Böl, G.F., 2009, "Public perceptions about nanotechnology: Representative survey and basic morphological-psychological study", Bundesinstitut für Risikobewertung (BfR)
[457] Nanoyou, 2010 http://cordis.europa.eu/publication/rcn/15319_fr.html
[458] Shipman, M., 2010, "Hiding risks can hurt public support for nanotechnology", News Services of the North Carolina State University
[459] http://www.oecd.org/sti/biotech/49961768.pdf

good or perceived individual benefit" (Böl, 2010; Fleischer et al., 2012)[460,461].

Table 10-9: Assessments by the public of various applications of nanotechnology
From German online discourses and a questionnaire survey (Böl et al. 2010)

Application	Ratio of positive to negative assessments	
	Online discourses	Population survey
Cancer therapies	90 : 10	(not asked)
"Other serious medical applications"	88 : 12	87 : 13
Surface treatment (textile & vehicle)	67 : 33	93 : 7 (paints) 91 : 9 (textile)
Textile; other than surface treatment	56 : 44	76 : 24
Food packaging	25 : 75	81 : 19 (detection) 64 : 36 (foil quality)
Foodstuffs	10 : 90	25 : 75 (lump prevention) 10 : 90 (appearance)
Dietary supplements	0 : 100	not asked
Cosmetics (excl. sunscreens)	59 : 41	51 : 49
Sunscreen products	10 : 90	78 : 22

460 Böl, G.F., Epp A., Hertel, R., 2010, "Perception of nanotechnology in internet-based discussions", Bundesinstitut für Risikobewertung (BfR)
461 Fleischer, T., Jahnel J., Seitz S.B., 2012, "NanoSafety – Risk governance of manufactured nanoparticles", European Commission

11 CONCLUDING SUMMARY

Nanomaterials have unique properties that have applications in prevention or remediation of air, water and soil pollution as well as in sensors to detect and monitor pollutants. Nanotechnology can also contribute to more efficient use of resources through improved recycling, reduced use of energy or lighter materials. At the same time there is concern about the potential toxicity of nanomaterials related to size, crystal structure and surface (surface area, chemistry and charge), as well as degradability (persistence) and potential for bioaccumulation.

The EU, its Member States and many other countries around the world have developed policies and programmes in support of nanotechnology as well as to assess and manage the potential risks. Funding is provided to projects with budgets from the EC or programmes in combination with industry (such as the Joint Technology Initiatives) or other public authorities (such as Joint Programming Initiatives).

Countries with a strong track record in environmental nanotechnology projects in the Framework Programmes were Germany, France and the UK; their organisations received more than one third of total EC funding for such projects. Almost 70% of funding goes to higher education and public research organisations; the share of large companies decreased from FP6 to FP7.

The countries with the strongest publication record in 2014 were China and the USA, followed by India and South Korea. Spain is the first European country in the list, in fifth place. The companies with the most nanotechnology/environment publications globally in 2014 were Aerodyne Research (USA) and Petrochina (PRC).

The patent league table is headed by the USA, followed by Japan and South Korea. Fourth place is Germany, followed by France, Spain and the UK. In total, 12 EU countries feature in the top 25. Three German and one French company are listed in the top ten in terms of patents applied for.

In line with the applications mentioned above, nanotechnology products in the environmental sector are sold for air, water and soil remediation. Global sales amounted to USD 23.5 billion in 2014 which is expected to nearly double to USD 41.7 billion in 2020. Although the market for air remediation products is currently the largest of the three, most products (45% of the products on the market) and strongest growth are in water remediation. The market for soil remediation products remains (comparatively) modest also in 2020. The market for sensors is emerging so that, even with strong growth expected, the total market will only reach USD 60 million by 2019.

The EU's environmental regulatory framework covers nanomaterials; the main act to regulate nanomaterials is the Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). While the EU has been developing a regulatory framework for nanomaterials under REACH, some European Member States, such as Belgium, Denmark and France, have developed their own definition and regulation of nanotechnologies.

For most of the materials examined, the highest potential health and safety risk from nanotechnology in environmental applications is during the production phase and primarily through respiratory exposure. Materials with the highest risk to human health and safety are carbon nanotubes, dendrimers, graphene and graphene oxides.

ANNEXES

ANNEX 1: METHODOLOGIES FOR LANDSCAPE COMPILATION REPORTS

The outline of this report is as follows:

- Introduction;
- Development of keywords;
- Methodology by task and sector: projects, publications, patents and products;
- Methodology for additional information: markets, wider economic data, environmental health and safety, regulation and standards; and
- Concluding remarks.

A Introduction

This paper outlines the main methodologies used in the NanoData project.

The data were in large part identified using keywords to search existing databases (e.g. for publications and patents) and to select projects (from eCorda) and products (e.g. from product databases). The report explains how the keywords were identified and what quality control measures were put in place.

It should be noted that eight sectors were included in the work – construction, energy, environment health, ICT, photonics, manufacturing and transport. Thus, the data are not comprehensive across all of nanotechnology. They are, instead, representative of the sectors selected within the context of the overall project for the European Commission.

B Development of keywords

The keywords were identified from known data sources, web searches and expert input. They were validated through discussions with consortium members[462] (where they had expertise and experience in the area concerned) and other experts. Following that validation process, the keywords were also tested by one or both of the following methods:

- The word 'nano' and the keywords were used to select the FP projects relevant to the sector (and sub-sectors if appropriate). The projects identified were checked manually for false positives. False negatives were also identified (projects that were expected to be selected that were not). The keywords were refined to optimise the number of projects correctly selected.
- The keywords were used to select publications. The lists of publications were checked, in part manually and in part semi-automatically using the CWTS VOSViewer bibliometric mapping tool (http://www.vosviewer.com/Home). Using the tool, it was possible to see how terms group together in publication space (by their proximity on a VOSViewer map) and how often they occur (by their size on the VOSViewer map). Thus, it was possible to determine which terms would be the most significant in the sector and also which terms would be likely to cause false positives. For example, in the partial map for nanotechnology and health below (bottom left corner) it can be seen that a very important term is 'scaffold', and related terms are about tissue and bone engineering. Moving further to the right, the related term 'biocompatibility' is seen and nearby the significant and related but more generic terms 'surface', 'morphology' and 'synthesis'.

[462] Partners of the Joint Institute for Innovation Policy for this project i.e. CWTS, Frost & Sullivan, Joanneum Research, Oakdene Hollins, the Nanotechnology Industries Association, Tecnalia and TNO.

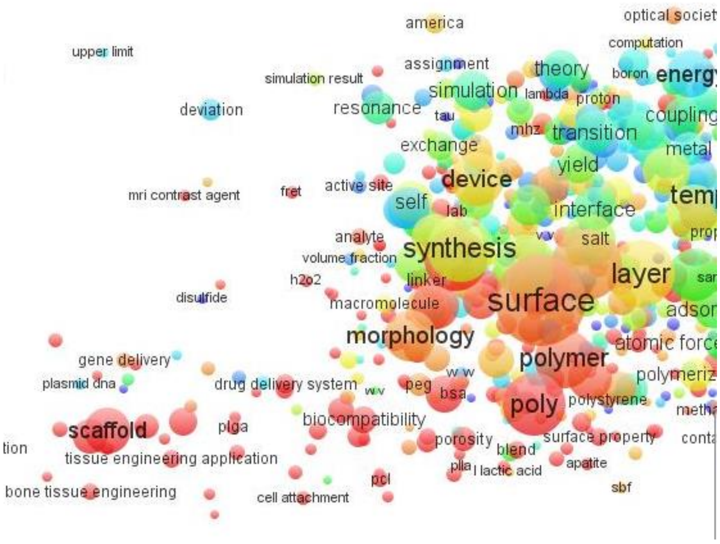

Figure A: Partial VOSViewer map for nanotechnology and health

Additional terms could also be identified for inclusion in the keyword list.

It should be noted that, where the use of a keyword could lead to false results, the keyword was omitted. This inevitably leads to some data of relevance being omitted from the resource base of the project, the alternative being the inclusion of much irrelevant information. For example, some words (e.g. photodetector, laser, photolithography) were omitted from the keywords for photonics as they have much wider applications that photonics alone.

In the searches, keywords were truncated to maximise the possible results. For example, in energy, "thermoelectric*" could identify data related to "thermoelectric", "thermoelectrics", "thermoelectrical" and "thermoelectricity", the * indicating the truncation.

Where possible, both British and American spellings were included (e.g. tumour and tumor) as were alternative spellings (e.g. orthopaedic and orthopedic).

Methodology by task and sector

C Framework Programme projects

The Framework Programme (FP) project details were provided by the European Commission from the eCorda database for FP6 and FP7. Abstracts for the FP6 projects were provided separately as these were not in the original database received. The total number of FP projects in eCorda database is 35,365 of which 25,238 are FP7 projects and 10,027 FP6 projects. These projects involved 210,177 participations by researchers of which 76,562 are in FP6 and 133,615 in FP7.

The table below presents an overview of the data for FP6 and FP7 according to the variables used in the NanoData analysis. It also identified the number of missing values per variable. It shows that the eCorda database is a nearly complete source of FP6 and FP7 project data and participant data with only relatively few data missing (between 2.4% and 0% of the total for FP6 and FP7 depending on the variable).

Table A: Number of actual observations and missing values for each of the eCorda variables used for the NanoData analysis.

Variable	Number of observations						
	FP6		FP7		Total		
	Actual	Missing	Actual	Missing	Actual	Missing	% Missing
Project ID	10,027	0	25,238	0	35,265	0	0.0%
Start date	9,966	61	24,906	332	34,872	393	1.1%
End date	9,965	62	24,906	332	34,871	394	1.1%
Duration	10,027	0	25,238	0	35,265	0	0.0%
Number of partners	10,027	0	25,238	0	35,265	0	0.0%
Specific Programme	10,027	0	25,238	0	35,265	0	0.0%
Sub-Programme[463]	10,027	0	25,238	0	35,265	0	0.0%
Call	9,989	38	25,238	0	35,227	38	0.1%
Instrument	1,0027	0	25,238	0	35,265	0	0.0%
EC contribution	10,027	0	25,238	0	35,265	0	0.0%
Project total cost	9,771	256	25,238	0	35,009	256	0.7%
Project ID	76,562	0	133,615	0	210,177	0	0.0%
Participant ID	76,550	12	133,615	0	210,165	12	0.0%
Participant role	76,562	0	133,615	0	210,177	0	0.0%
Participant legal name	76,561	1	133,615	0	210,176	1	0.0%
Participant country[464]	76,562	0	133,615	0	210,177	0	0.0%
Participant region	76,562	0	133,615	0	210,177	0	0.0%
Participant organisation type	74,271	2,291	133,615	0	207,886	2,291	1.1%
EC contribution per participant	71,748	4,814	133,569	46	205,317	4,860	2.4%
Project cost per participant	72,960	3,602	133,575	40	206,535	3,642	1.8%

In the eCorda database, the EC contribution per project shows some small differences between the data presented by project (project database) and the data presented by participant (participant database). The table below illustrates the differences, both in millions of euros and as shares of the EC contribution. It can be seen that the difference in EC contribution between the project and participant data is almost zero in FP7 and small in FP6. However, the differences can become significant when the data is aggregated.

[463] In FP6 these were called Priorities and in FP7 Work Programmes.
[464] The report uses ISO 2-digit codes for countries. See http://www.iso.org/iso/country_codes

Table B: Number of projects and EC contribution for the project data and participant data in eCorda

	Number of projects		EC contribution (MEUR)		Difference (Project – Participant) (MEUR)	Difference %
	Project Data	Participant Data	Project Data	Participant Data		
FP						
FP6	10,027	10,027	16,692.320	16,653.860	38.460	0.23%
FP7	25,238	25,238	44,917.330	44,917.200	0.130	0.00%
Total	35,265	35,265	61,609.650	61,571.060	38.600	0.06%
NT						
NT-FP6	908	908	1,702.740	1,695.500	7.250	0.43%
NT-FP7	2,636	2,636	4,660.840	4,660.750	0.090	0.00%
Total	3,544	3,544	6,363.580	6,356.250	7.340	0.12%

C1 Classification of projects

C1.1 Classification of nanotechnology projects

In order to identify the baseline set of nanotechnology-related projects for the NanoData work, a search was made for all FP projects that contained 'nano'[465] in the title or abstract of the project. 3,544 projects were selected in this way[466], of which 74% were FP7 projects and 26% were FP6 projects. Comparing the distribution of projects between FP6 and FP7 for nanotechnology and for the two FPs overall, it is found that the distributions are very similar the latter being 72% in FP7 and 28% in FP6. Nanotechnology projects make up 10% of Framework Programme projects, the share increasing slightly from FP6 (9.1%) to FP7 (10.4%).

The table below shows the distribution of total FP projects and of nanotechnology projects.

[465] The term "nano" could appear as a part of a word (e.g. nanotechnology, nanoscience, nanomaterial, nanoscale), as a part of compound word separated with hyphen (e.g. nano-science) or as an independent word "nano".

[466] Unlike the other sectors considered by the project (HT, EN, PH, MF), for ICT additional projects were identified by use of keywords such as graphene. These were judged to be too important in ICT to be omitted. This did, however, result in the total number of nanotechnology projects being different for ICT (4,143) and the other sectors (3,544).

Table C: Number and share of nanotechnology projects in FP6 and FP7

		Total	FP7	FP6
FP total	Number of FP projects	35,265	25,238	10,027
	Share of FP (total)	100%	71.6%	28.4%
Nanotechnology	Number of FP projects	3,544	2,636	908
	Share of FP	100%	74.4%	25.6%
Share of nanotechnology of total FP		10.0%	10.4%	9.1%

C1.2 Classification of projects by sector and sub-sector

The 3,544 projects relevant to nanotechnology were subjected to a search using the sector keywords to identify projects relevant to each sector. This search was undertaken using the keywords identified for each sector. The project details for the selected projects were reviewed manually, where possible, as a further check of the quality of the outputs of the keyword search process.

For example, using the method described above, 944 projects were categorised as being related to nanotechnology and health, approximately 27% of total nanotechnology projects. Using the keywords identified for each of the five health sub-sectors[467], a further classification could be made. In addition, nanotechnology projects relevant to health but not specifically to any of the five sub-sectors were categorised as Other. In this way, the breakdown of health nanotechnology projects was found to be: cancer 26% (CT); infectious diseases 7.8% (ID); cardiovascular diseases 5.2% (CV); neurodegenerative diseases 4.6% (ND); and diabetes (2.2%) (DB) with Other being 62% (OTH).

Where projects were classified as belonging to more than one sub-sector, a proportion of each such project was allocated to the sub-sector concerned. Thus a project relevant to cardiovascular disease and cancer would be allocated 50% to cardiovascular disease and 50% to cancer. The aim was to ensure an accurate analysis of the FP project data and to minimise double counting. The table that follows shows the number of project overlaps and the distributions of fractions of projects for the health sub-sectors.

[467] Cancer, cardiovascular disease, diabetes, infectious diseases and neurodegenerative diseases.

Table D: Distribution of projects with overlaps across health sub-sectors

	Total	CT	CV	ID	NE	DB	Other
Projects without overlaps	**883**	**196**	**23**	**48**	**24**	**11**	**581**
Projects with overlaps: fractions as allocated							
CT & ID	17	8.5		8.5			
CT & CV	12	6	6				
CT & ND	9	4.5			4.5		
CV & ID	5		2.5	2.5			
CV & ND	4		2		2		
CT & DB	4	2				2	
CV & DB	3		1.5			1.5	
ND & DB	2				1	1	
CT, ID & ND	1	0.33		0.33	0.33		
CT, ND & DB	1	0.33			0.33	0.33	
CT, CV & ID	1	0.33	0.33	0.33			
CT, CV, ID & ND	1	0.25	0.25	0.25	0.25		
ID & ND	1			0.5	0.5		
Sum of fractions	*61*	*22*	13	12	9	5	0
Total nanotechnology and health	**944**	**218**	**36**	**60**	**33**	**16**	**581**

C2 Harmonisation of data across FP6 and FP7

In order to have harmonised variables across both Framework Programmes, some names and coding of variables were required. These included the following:

i) Harmonising the participant types. The categories used in this report are presented in the table below. In the tables of top performers, if the same organisation appeared in FP6 and FP7, the FP7 code was used.

Table E: Harmonising participant type codes

Codes used	Description	FP6 Code	FP7 Code
HES	Higher or secondary education establishment	HES	HES
REC	Research organisations	REC	REC
PRC	Private commercial (excluding SMEs)	IND	PRC
SME	Small and medium-sized enterprises	SME	SME
OTH	Other including public bodies excluding research and education	OTH	OTH, PUB

ii) Introducing a classification of instruments in order to allow enhanced comparison between the varieties of instruments. The categorisation follows that of Arnold et. al (2012)[468].

Table F: Classification of instruments

Action	Instrument	FP
Research actions	ERC Grants	FP7
Collaborative RTD actions	Integrated Projects	FP6
	Specific Targeted Research Projects	FP6
	Large-scale Integrating Project	FP7
	Small or medium-scale focused research project	FP7
	Integrating Activities / e-Infrastructures	FP7
	Collaborative project (generic)	FP7
Actions for RTD knowledge transfer	Specific Actions to Promote Research Infrastructures	FP6
	Marie Curie Actions	FP6
	Coordination Actions	FP6
	Network of Excellence	FP6
	Coordinating Action	FP7
	Marie Curie Actions	FP7
	Research Infrastructure	FP7
	Collaborative project dedicated to international cooperation partner countries (SICA)	FP7
Actions for adoption and innovation	Co-operative Research Projects	FP6
	Collective Research Projects	FP6
	Joint Technology Initiatives	FP7
	Research for SMEs	FP7
Actions to support policymaking	Specific Support Actions	FP6
	Supporting Action	FP7

iii) Participant organisations identifiers

For the FP6 and FP7 participants the following organisation identifiers were used:

- FP7: CD_ORG_ID and
- FP6: Participant Identifying Code-PIC.

If these were not available, the programme participant identifiers were used. In order to improve the comparability of the FP6 and FP7 participant identifiers, some manual matching based on organisation legal name and address data was conducted for the NT participant sample. As a result, 5,945 unique nanotechnology participants were identified.

[468] In their work Arnold et. al. (2012) Understanding the Long Term Impact of the Framework Programme classifies the instruments of FP4, FP5 and FP6 into four categories that are used as guidance for our classification. For FP7 the classification is done by authors of this report.

C3 Treatment of decimals

As a general rule, the data in the tables and figures are produced by utilising the method of first summing the unrounded figures and then rounding the sum. Due to this process, some totals may not correspond with the sum of the separate figures (generally presented as limited to one decimal).

C4 Key terminology and abbreviations used

Table G: FP6 funding instrument types

Code	FP6 Type of instrument
STREP	Specific Targeted Research Projects
CA	Coordination Actions
SSA	Specific Support Actions
II	Specific Actions to Promote Research Infrastructures
IP	Integrated Projects
NOE	Networks of Excellence
MCA	Marie Curie Actions
CRAFT	Co-operative Research Projects
CLR	Collective Research Projects
I3	Specific Actions to Promote Research Infrastructures

Table H: FP7 funding instrument types

Code	FP7 Type of instrument
CP	Collaborative project
ERC	Support for frontier research (European Research Council)
MC	Support for training and career development of researchers (Marie Curie)
JTI/169	Activities under Article 169 or 171 European Treaty, Joint Technology Initiatives, Public Private Partnerships
CSA	Coordination and support action
BSG	Research for the benefit of specific groups
NOE	Network of Excellence

Table I: Organisation types

Code	Description
HES	Higher or secondary education est.
PCO	Private companies excluding SMEs
REC	Research organisations
SME	Small and medium-sized enterprises
OTH	Other (incl. public bodies and bodies with unknown organisation types)

Table J: Country codes EU28+[469].

NUTS0	Country		NUTS0	Country
AT	Austria		LU	Luxembourg
BE	Belgium		LV	Latvia
BG	Bulgaria		MT	Malta
CY	Cyprus		NL	Netherlands
CZ	Czech Republic		PL	Poland
DE	Germany		PT	Portugal
DK	Denmark		RO	Romania
EE	Estonia		SE	Sweden
ES	Spain		SI	Slovenia
FI	Finland		SK	Slovakia
FR	France		UK[470]	United Kingdom
EL[471]	Greece		CH	Switzerland
HU	Hungary		IL	Israel
HR	Croatia		IS	Iceland
IE	Ireland		TR	Turkey
IT	Italy		NO	Norway
LT	Lithuania		ZK	Macedonia

D Publications

Identification of publications relied on analysis of the data in the database at CWTS (the Centre for Science and Technology Studies, Leiden University, the Netherlands), data that is based on that in the Web of Science[472].

The CWTS database is organised and structured such that it allows (dynamic) field delineation and the collection of relevant publications. Hence it was possible to identify nanoscience and nanotechnology (NST) publications and, within those, to identify publications relevant to the sectors. More specifically, publications were sought within the NST group using the keywords. In addition, using the tools available at CWTS, related publications could be identified and included in the output.

Data available from the resource at CWTS included the journals in which the publications are found, the date of publication and the doi (digital object identifier). For licensing reasons, some of the data in the database at Leiden can be accessed by external parties only in aggregate form. For example, personal details of individual researchers cannot be accessed (e.g. address, email, phone number).

The report uses ISO 2-digit codes for countries. See http://www.iso.org/iso/country_codes

[469] Data was also analysed from countries outside of the EU28 namely Iceland (IS), Israel (IL), Norway (NO), Switzerland (CH) and Turkey (TR).
[470] GB is also used
[471] GR is also used
[472] http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html

E Patents

The patents analysed were collected from the database PATSTAT. That database includes patents from over 30 patent offices e.g. the European Patent Office, the US Patent Office and the Japanese Patent Office.

All patent offices worldwide tag nanotechnology-related patent applications using a special symbol of the International Patent Classification (IPC), namely B82Y. This special symbol is also part of the CPC (Co-operative Patent Classification). The core dataset of nano-related patents were selected using this special symbol (B82Y) from both the IPC and the CPC classifications.

All patent applications at the USPTO, the EPO and PCT (WIPO) classified as B82Y were identified in PATSTAT as well as the (simple) patent family to which they belong. From all these patent families, only patent applications at the USPTO, the EPO and PCT (WIPO) were collected. Such use of multiple patent offices helps to diminish the bias that might be caused by the so called 'home advantage' effect, i.e. the propensity of nationals to file the first patent application in their own country. By analysing across these three patent authorities a less biased overview of nanotechnology patents worldwide can be obtained.

As the patent information is being collected from more than one patent authority, and given that the same invention might be protected in more than one of these patents authorities, the (simple) patent families are used to avoid multiple counting of the same invention.

The identification of patents by sector from amongst the nanotechnology patents was based in most cases on the combination of two strategies. First, all patents including in their title and/or abstract at least one relevant keywords for a particular sector were retrieved. Second, to ensure that the patents retrieved in the first step are truly related to the sector, a number of representative IPC symbols of the sector were selected from PATSTAT[473]. For example, for the nanotechnology patents related to the health sector, the IPC symbols related to 'Pharmaceuticals' and 'Medical technology' were used. However, it was not possible to undertake this second step for all sectors as for some (e.g. manufacturing) there were no appropriate IPC symbols.

Organisations and/or individuals are listed in patent applications, these being applicants and/or inventors. This information is used in the identification of companies, universities and other research organisations active in patenting. The year of reference used is the year when the oldest priority of each patent family was applied (the closest date to the invention). The report uses ISO 2-digit codes[474] for countries.

F Products

Products were identified primarily through keyword, sector and sub-sector searches of reports and databases. This search strategy was based on a triangulation approach making use of complementing perspectives. For all perspectives the NanoData team made use of the sector specific lists of key words.

The first step was to use peer-reviewed and grey literature on products in the different sectors[475] as well as existing market reports[476]. The market reports were used to identify where nanotechnology is being applied already in products as there are many reports that appear to identify products but no product is for sale at a commercial level, being at the research stage or for very limited supply e.g. to the research community or for test purposes. These investigations were then complemented by querying web-based databases on nanotechnology products such as AZONANO[477], Nanowerk[478],

[473] PATSTAT also contains a table mapping 44 industrial sectors and the IPC classification. The linkage between technology areas and industrial sector is described in Schmoch et al (2003), "Linking Technology Areas to Industrial Sectors", final report to the European Commission, DG Research.
[474] http://www.iso.org/iso/country_codes
[475] E.g. Nanomedicine: Nanotechnology, Biology, and Medicine 9 (2013) 1–14, Hessen Nanotech (2008) Applications of Nanotechnologies in the Energy Sector.
[476] See BCC Research www.bbcresearch.com
[477] http://www.azonano.com/
[478] http://www.nanowerk.com/

the consumer products inventory of the Project on Emerging Nanotechnologies[479], the product database of understandingnano.com[480], the Nanoinformationsportal of the Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH[481], the Danish Inventory of Nanoproducts[482] and the nanowatch.de database[483]. Further sector-specific databases, such as the German database for medical practitioners and the database on European public assessment reports of the European Medicines Agency[484], were used for the identification and classification of nanotechnology related products in health, for example.

By querying databases on existing innovation policy projects, initiatives and industry platforms such as NANORA[485], the Nano-Map of the German Federal Ministry of Research[486], the database on photonic companies compiled by EPIC, the members directory of SEMI[487], and the Nano-Bio Manufacturing Consortium (USA)[488], additional enterprises active in nanotechnology sectors were identified.

A third perspective on products was developed by gathering additional information about the products from company websites identified in previous work, commercial databases and open sources of information on the web. The information was verified through additional searches (e.g. of product data sheets and company websites).

The information in the database was extensively verified. Where, for example, it was found that a product was identified but not verified, searches were made of sources including reports and company websites to check the information. Contact was also made, in some cases, directly with the company in order to ratify the existence on the market of the product. While some other databases actually state the level of known accuracy of their information (e.g. the entries in the Woodrow Wilson database are classified using a system that has categories from level 1 (extensively verified claim) to level 5 (not advertised by manufacturer – claims made only by third party)) others are not specific.

In NanoData, the aim is only to include products that can be verified.

G Other information

Several types of information are provided on the NanoData site as fixed text where data is limited or one-off. These include information on markets and wider economic data, as well as reports on environmental health and safety and information about regulation and standards.

Markets

The market data is based on available sources of information and sources of Frost & Sullivan and BCC Research, who gather their information through discussions with practitioners (e.g. company representatives) and open sources (e.g. commercial reports, web sites). The aim was to track, evaluate and measure the activities of major industry participants in the nanotechnology arena, looking at markets and usage of nanotechnology. The activities included the definition and specification of nano-materials and nano-enabled products, identification of current and upcoming products and applications, accumulating qualitative and quantitative data, identification and mapping of EU participants and last but not the least, identification and analysis of target markets.

A wide set of definitions, categorisations, data collection and forecasting methods were available. Data gathering was driven by experienced analysts and based on a data-rich portfolio of previous EU and OECD projects as well as on internal Frost & Sullivan databases and consortium members,

[479] http://www.nanotechproject.org/cpi/
[480] http://www.understandingnano.com/nanotechnology-product-suppliers.html
[481] http://nanoinformation.at/produkte.html
[482] http://nanodb.dk/
[483] http://www.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank/
[484] http://www.ema.europa.eu/
[485] http://www.nanora.eu/
[486] http://www.werkstofftechnologien.de/en/
[487] http://www.semi.org/en/Membership/MemberDirectory/
[488] http://www.nbmc.org/members-only/

and public database. European Patent Office[489], PRODCOM[490] and patentlens[491] databases could be used to provide in-depth information about a particular technology and to identify the key industry participants dominating the sector. Analysis of key value chains was undertaken and corroborated with other work-streams. The information thus acquired would be verified with the help of an array of primary interviews with leading technology researchers, industry experts and other active stakeholders.

The range of primary and secondary research processes would be followed by the application of innovation diffusion tools in order to forecast probable market scenario of the future. This would also include estimating the shape of the diffusion curve and prediction of market development of nano-enabled products.

Wider economic data

External information sources such as Eurostat, OECD and WHO data sources were used to put the nanotechnology data obtained in the project into context.

For example:

- A brief overview of the energy industry was based on Eurostat data.
- The health industry overview was based on Eurostat data supplemented by reports from industry organisations (both technical (e.g. the industry association for European pharmaceutical enterprises) and financial (e.g. the European Private Equity & Venture Capital Association))

While reports on industry as a whole were available, there were found to be very few reliable reports on nanotechnology and industry. Nanotechnology databases were also explored (e.g. those of Nanowerk and Nanora).

Environmental health and safety

For the sectors in which materials were the main focus, the tool used for the environmental health and safety evaluation was the "Stoffenmanager Nano" application[492]. In summary, Stoffenmanager Nano is a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios. In the absence of a comparable tool for consumer exposure, it was also used for this type of exposure. Stoffenmanager Nano combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. Stoffenmanager Nano does not consider dermal and oral routes of exposure.

In Stoffenmanager Nano, the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). Likewise, exposure bands are labelled 1-4 (1=low exposure, 4= highest exposure).

The hazard and exposure bands are combined to yield so called priority bands ranging from low priority (=4) to high priority (=1). A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures or to establish the risk involved with more precision.

See also Annex: *Human health and safety.*

Regulation and standards

International, European, national and regional data sources for regulation and standards include:

European documents:

- Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) - 1907/2006(EC);
- Regulation on Medical Devices - 2012/0266(COD); and

[489] https://www.epo.org/searching.html
[490] http://ec.europa.eu/eurostat/web/prodcom
[491] https://www.lens.org/lens/search?n=10&q=nanotechnology&p=0
[492] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

- European Commission Recommendation on the Definition of a Nanomaterial, as well as sectoral documents such as
- Nanomaterials in the Healthcare Sector: Occupational Risks & Prevention - E-fact 73; and
- Guidance on the Determination of Potential Health Effects of Nanomaterials Used in Medical Device.

National documents:

- Decree on the annual declaration on substances at nano-scale - 2012-232 (France);
- Royal Decree regarding the Placement on the Market of Substances manufactured at the Nano-scale (Belgium); and
- Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register – BEK nr 644 (Denmark).

H Concluding remarks

This Annex outlines the main methods for the selection of data for analysis, some data sources, the aggregation of data classes in order to enable analysis (mainly for the FP projects) and the ways in which data was analysed. References are made to some of the main quality control issues.

ANNEX 2: ENVIRONMENT KEYWORDS

Below is the list of the main keywords used in the extraction of data and the subsequent analyses.

Asterisks are used to indicate that part of a word is missing. For example, the search for "green manufactur*" would identify data related to "manufacturing" and "manufacturer". Thus one search term was used to cover each of the words with multiple possible endings.

Keywords nanotechnology for the environment

air pollution	groundwater remediation
airborne pollutant	groundwater
airborne pollution	hazardous waste
atmospheric pollution	human exposure
bio nano remediation	landfill
bio-nano-remediation	nanoremediation
bionanoremediation	noise pollution
bioremediation	nuclear waste
carbon dioxide capture	oil pollution
circular econom*	oil spill*
climate change	oily waste treatment*
critical raw material	protection against radiation
desalination	radiation protection
dewatering of sludge	radioactive waste
eco-innovation	recycling
ecotoxic*	remediation
environmental benefit	road traffic noise
environmental monitoring	sludge dewatering
environmental protection	soil pollution
environmental remediation	soil remediation
environmental sustainability	sustainable manufactur*
green car	toxic site remediation
green chemistry	waste treatment
green innovation	wastewater treatment
green manufactur*	water pollution
green vehicle	water purification
greenhouse gas*	water recycling
groundwater cleanup	water treatment
groundwater pollutant	waterborne pollutant
groundwater pollution	waterborne pollution

Keywords nanotechnology in the environment

EHS	environmental risk
engineered nanoparticle	environmental toxicit*
environmental hazard*	LCA*
environmental health and safety	life cycle assessment
environmental pollutant	

ANNEX 3: ABBREVIATIONS

Abbreviation	Definition
CAGR	Compound annual growth rate
CEN	European Standardisation Committee
CMOS	Complementary metal-oxide semiconductor
CNT	Carbon nanotubes
CO	Carbon Monoxide
CO2	Carbon dioxide
Cu	Copper
COSME	Competitiveness for the Competitiveness of Enterprises and SMEs
CW	Chemical Warfare (agents)
EARDF	European Agricultural Fund for Rural Development
EAP	Environmental Action Programme
EC	European Commission
ECHA	European Chemicals Agency
EEA	European Environment Agency
EFSA	European Food Safety Authority
EGGS	environmental goods and services sector
EHS	Environmental Health and Safety
EIT	European Institute of Innovation and Technology
EMFF	European Maritime and Fisheries Fund
EMPIR	European Metrology Programme for Innovation and Research
EP	environmental protection
EPA	Environmental Protection Agency
EPO	European Patent Office
ERC	European Research Council
ERDF	European Regional Development Fund
ESIF	European Structural and Investment Funds
ETP	European Technology Platform
EU	European Union
EV-NT	Environment nanotechnology
FET	Future and Emerging Technologies
FP	Multi-annual Framework Programmes for Research and Technological Development
ICT	Information and Communication Technologies
IPC	International Patent Classification
IPR	Intellectual property rights
ISO	International Organisation for Standardisation
JPI	Joint Programming Initiative
JRC	Joint Research Centre
JTI	Joint Technology Initiatives
KET	Key Enabling Technology
KIC	Knowledge and Innovation Community

LED	Light Emitting Diode
MEMS	Micro-electromechanical system
MnCo	Manganese
MWCNT	Multi-walled carbon nanotubes
NACE	Nomenclature statistique des activités economiques dans la communauté européenne
NMP	Nanosciences, Nanotechnologies, Materials and new Production Technologies
NOx	Nitrogen oxides
NP	Nanoparticles
NST	Nanoscience and nanotechnology
NT	Nanotechnology
OECD	Organisation for Economic Co-operation and Development
Pb	Lead
ppm	Parts per million
PRC	People’s Republic of China
QCA	Quantum Caged Atom
QD	Quantum dot
R&D	Research and development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RM	resource management
SAMMS	self-assembled monolayers on mesoporous silica
SEN	single nanoparticle enzymes
SME	Small or medium sized enterprise
SOER	State of the Environment
SSD	Site-selective deposition
SWCNT	Single walled carbon nanotubes
TFEU	Treaty on the Functioning of the European Union
TiO2	Titanium dioxide
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
US	United States
US EPA	US Environmental Protection Agency
US NIOSH	US National Institute for Occupational Safety and Health
USA	United States of America
USPTO	US Patent and Trademark Office
UWWTD	Urban Waste Water Treatment Directive
VOC	Volatile organic compounds
WEEE	Waste electrical and electronic equipment
WHO	World Health Organization
WIPO	World Intellectual Property Organisation
WssTP	Water Supply and Sanitation Technology Platform
Zn	Zinc

ANNEX 4: TERMINOLOGY

Word/phrase	Definition/explanation
Carbon nanotubes	Allotropes of carbon with a cylindrical nanostructure.
Dendrimers	Nanostructured synthetic molecules having evenly spread branching structure originating out of a central core.
Nanobiosensors	Biosensor at nano-scale: measurement system for detection of an analyte that combines a biological component with a physiochemical detector
Nanobiotechnology	Intersection of nanotechnology and biology, the ways that nanotechnology is used to create devices to study biological systems, this is different from bionanotechnology
Nanocapsule	Nano-scale shells made out of a nontoxic polymer
Nanocarrier	Nano-object or objects, which are at a larger scale but which carry nanoscale payloads able to transport a diagnostic or therapeutic agent either on its surface, within its bulk structure or within an internal cavity
Nanocoatings	Applying a coating of nano-scale structures to a surface.
Nanocrystal	Nano-object with a crystalline structure
Nanodiagnostics	Application of nanotechnology in molecular diagnostics
Nanoemulsion	Nanodispersion with a liquid matrix and at least one or more liquid nano-objects
Nano-enabled	Products, systems, devices integrating, using, enabled by nanotechnology
Nano-fibres	Nano-object with two external dimensions in the nanoscale and the third dimension significantly larger
Nanoindentation	Variety of indentation hardness tests applied to small volumes. For testing the mechanical properties of materials (hardness).
Nanomaterials	Materials the single units of which is sized (in at least one dimension) between 1 and 1000 nanometres (10^{-9} meter) but is usually 1—100 nm (the usual definition of nano-scale).
Nanomedicine	Medical application of nanotechnology
Nanometres	One billionth of a metre
Nano-needles	Conical or tubular needles in the nanometre size range, made from silicon or boron-nitride with a central bore of sufficient size to allow the passage of large molecules
Nanoparticle	Small object that behaves as a whole unit with respect to its transport and properties, between 1 and 100 nanometres in size.
Nanopolymers	Nanostructured polymers
Nanoproducts	Any product containing nanoparticles
Nanorod	One morphology of nano-scale objects, produced by direct chemical synthesis.
Nano-scale	Refers to structures with a length scale applicable to nanotechnology, usually cited as 1–100 nanometres, also called nanoscopic scale
Nanoscience	The study of the fundamental and functional properties of matter on the nano-scale ($\sim10^{-9}$m).
Nanosensor (proteomic, gold)	Any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world
Nanoshells (plasmon)	This is also called nanoshell plasmon, is a type of spherical nanoparticle consisting of a dielectric core, which is covered by a thin metallic shell (usually gold).
Nano-specific	Refers to a system or response that is sensitive to nanomaterials

Nanostructures	An object of intermediate size between microscopic and molecular structures
Nanosuspensions	Submicron colloidal dispersions of nanosized drug particles stabilised by surfactants. Nanosuspensions consist of the poorly water-soluble drug without any matrix material suspended in dispersion
Nanotechnologies / nanotechnology	Manipulation of matter with at least one dimension sized from 1 to 100 nanometres
Nanotechnology-based platforms	Suite of technologies using nanomaterials, structures and objects
Nanotube	Hollow nano-fibre
Quantum dots	A nanocrystal made of semiconductor materials that are small enough to exhibit quantum mechanical properties

ANNEX 5: ADDITONAL INFORMATION ON MEMBER STATE POLICIES AND PROGRAMMES

In addition to actions at the level of the whole of the European Union, many countries have developed strategies and action plans and funded programmes and projects. Some of these are identified and outlined below, by country.

The aim in this section is to give a flavour for the policies and programmes that are or have been in place for nanotechnology at Member State level, in the wider context of national strategies for science, technology, research and development. As it focusses on targeted initiatives for nanotechnology, not all EU28 countries are included.

This section has been prepared from existing data sources (e.g. Member State government and agency reports and web sites, European Commission sources (such as ERAWATCH/RIO[493]), evaluation reports). While efforts have been made to use the most up-to-date sources, it cannot be guaranteed that all information is current.

AUSTRIA

In Austria, the two main ministries involved in the funding of research and development (R&D) are the Federal Ministry of Science and Research (BMWF)[494] and the Federal Ministry for Transport, Innovation and Technology (BMVIT)[495]. The largest share of direct support for R&D is channelled through three funding agencies: The Austrian Science Fund (FWF)[496] that focuses on funding academic research; the Austrian Research Promotion Agency (FFG)[497] specialising in funding applied industrial research and the co-operation between the higher educational sector and industry; and the Austria Economic Service (AWS)[498] that is mainly active in support programmes for SMEs.

In 2004, the Federal Ministry for Transport, Innovation and Technology launched the "Austrian NANO Initiative" and in 2010, the "**Austrian Nanotechnology Action Plan**"**[499]** was adopted by the Federal Government. The NANO initiative was a response to regional activities in the Austrian Bundesländer (such as NanoNet Styria [for more information, see later in this Annex]) that sought to identify existing competences and to formulate potential themes for large-scale co-operative projects.

An important motivation in the establishment of such a national research programme was the expectation that its creation would strengthen the national research community in specific fields thereby better linking them to international communities. At that time, most Austrian peer countries (Germany, Switzerland, UK, and Finland), as well as the European Framework Programmes, were using the label nanotechnology for framing focused research programmes.

The NANO initiative aimed to address the following issues: What would be the best way for Austria to harness the opportunities in nanotechnology (for instance, in environmental and energy technology and new resource-saving products or for small- or medium-sized enterprises)? How could Austria contribute to ensuring the safety for its citizens of nanotechnology applications?

NANO had the following objectives: to increase networking among actors so as to achieve critical mass; to open up ways to exploit the benefits of nanotechnology for industry and society; and to ensure proper support for qualified personnel. To achieve these objectives it had two programme action lines:

1. National co-operative RTD Projects (Research and Technology Development in Project Clusters (RPCs) and
2. Transnational co-operative RTD Projects (Research and Technology Development in

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[493] https://rio.jrc.ec.europa.eu/
[494] http://www.en.bmwfw.gv.at/
[495] https://www.bmvit.gv.at/en/
[496] https://www.fwf.ac.at/en/
[497] https://www.ffg.at/en
[498] http://www.awsg.at/
[499] https://www.bmlfuw.gv.at/dam/jcr:00058164-0320-4544-b6a4-320325dcfd86/Austrian%20Nanotechnology%20Action%20Plan.pdf

Transnational Projects).

A key aspect of the **Nanotechnology Action Plan** to implement the NANO initiative was to strengthen communication and the dissemination of information to specific target groups, particularly the interested public. Information on the fundamentals, opportunities and risks of nanotechnology was provided to the public through an information portal for nanotechnology. A primary objective was to engage the public in the process of drawing up and implementing a Nanotechnology Action Plan[500], which underwent public consultation via the Internet in Autumn 2009, as did the Implementation Report in November 2012. The feedback received was published online and taken into account in the follow up to the Action Plan and Implementation Plan respectively.

One of the central measures of the Austrian Nanotechnology Action Plan was the establishment of a programme for the environment, health and safety (EHS). NANO EHS was established to provide targeted funding for environment- and health-related research into assessing the risks of synthetic nanomaterials.

NANO was implemented from 2004 to 2011 by the Austrian Research Promotion Agency (FFG)[501] and, in total, nine large-scale co-operative projects were funded across a wide array of sectors such as photonics, nanomedicine, and nanomaterials. Since 2012, support for nanotechnology R&D has been provided through the thematic programmes of FFG.

In addition to the above governmental actions, an Austrian network was created, **BioNanoNet**[502]**,** combining a wide range of expertise in numerous disciplines of medical and pharmaceutical research in nanomedicine and nanotoxicology. The BioNanoNet Association is also the owner of BioNanoNet Forschungs GmbH. Working across both biotechnology and nanotechnology, and visible at international levels, BioNanoNet addresses the scientific areas of:

- Nanotoxicology,
- Sensor technology
- Health and safety, including (nano-) medicine and nanosafety.

The BioNanoNet coordinates **EURO-NanoTOX**[503], which is an open virtual centre and national platform. EURO-NanoTOX is co-funded by the Federal Ministry of Science and Research (BMWF). It elaborates strategies to conduct standardised toxicological in-vitro as well as in-vivo methods on nanostructured materials. Its main focus is on human nanotoxicology and human risk assessment.

Regional Nanotechnology initiatives:

Wirtschaftsstrategie Steiermark 2020 (2011)[504]**:** Styria's Economic Strategy 2020 is a successor to the State Government's previous economic strategy 2006. The 2006 strategy identified so-called economic and technological strong-points ("Stärkefelder") of the region, on which innovation policy activities were focused: material sciences; mechanical engineering/automotive and transport technologies; chemical and process engineering; human technology; information and communication technologies; environmental technologies; energy; building services engineering (including timber construction); nanotechnology; computer simulation and mathematical modelling. The 2011 strategy bundles activities in these fields under three major leading themes: i) mobility, ii) eco-technology, and iii) health technology. The central aim is to focus on future activities and to establish Styria as a "European benchmark for the structural change towards a knowledge based production-society".

BELGIUM

Since its two regions play a central role in Belgian policy making, the main nanotechnology activity in the country is carried by the regional government of Flanders, with a number of institutions working in the area of nanotechnology.

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[500] http://www.sozialministerium.at/cms/site/attachments/6/1/7/CH2120/CMS1371046721712/umsetzungsbericht_2012_en.pdf
[501] https://www.ffg.at/en
[502] http://www.bionanonet.at/about-bionanonet
[503] http://www.bionanonet.at/about-nanotoxicology?lang=english
[504] http://www.wirtschaft.steiermark.at/cms/beitrag/10430090/12858597

Strategische onderzoekscentra[505] (SOC's) is a strategy of the Region of Flanders which gives institutional funding to four Strategic Research Centres that collaborate with the academic and business worlds. Each of the institutes have their own specific focus.

- Imec[506] is a leading European independent research centre in micro- and nanoelectronics, *nanotechnology,* design methods and technologies for ICT systems. It carries out research that runs three to ten years ahead of industrial needs. The world's top integrated device manufacturers, equipment and material suppliers, system houses and electronic design automation (EDA) vendors participate in the research conducted there. Work at Imec has a strong connection to nanotechnology given its use in electronics and as the next generation technology for electronics and ICT.
- VIB[507], the Flanders Institute for Biotechnology, is an autonomous entrepreneurial research institute that conducts strategic basic research in life sciences, including molecular biology, cell biology, developmental biology, structural biology, genetics, biochemistry, microbiology, genomics and proteomics. It is considered to be a leading European centre. Much of its work is at the *nanoscale*.
- VITO[508], the Flemish Institute for Technological Research, is an independent contract research and consulting centre. It converts the latest scientific knowledge and innovative technologies into practical applications, both for public authorities and industry. The research centre operates in the fields of energy, environmental and material technology, in industrial product and process technologies and in remote sensing, with *nanotechnology* applications.
- iMinds[509] is an independent research institute that stimulates innovation in information & communication technology (ICT) and broadband. This research is interdisciplinary and demand-driven, and takes place in close collaboration with businesses and governments, both local and international. Its aim is to provide solutions to complex problems and thus help meet society's future challenges.

In 2003, the Regional Government of Wallonia launched a nanotechnology programme in order to support research projects in that field which led to the creation of **NanoWal[510]**, a structure to favour interactions between actors in nanotechnology field. Nanowal became a non-profit organisation in 2009.

THE CZECH REPUBLIC

In 2005, the Academy of Sciences of the Czech Republic approved the programme "**Nanotechnology for the Society**" with the objective of achieving progress in the development of research and utilisation of nanotechnologies and nanomaterials within Czech society[511]. It included four different sub-programmes in the areas of: nanoparticles, nanofibres and nanocomposite materials; nanobiology and nanomedicine; nano-macro interface; and new phenomena and materials for nanoelectronics, with specific priorities in all of them. The programme was planned to end in 2012.

Other general programmes with a less specific mention to nanotechnology came from the Grant Agency of the Czech Republic, the Ministry of Education, Youth and Sports and the Ministry of Industry and Trade.

In the National Research, Development and Innovation Policy document of the Czech Republic in 2009-2015[512], nanotechnology is addressed under the **Materials Research** priority, where it is set as an area to be supported by national budget in order to increase the global competitiveness of the Czech economy through products with high added-value.

505 http://www.ewi-vlaanderen.be/wat-doet-ewi/excellerend-onderzoek/strategische-onderzoekscentra
506 http://www2.imec.be/be_en/home.html
507 http://www.vib.be/en/Pages/default.aspx
508 https://vito.be/en
509 https://www.iminds.be/en
510 www.nano.be/
511 http://www.csnmt.cz/getfile.php?type=file&IDfile=24
512 http://www.vyzkum.cz/FrontClanek.aspx?idsekce=1020

DENMARK

In Denmark, the Ministry of Higher Education and Science[513] has the main responsibility for research and innovation policy.

In the period from 2001 to 2004, steering groups set up by the Danish government carried out a Technology Foresight pilot programme. The aim of the programme was to carry out eight foresight studies in the three-year period, and to identify issues of strategic importance for science, technology, education, regulation and innovation policy in these areas. The foresight studies included bio- and health care technologies, and ICT (pervasive computing, future green technologies, hygiene and nanotechnology, especially nanomedicine[514]). The last phase of the foresight programme was closely linked to the establishment of the Danish National Advanced Technology Foundation[515] for the development of generic technologies of future importance such as ICT, biotechnology and nanotechnology.

The Action Plan "Strategy for Public-Private Partnership on Innovation", launched in 2003, focused on how to improve co-operation between education, research and trade/ business. The goal was for more enterprises, especially SMEs, to have faster and easier access to knowledge. In 2004, the Ministry of Science, Technology and innovation issued **the Technology Foresight on Danish Nanoscience and Nanotechnology – Action Plan[516]** as a basis for Danish policy on research, education and innovation in the area. The vision was to raise awareness of and promote the utilisation of nanotechnology in Denmark.

In 2003, on foot of the above developments, the Ministry of Science, Technology and innovation published a call for the establishment of high-tech public-private networks in bio, nano and information technology. The goal was to create stable collaboration patterns between companies and knowledge institutions to increase knowledge transfer to, and use in, private industry. The funding was to be used to finance networking. In the first round (in 2004) the Ministry provided seven networks with a budget of EUR 3.7 million (around EUR 0.5 million each). Amongst the networks was NaNet which, (together with Nano Øresund) became one of the two most important Danish nanotechnology networks. NaNet's mission was to create platforms for the exchange of information on nanotechnology, and to facilitate its utilisation on all levels of society, from research and education to industrial application and development.

Between 2005 and 2010, EUR 116 million was allocated to strategic research centres, research alliances and research projects, EUR 62 million being for nanotechnology, biotechnology and ICT. Among the strategic research centres funded under the programme is a Centre for Nano-vaccines[517].

Since 2009, the Danish National Advanced Technology Foundation has channelled funding for projects in high-tech sectors, such as nanotechnology, biotechnology and ICT.

Support for nanotechnology research has been managed through a number of sources. The Danish Council for Strategic Research, part of the Danish Agency for Science, Technology and Innovation is one of these, although the council itself did not authorise funds for research, dependent instead on the Programme Commission, which covers Nanoscience, Biotechnology and IT (NABIIT). The Strategic Research Programme for the Interdisciplinary Applications of NABIIT technologies supported the establishment of networks and research initiatives. Research support also came from the Danish National Research Foundation, the Danish Ministry of the Interior and Health's inter-ministerial working group on Nanotechnology and Human Health, and the Danish National Advanced Technology Foundation. Latterly, also under the Danish Council for Strategic Research, the Programme Commission on Strategic Growth Technologies has had annual calls of total annual value approximately EUR 10 million for research projects on nanotechnology, biotechnology and information- and communication technology. In 2013, The Danish government and five political parties decided to revise the research and innovation system, agreeing to merge the Danish National Advanced Technology Foundation, the Danish Council for Strategic Research and the Danish Council for Technology and Innovation into a new innovation foundation. Thus, the new organisation

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513 http://ufm.dk/en
514 Danish Nano-science and Nano-technology for 2025, Foresight Brief No. 032
515 http://www.tekno.dk/about-dbt-foundation/?lang=en
516 http://ufm.dk/en/publications/2004/technology-foresight-on-danish-nanoscience-and-nanotechnology
517 http://www.nano-vaccine.org/

Innovation Fund Denmark[518] (IFD), has been the responsible body since 2014.

FINLAND

The main focus areas of public research and development (R&D) funding in Finland are energy and the environment, health and well-being, the information and communications industry, the forest cluster, and metal products and mechanical engineering. Nanotechnology is treated as a technology to be applied across all these focus areas. Finland spends approximately 3.5 % of its gross national product on (R&D). Exploitation of research results being seen as even more important than the amount of investment, the Finnish innovation environment seeks to promote the exploitation of scientific and technological results in Finnish companies.

The main research policy decisions are drawn up in the Science and Technology Policy Council of Finland chaired by the Prime Minister. The principle instruments in the implementation of the policy are the funding organisations working under the ministries. Tekes, the Finnish Funding Agency for Technology and Innovation operates under the remit of the Ministry of Trade and Industry while the Academy of Finland is governed by the Ministry of Education. Nearly 80% of all public research funding is channelled through these two organisations.

The **first Finnish nanotechnology programme** was financed jointly by Tekes and the Academy of Finland in 1997–1999[519]. Its objective was to build know-how, multi-disciplinary infrastructure and linkages between fundamental and applied research. The programme also established a new form of co-operation using joint funding between Tekes and the Academy of Finland. The total value of the programme was EUR 7 million (Tekes EUR 4m, the Academy of Finland EUR 3 m).

FinNano, the Finnish nanoscience and nanotechnology programme, was established in 2005. The programme was co-ordinated jointly by Tekes and the Academy of Finland and covered the whole innovation chain from basic research to commercial products. The aim of the programme was to strengthen Finnish nanotechnology research in selected focus areas and to accelerate the commercial development of nanotechnology in Finland. The key objective was to boost internationally recognised high-level research and competitive business based on nanotechnology.

In addition to FinNano, the Ministry of Education provided funding to develop nanoscience education and infrastructure in Finnish universities and the Nanotechnology Cluster Programme was initiated in 2007 with the Centre of Expertise Programme. In total, Finnish public funding for nanotechnology during 2005–2010 was approximately EUR 235m.

In practice, the FinNano programme was executed in two parts: Tekes' FinNano – Nanotechnology Programme (2005–2009) and the Academy of Finland's FinNano – Nanoscience Programme (2006–2010). The Programme had a total value of approximately EUR 70m, including EUR 25m in research funding and EUR 20m in corporate financing from Tekes. The original programme plan defined three main focus areas:

1) Innovative nanostructure materials;
2) Nanosensors and nanoactuators; and
3) New nanoelectronics solutions.

In 2007, the aims of the programme were redefined as being for:

- Society: Renewal of industry clusters and production, environment and safety;
- Applications: Electronics, forest cluster, chemical sector, health and well-being; and
- Technologies: Nanostructured and functional materials, coatings and devices; Measurement methods, production and scalability.

According to a programme's interim evaluation in 2008, the main successes of FinNano were to activate companies in research and product development, to map all the existing nanotechnology infrastructure and to create cross-cutting networks of nanotechnology professionals.

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[518] http://innovationsfonden.dk/en; In 2015, IFD had an annual budget of DKK 1.6 billion, but their budget is expected to decrease to DKK 1.47 billion in 2016. The total budget for innovation funds areas was over DKK 2 billion in 2010, so a significant loss of funding took place during the last 5 years. http://innovationsfonden.dk/da/nyhed/innovationsfonden-investerer-ogsaa-i-forskernes-gode-ideer
[519] http://www.tekes.fi/globalassets/julkaisut/research_and_technology.pdf

In 2011, the final report on FinNano was published, showing the results of the Programme[520]. According to that report and an independent evaluation by Gaia Consulting Ltd., all the Finnish nanotechnology programmes succeeded and fulfilled their objectives, which ranged from capturing knowledge in nanoscience and technology to boosting Finnish nano research and business. The next steps in the development of nanotechnology for industry in Finland were recommended to be achieved by other means. These included measures to enhance technology transfer, encouragement of entrepreneurship, and seed funding and basic research funding based on problems and not in disciplines.

In more recent years, Finland has therefore stopped identifying nanotechnology as a separate area for funding, opting to fund it under general R&D funding programmes and actions to enhance technology transfer and commercialisation by industry in Finland.

FRANCE

In 1999, the "**French Research Network in Micro and Nano Technologies**" (RMNT) was created for the purpose of strengthening and reorganising micro- and nano research and aligning it with the private sector.

In 2003, a **network of major technology centres** was created, linking together the facilities at the following organisations:

- CEA-LETI[521] in Grenoble (centred in Minatec);
- The Laboratoire d'Analyses et d'Architectures des Systemes[522] (LAAS) in Toulouse ;
- The Laboratoire de Photonique et de Nanostructures[523] (LPN) in Marcoussis ;
- The Institut d'Électronique Fondamentale[524] (IEF) Orsay, in Minerve; and
- The L'Institut d'Electronique, de Microélectronique et de Nanotechnologie [525] (IEMN) in Lille.

The creation of this network was supported by a total subsidy of EUR 100 million for the period 2003 to 2006.

Launched in 2003 to fund fundamental research, France's national N**anosciences Programme** was co-ordinated by the Ministry of Research in co-operation with the CNRS (National Scientific Research Centre), the CEA (French Atomic Energy Commission) and the DGA (General Delegation for Weaponry).

In 2005, the French National Research Agency (ANR) was established to assume responsibility for the funding and organisation of all national R&D projects, in order to improve co-ordination. Today, national nano research is funded within the national programme for nanosciences and nanotechnologies (**PNANO[526]**) under the ANR. The budget of the ANR for 2005 was EUR 539m, EUR 35.3m of which was dedicated to PNANO. The ANR has funded research projects in nanosciences and nanotechnologies mostly through the following research programmes:

- Non-thematic programmes (called "programmes blancs")
- Nanotechnologies and Nanosystems programmes P2N.
- Additional programmes, which are more specific to a given topic, such as those on hydrogen storage and fuel cells or on home photovoltaics.

A EUR 35 billion economic stimulus package **Investissements d'Avenir[527]** (Investments for the Future) was launched at the end of 2009. Within that context and since 2011, nano-bio-technology has been one of the priority areas for funding under the ANR, with a particular focus on health and environmental research. The package aims to support scientific research, accelerate its transfer to a pilot stage and to consolidate knowledge about toxicology and nanomaterials, the programme is funding therapies, imaging, diagnostics and medical devices base on nanotechnology and

[520] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf
[521] http://www-leti.cea.fr/en/
[522] https://www.laas.fr/public/
[523] http://www.lpn.cnrs.fr/fr/Commun/
[524] http://www.ief.u-psud.fr/
[525] http://exploit.iemn.univ-lille1.fr/
[526] http://www.agence-nationale-recherche.fr/suivi-bilan/historique-des-appels-a-projets/appel-detail1/programme-national-en-nanosciences-et-nanotechnologies-pnano-2005/
[527] http://www.gouvernement.fr/investissements-d-avenir-cgi

biotechnology.

GERMANY

As far back as 1998, the Federal Ministry of Education and Research (BMBF) increased collaborative project funding for nanotechnology. In addition, an infrastructure plan was put in place in the form of the establishment of six competence centre networks. The measures were implemented two years before the USA began its national nanotechnology initiative and four years before the European Union’s comparable measures under the Sixth Framework Programme.

In 2004, the German Innovation Initiative for Nanotechnology - “**Nanotechnology Conquers Markets**[528]” was launched and presented to the public. On the basis of the White Paper presented at the nanoDe congress in 2002 and intensive discussions with representatives from business and science, the BMBF’s new approach to nanotechnology funding was based on Germany’s highly-developed and globally competitive basic research in sciences and technology and primarily aimed to open up the application potential of nanotechnology through research collaborations (leading-edge innovations) that strategically target the value-added chain. The main elements of the strategy were to open up potential markets and boost employment prospects in the field of nanotechnology. Five leading-edge innovation programmes were funded initially:

- NanoMobil, for the automotive sector;
- NanoLux, for the optics industry;
- NanoforLife, for pharmaceuticals and medical technology;
- NanoFab, for electronics; and
- NanoChance, a BMBF funding measure for targeted support of R&D -intensive small and medium-sized enterprises.

Existing policy actions were re-organised under the umbrella of the **High-Tech Strategy**[529] in 2006. This was done through the **Nano Initiative—Action Plan 2010**[530], a cross-departmental initiative by seven departments of the Federal Government that started in 2007 and was headed by the BMBF. Tying in with BMBF's 2004 Innovation Initiative for Nanotechnology, the action plan aimed to integrate nanotechnology funding in the various policy fields into a national nanotechnology strategy. The Action Plan's main goals were (1) to speed up the use of the results of nanotechnological research for innovations; (2) to introduce nanotechnology to more sectors and companies; (3) to eliminate obstacles to innovation by means of early consultation in all policy areas; and (4) to enable an intensive dialogue with the public. The focus was on the opportunities offered by nanotechnology, but possible risks were also taken into account. The total funding for the years 2007 to 2009 was EUR 640 million.

In 2011, the German Ministry for Education and Research (BMBF) published the **Action Plan Nanotechnology 2015**[531], outlining the strategy for responsible development, innovation and public dialogue for the period 2010-2015. The plan included proposals for developing nanotechnology in five main areas (climate/energy, health/food and agriculture, mobility, communication and security). In parallel, a new funding instrument was launched - **Innovation Alliances** - to provide funding for strategic co-operation between industry and public research in key technology areas that demand a large amount of resources and a long time horizon, but promise considerable innovation and economic impacts. Public funds and funding from the industry is combined in a typical proportion of 1:5 (public: private). Innovation was supported with special emphasis on SMEs and development of value chains. Risk assessment was incorporated as well as an improvement of boundary conditions such as educating the workforce, and addressing issues of legislation, norms and standards. The public dialogue on nanotechnology was intensified, including information and dialogue with citizens as well as stakeholders and NGOs.

Innovation alliances were launched as a successor to the leading edge innovation programmes. They were planned as an instrument of public support to ground-breaking industrial innovation, providing support funding for strategic co-operation between industry and public research in high-potential technology areas that require high levels of funding and long lead times. Through a public-private

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528 http://d-nb.info/97392179x/34
529 http://www.research-in-germany.org/en/research-landscape/r-and-d-policy-framework/high-tech-strategy.html
530 http://www.cleaner-production.de/fileadmin/assets/pdfs/Nano_initiative_action_plan_2010.pdf
531 http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf

partnership, the Federal Government provided funding for R&D and other innovation-related activities for specific, long-term co-operative R&D projects. R&D activities could range from fundamental research to prototype development. Public funds were complemented by private money from industry, typically at a proportion of 1:5 (public: private). Each innovation alliance was set up through an industry initiative, organised as a long-term co-operative research project and involving several industry partners as well as public research organisations.

An Innovation Alliance that followed this policy approach was on "Molecular Imaging for Medical Engineering" (nanotechnology) and was formed by Bayer Schering Pharma AG, Boehringer Ingelheim Pharma GmbH & Co. KG, Carl Zeiss AG, Karl Storz & GmbH Co. KG and Siemens AG. The alliance's goal was creating new diagnostic agents and imaging procedures for clinics and the development of pharmaceuticals.

In addition to policies and programmes to support R&D and commercialisation, Germany took action to address concerns about the environmental and safety costs of the nanotechnology. These are particularly important to look at when trying to develop and label commercial nanotechnology products for the market. In response to these issues, governments have increasingly included the concept of responsible development in their nanotechnology activities. Responsible development aims to stimulate the growth of nanotechnology applications in diverse sectors of the economy, while addressing the potential risks and the ethical and societal challenges the technology might raise. Germany has dedicated policies for the responsible development of nanotechnology. The report "Responsible Handling of Nanotechnologies" ("Verantwortlicher Umgang mit Nanotechnologien") launched by the Nano-Commission of the German Federal Government in December 2010 showed that the nanotechnology sector is continuing to develop dynamically.

Regional initiatives in Germany that make specific mention of nanotechnology include:

- Innovation Strategy of Nordrhein-Westfalen (2006): This strategy was a government statement dated 26 June 2006. It presented a short analysis of the importance of innovations for North Rhine-Westphalia, and in the following elaborated the overall strategy and the measures employed and purposes targeted. The government strategy aimed to generate new potential for growth by reinforcing strengths, sharpening profiles, promoting excellence and pooling forces. Thus, the funding of research and technology was focused on four priority areas with high potential both related to innovation, employment and growth: (i) ***nanotechnology,*** microtechnology and new materials; (ii) biotechnology; (iii) energy- and environmental research; and (iv) medical research, medical engineering.
- Cluster Offensive Bayern (2007)[532]: The Bavarian cluster policy was initialised in 2007 and focused on 19 branches/technologies with high importance for the future of Bavaria. These were organised into five fields:
  - materials engineering (including ***nanotechnologies***, materials engineering, chemical industries);
  - mobility (including automotive, rail, logistics, aerospace and satellite navigation);
  - life sciences and environment (including biotechnology, medical technologies, energy technologies, environmental technologies, forestry and food);
  - IT and electronics (ICT, high-performance electronics, mechatronics and automation); and
  - service and media (financial services, media).

After a positive evaluation in 2010, the State Government announced some changes in the future organisation of the overall initiative: A major change is that the (nonetheless successful) clusters high-performance electronics, logistics, biotechnology and medical technologies would be restructured into networks, while future funding would be focused on the other clusters, where funding so far was most successful in generating additionality.

- Research Strategy of Thuringia (2008): Main objectives of Thuringia's research policy were to strengthen regional universities and non-university research institutes and regional companies in their research and development efforts in order to achieve scientific excellence, to initiate knowledge and technology transfer as well as innovation. The document described outstanding research areas of the state and measures to strengthen and relate the regional research landscape to target fields in the regional economy: micro and nano technologies, microelectronics; information and communication technologies; media and communication;

532 https://www.cluster-bayern.de/en/

health research and medical technology; microbiology and biotechnology; optical technologies, photonics; materials and production technologies; environmental and energy technologies, infrastructure; and cultural and social change. Main fields of activity of regional research policy were (i) to support competitiveness, (ii) to strengthen networks, (iii) to support young researchers, and (iv) to invest in infrastructure.

IRELAND

Following the establishment of Science Foundation Ireland (SFI) in 2000, public funding was made available to support many public research initiatives including the **Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN)[533]**. Since its foundation in 2003, CRANN has become a research institute of international standing with 17 Principal Investigators (PIs) across multiple disciplines including physics, chemistry, medicine, engineering and pharmacology, and a total of 250 researchers. CRANN was funded predominately by Science Foundation Ireland (SFI), in partnership with two universities (Trinity College Dublin and University College Cork) and industry, and was formed to harness the cross-disciplinary nanoscience research of individual PIs to deliver world leading research outputs and to enable CRANN researchers to address key industry challenges.

In addition, in December 2009, the **Competence Centre in Applied Nanotechnology (CCAN)** was launched. It was an industry-led, collaborative, applied research centre enabling its member companies and research providers to work together to develop nanotechnology enabled products and solutions for the ICT and biomedical industries (i.e. diagnostics, drug delivery, and regenerative medicine). It was co-hosted by CRANN and Tyndall National Institute at University College Cork. With a growing membership, the founding industry members were Aerogen, Analog Devices, Audit Diagnostics, Creganna-Tactx, Intel, Medtronic, Proxy Biomedical and Seagate. CCAN ran until mid-2015.

Ireland has developed its reputation in nanoscience with its researchers recently ranked sixth globally for the quality of their research. Active collaborations between industry and academia exists and are beginning to deliver significant economic benefits to Ireland. Three of the largest industries in Ireland are directly impacted by nanoscience research in perhaps – medical devices, pharmaceuticals and ICT.

The industry ministry, the Department for Jobs, Enterprise and Innovation (formerly the Department of Enterprise, Trade and Employment) plays a pivotal role in industrial innovation policy with its agencies, Enterprise Ireland (EI) (responsible for supporting Irish companies); Science Foundation Ireland (SFI) (funding basic and applied research); and IDA Ireland (in charge of overseas inward investments).

Apart from the establishment of research infrastructures, policy priorities were also being addressed in the Irish national innovation system. In 2004, the Irish Council for Science, Technology and Innovation, with its Secretariat provided by Forfás, launched **its ICSTI Statement on Nanotechnology**. The Statement assessed Ireland's capabilities in the field of nanotechnology, mapped out specific areas of opportunity for the Irish economy and presented a sustainable vision and strategy for the promotion, development and commercialisation of nanotechnology in Ireland. Among the key application areas that were identified were also pharmaceutical and medical technologies.

In 2010, Forfás[534] itself launched a report on **'Ireland's Nanotechnology Commercialisation Framework 2010 – 2014'**. The report presented a national framework to position Ireland as a knowledge and innovation centre for certain niche areas of nanotechnology. It highlighted that Ireland's nanotechnology players should focus on three main technology areas (advanced materials, "More than Moore" and nanobiotechnology) and four application areas (next generation electronics, medical devices & diagnostics, environmental applications, and industrial process improvements).

The BioNano Laboratory in CRANN (mentioned above) is dedicated to interdisciplinary research at the interface between the physical and life sciences including nanotechnology and diagnostics, nanotoxicology and nanomedicine. The group investigates molecular, cellular and physiological interactions using novel biophysical tools such as cell actuators, and magnetic and ultrasound fields.

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[533] http://www.crann.tcd.ie/

[534] Forfás ceased to exist in 2015 and was, in part, subsumed under the Department of Jobs, Enterprise and Innovation.

Members of the BioNano Laboratory are also members of the **Integrated Nanoscience Platform for Ireland (INSPIRE)[535],** a consortium of all Irish third level institutions with international leading research capability in nanoscience and nanotechnology. Furthermore, CRANN is also part of the Molecular Medicine Institute which is a not for profit company established by an extended network of Irish Universities and their associated academic hospitals. The BioNano Laboratory aims to facilitate and accelerate the translation of biomedical nanotechnology research into improved nanoscale diagnostics and nanomedicine.

In October 2013, a new Science Foundation Ireland funded research centre, **Advanced Materials and BioEngineering Research (AMBER)[536]** was launched. AMBER is jointly hosted in TCD by CRANN and the Trinity Centre for BioEngineering, and works in collaboration with the Royal College of Surgeons in Ireland and UCC. The centre provides a partnership between leading researchers in material science and industry to develop new materials and devices for a range of sectors, particularly the ICT, medical devices and industrial technology sectors.

THE NETHERLANDS

In the Netherlands, nanotechnology was established as a distinct field of scientific research in the early years of the 21st century. A foresight study (Ten Wolde 1998) conducted by the Dutch Study Centre for Technology Trends (STT) between 1996 and 1998 laid the foundation of a national research agenda. The study showed the importance of nanotechnology for electronics, materials, molecular engineering and instrumentation, and also recommended to pay due attention to nanosafety issues and set up research in that area.

The Netherlands hosts three dedicated nanotechnology research centres: The University of Twente (with the **Mesa+** research centre in microsystems technology and nanomaterials[537]), Delft University of Technology (with the **Else Kooi Laboratory**[538], previously called Dimes research centre on nanoelectronics) and the University of Groningen (with **BioMaDe[539]** focused on bio-nanotechnology). The early 2000s, these formed the core of **NanoNed** - the Nanotechnology R&D initiative in the Netherlands[540]. NanoNed was initiated after three years of preparatory work in 2004 by nine industrial and scientific partners including Philips and TNO. It clustered the Dutch expertise on nanotechnology and enabling technology into a national network. The total budget of the NanoNed programme amounted to EUR 235 million, funded by the Dutch Ministry for Economic Affairs. The NanoNed programme was organised into eleven independent programmes or flagships. Each of those was based on regional R&D strength and industrial relevance. The flagships were Advanced NanoProbing, BioNanoSystems, Bottom-up Nano-Electronics, Chemistry and Physics of Individual Molecules, Nano Electronic Materials, NanoFabrication, Nanofluidics, NanoInstrumentation, NanoPhotonics, Nano-Spintronics and Quantum Computing.

In 2006, the Cabinet vision on Nanotechnology "**From Small to Great**" was published. The content of the document mirrored the outline of the European Commission's 2005 Action Plan, with sections on business and research opportunities; societal, ethical, and legal issues; public engagement; and risk assessment.

In 2008, the Dutch Government published its **Nanotechnology Action Plan[541]**. The plan, prepared by the Interdepartmental Working Grou #p on Nanotechnology (ION) and building on the 2006 vision document, incorporated the most up-to-date scientific findings, and reflected information and agreements from European Union and other international initiatives. Four generic themes were defined on the basis of the central theme impact on society and risk analysis, i.e.: bio-nano-technology, beyond Moore, nanomaterials, and nano production (including instrumentation and characterisation). In addition, four application areas were singled out: clean water, energy, food and "nanomedicine".

The Dutch systematic approach to nanotechnology strategy resulted in the development of stable

[535] http://www.crann.tcd.ie/Research/Academic-Partners/testt.aspx
[536] http://ambercentre.ie/
[537] https://www.utwente.nl/mesaplus/
[538] http://ekl.tudelft.nl/EKL/Home.php
[539] http://www.biomade.nl/
[540] However, four other universities, and TNO, the Netherlands Organisation for Applied Scientific Research, are also represented.
[541] http://www.rritrends.res-agora.eu/uploads/27/8079721-bijlage%281%29.pdf

research groups, centres, department and laboratories. On the national level, **NanoLab NL**[542] formed a consortium that built, maintained and provided a coherent and accessible infrastructure for nanotechnology research. NanoLab drew on government funding, which was first spent on upgrading existing infrastructure. Only when the existing infrastructure was fully used and a well-characterised additional need was identified and additional investment made. As a consequence, the Dutch nanotechnology research infrastructure was heavily used by research groups and the local industry. The partners in this enterprise considered themselves often as competitors but co-operate and co-ordinate their actions because of the substantial government funding.

In 2011, the **NanoNextNL**[543] national research programme on nanotechnology was started as a continuation of NanoNed and MicroNed (the Netherlands Microtechnology program). NanoNextNL is based on a Strategic Research Agenda that was asked for by the government in both the cabinet and the action plan. Risk evaluation and Technology Assessment form part of this research programme. 15% of the budget is dedicated to risk-related research, as was demanded by government in the action plan. It is planned that NanoNextNL programme will finish in 2016 but anticipated that many aspects of it will be continued under an industry umbrella. Since 2011, the research agenda for nanotechnology is also part of the **Top sector policy of the Netherlands**[544], which aims to enhance the knowledge economy by stimulating nine top sectors (leading economic sectors).

The Top sector policy is implemented via innovation contracts, in which agreements are laid down between business leaders, researchers and government, jointly focusing the available resources for knowledge and innovation towards the leading economic sectors. Support programmes that aim to support the development and deployment of nanotechnology, are mostly project based. The formats for such supports range from small business oriented measures to financing large research project which involve co-operation between private and public research performers.

POLAND

In 2000, the Polish State Committee for Scientific Research (KBN) started a targeted research project in the topic of nanotechnology called "**Metallic, Ceramic and Organic Nanomaterials: Processing – Structure – Properties – Applications**" with two aims:

- stimulating research on nanomaterials in Poland and promoting collaboration between researchers in this field; and
- making a landscape of the status of nanotechnology in Poland.

The project involved 15 scientific institutions working on 26 research tasks.

In the Polish National Development Plan for the years 2007-2013, launched by the State Committee for Scientific Research in Warsaw in 2004, nanotechnology was foreseen as an area that should contribute to achieving a significant competitive potential in the European Arena.

During 2006, the Ministry of Science of Higher Education established the Interdisciplinary Committee for Nanoscience and Nanotechnology. This Committee analysed the nanotechnology situation and capabilities in Poland and proposed the basic fields that should be strategically supported and launched in 2007 the "**Strategy for the Reinforcement of Polish Research and Development Area in the Field of Nanosciences and Nanotechnologies**"[545]. The areas to be supported were nanoscale phenomena and processes, nanostructures, nanomaterials and nanoscale devices on the one side and nano-analytics/nano-metrology and manufacturing processes and devices for nanotechnology on the other. The priority of the strategy of nanosciences and nanotechnologies was the development, co-ordination and management of the national system of research, education and industry in this field in the short-, medium-, and long-term perspective. Other main objectives to be achieved by 2013 were the development of high added-value nanotechnology products, the creation and commercialisation of manufacturing devices for the production of nanomaterials, the development of the education system in the field of nanotechnology, educating about 20-30 doctors yearly in the specialisation of nanotechnology, building specialist laboratories, establishing co-operation networks of research and industrial units, financial institutions, etc. and integrating

[542] http://www.nanolabnl.nl/
[543] http://www.nanonextnl.nl/
[544] http://topsectoren.nl/english
[545] www.bioin.or.kr/fileDown.do?seq=5186

dispersed activity of research units in a joint programme of nanotechnology development.

In 2014, the Government approved the **National Smart Specialisation Strategy** as an integral part of the Enterprise development Programme, setting "Multifunctional materials and composites with advanced properties, including nano-processes and nano-products" as a horizontal smart specialisation area in Poland.

PORTUGAL

In 2005, the Portuguese and Spanish Governments decided to jointly create the **International Nanotechnology Laboratory (INL)**[546] in Braga, Portugal, which was partly funded under the European Regional Development Fund (ERDF). The decision of Portugal and Spain to create an international research laboratory was announced by the head of Government of Spain and the Prime Minister of Portugal at the end of the XXI Portugal-Spain Summit that took place in Évora, Portugal.

The International Nanotechnology Laboratory (INL) was installed in Braga, Portugal, its Director is the Swedish Professor Lars Montelius, and it has over 90 employees.

INL concentrates on nanotechnology, and considers applications to several other areas, following a truly interdisciplinary approach. The Laboratory has been conceived to:

- Assure world class research excellence in all areas of activity;
- Develop partnerships with the industry and foster the transfer of knowledge in economic values and jobs;
- Train researchers and contribute to the development of a skilled workforce for the nanotechnology industry; and
- Survey, prevent and mitigate nanotechnology risks.

Among its research areas nanomedicine, nanoelectronics, nanomachines & nanomanipulation and environment monitoring, security and food quality control can be found.

Further information on the policies and programmes of Spain is given below.

SPAIN

The Minister of Economy and Competitiveness is responsible for the design of the national innovation strategy in Spain. An Inter-ministerial Commission on Science and Technology (CICYT) has the role of co-ordinating the actions of the different bodies involved in innovation policy in a complex governance structure. The regions of Catalonia, the Basque Country and Valencia are especially active in S&T policy.

The 2004-2007 R&D plan was the first Spanish national R&D plan containing a specific cross-programme action regarding nanoscience and nanotechnology. The **Strategic Action (SANSNT)** was designed for the overall enhancement of Spanish industry competitiveness through the implementation of deep changes in several industrial sectors by generating new knowledge and applications based on the convergence of new technologies, where nanotechnology plays a central role. The SANSNT included seven thematic lines among which the first one is "***Nanotechnologies*** applied in materials and new materials within the field of health". Also included are systems biology, synthetic biology and ***nanobiotechnology***. The Strategic Action encompassed the development of activities within the six Instrumental Lines of Action (human resources; projects; institutional strengthening; infrastructures; knowledge use; and articulation and internationalisation of the system).

Nanoscience and nanotechnology were included as a **Strategic Action** of both the 2004-2007 National Plan for Research, Development and Innovation (R+D+I) and the funding set aside within this Plan for the Industrial Sector (PROFIT Programme), with the aim of promoting the development of industrial projects (carried out by companies) with nanotechnology-focused objectives.

During the 2004-2007 periods, around 40 projects were funded as a result of this Strategic Action, receiving a total of EUR 2 million in subsidies and EUR 8.5 million in associated investments. All the projects were coordinated by industrial companies, although universities and technological centres were involved in the development of many of them either on a collaborative basis, or were subcontracted by the company carrying out the project.

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[546] http://inl.int/

In 2005, the Government of Spain launched the strategic programme **INGENIO 2010**[547] to align Spain with the strategy of the European Union to reach a 3% of the GDP invested in R&D by year 2010, thereby reducing the gap between Spain and other countries. Its general objective was to achieve a gradual focus of Spanish resources on strategic actions to meet the challenges faced by the Spanish Science and Technology System. This was to be achieved by continuing the existing policies, agendas and successful programmes, as well as by implementing new actions needed to finish meeting the challenges identified for the national science, technology and engineering system.

In order to enhance critical mass and research excellence, the goals of the INGENIO 2010 Programme, within the **CONSOLIDER programme** (launched by the Ministry of Education and Science, through the General Secretariat of Scientific Policy, to promote high quality research and to reach critical mass and research excellence), included creating Centros de Investigación Biomédica en Red (Biomedical Research Networking Centres, CIBER) by setting up consortia, with their own legal personality, without physical proximity, which were designed to conduct single-topic research on a specific broadly-defined disease or health problem. CIBER were formed through the association of research groups linked to the national health system to help form the scientific basis of the programmes and policies of the national health system in the priorities areas of the National R+D+I Plan. Among the centres that have been created within this programme is the Biomedical Research Networking centre in Bioengineering, Biomaterials and ***Nanomedicine*** (CIBER-BBN), founded in 2006. The ***Nanobiomed consortium***, which researches the use of nanoparticles for drug delivery, was also founded with CONSOLIDER funds.

Between 2008 and 2011 the **National Strategy of Nanoscience and nanotechnology, new materials and new industrial products**[548] was implemented by the Ministry of Economy and Competitiveness. This policy measure was part of the National Plan for R+D+I 2008-2011[549] and its objective was to enhance the competitiveness of Spanish industry by promoting knowledge about and stimulating the development of new applications based on nanoscience, nanotechnology, material science and technology, and process technologies. Six themes were targeted: Nanotechnologies applied to materials and new materials in health sector, nanotechnologies for information and telecommunications, nanotechnologies in relation to industry and climate, smart materials with tailored properties based on knowledge as materials and performance coatings for new products and processes, advances in technology and materials processing, development and validation of new industrial models and strategies/new technologies for manufacturing design and process/network production, and exploitation of convergent technologies. The measure covered different lines such as supporting investments, projects, institutional strengthening, infrastructure and utilisation of knowledge, supporting first market operations for innovative products and access to early stage/development funding, system articulation and internationalisation and targeted public research organisations, SMEs and other companies.

Both in the last Spanish Strategy of Science, Technology and Innovation 2013-2020[550] and in the State Plan of Scientific and Technical Research and Innovation 2013-2016[551] (both dependent on the Ministry of Economy and Competitiveness), nanotechnology is considered a sector to be boosted when referring to Key Enabling Technologies (KETs), but there is not a strategic plan such as in previous periods.

Regional initiatives in Spain include:

- Estrategia Nanobasque (2008)[552]: In order to promote the implementation of micro and nanotechnologies in the Basque companies, the Basque Government designed a strategy called NanoBasque in 2007. On December 3 2008, the Department of Industry, Trade and Tourism of the Basque Government launched the nanoBasque Strategy in the framework of the Basque Science, Technology and Innovation Plan 2010. The nanoBasque Strategy was an initiative designed to develop a new economy sector enabled by nanotechnology. It was created with the purpose of covering three main areas of action, namely: company, knowledge

547 http://www.ingenio2010.es/
548 http://www.idi.mineco.gob.es
549 Ibid
550 http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_Strategy_Science_Technology.pdf
551 http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_RDTI_Plan_2013-2016.pdf
552 http://www.nanobasque.eu/aNBW/web/en/strategy/index.jsp

and society. One of the objectives was to create a new model of relations to involve both national and international companies, scientific, technological, political and social agent. The expected result were targeting the efficiency and the integration of the ecosystem of innovation that was clearly aimed at the market, based on the co-operation between all parties. The launch of the nanoBasque Strategy was accompanied by the creation of a dynamic support agency, the nanoBasque Agency, with the mission of coordinating and managing the development of the Strategy. The nanoBasque Strategy strived to boost Basque the presence of companies and research agents on international nanotechnology initiatives and markets. EUR 550 million were expected to be mobilised in the 2009-2015 period, with a proportion of public funding of 52% on the total.

- Within the nanoBasque strategy and using CONSOLIDER funds, the Cooperative Research Center NanoGUNE was created with the mission of performing world-class nanoscience research for the competitive growth of the Basque Country, thereby combining basic research with the objective of boosting nanotechnology-based market opportunities and contributing to the creation of an enabling framework to remove existing barriers between the academic and business worlds.
- The Andalusian Centre for Nanomedicine and Biotechnology, BIONAND, is a mixed centre part owned by the Regional Ministry of Health and Social Welfare, the Regional Ministry of Finance, Innovation, Science and Employment and the University of Malaga. BIONAND has been co-financed, with a contribution of 70% of the total cost, by the European Regional Development Fund (ERDF) together with the Ministry of Economy and Competitiveness in the frame of The Spanish National Plan for Scientific Research, Development and Technological Innovation 2008-2011 (record number, IMBS10-1C-247, quantity. EUR 4.9m). The three main research areas are nanodiagnostics, therapeutic nanosystems, and nanobiotechnology.
- IMDEA-Nanociencia is a private non-profit Foundation created by the regional Government of the Community of Madrid in November 2006 to shorten the distance between the research and society in the Madrid region and provide new capacity for research, technological development and innovation in the field of nanoscience, nanotechnology and molecular design. Researchers at IMDEA Nanoscience are developing distinct diagnostic tools, including nucleic acid-based and nanoparticle-based sensors for detection of biological targets of medical interest, and magnetic nanoparticles to be used in medical imaging as high-sensitive contrast agents.

The United Kingdom (UK)

The main player in UK policy measures related to nanotechnology as a key enabling technology (KET) is the Department for Business, Innovation and Skills (BIS) and its agency, the Technology Strategy Board, now called Innovate UK[553]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[554] and identified future potential growth sectors. Both institutions have also developed a number of measures facilitating the knowledge exchange and technology adoption, such as: commercialisation opportunities and Knowledge Transfer Partnerships, Knowledge Transfer Networks, Technology and Innovation Centres, and Small Businesses Research Initiative.

The main interest of the UK government for nanotechnology started in 2002, when they published the **Taylor Report**[555] which recognised that investment in nanotechnology was increasing rapidly worldwide. Following the Taylor Report, an announcement was made by Lord Sainsbury of GBP 90m of funding for the Micro and Nano Technology Manufacturing Initiative. This funding was committed between 2003 and 2007. **Micro- and Nano-technology Manufacturing Initiative** (MNT Initiative) were joint investments by the Government, the Regional Development Agencies (RDAs) and the devolved administrations of Wales and Scotland. The Initiative was launched to help the industry build on the expertise of the UK science base and win a share of this developing market, harnessing the commercial opportunities offered by nanotechnology.

Approximately one third of this investment went to Collaborative R&D MNT Projects, and two thirds

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[553] https://www.gov.uk/government/organisations/innovate-uk
[554] https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative
[555] http://webarchive.nationalarchives.gov.uk/20130221185318/http://www.innovateuk.org/_assets/pdf/taylor%20report.pdf

to capital infrastructure. Generally built on existing university or business expertise, the twenty-four facilities were targeted at addressing a broad range of key application areas where micro/nano scale activity was considered key to future UK industry capability and where the UK had some strength. Micro/nano technologies were included within relevant broader collaborative R&D competitions, principally in the materials, medicine and electronics areas. In 2007 the **Nanotechnology Knowledge Transfer Network (NanoKTN)[556]** was created with the objective of supporting the exploitation and commercialisation of MNT through informing, linking and facilitating innovation and collaborations between users and suppliers of nanotechnology in order to build a strong MNT community in the UK. The centres were grouped into four main themes: nano-metrology; nanomaterials (including health and safety); nanomedicine; and nanofabrication. Between its creation and 2014 the NanoKTN secured about £82million for UK industry, mainly focussed on SMEs, providing a good return investment on the initial input of £3million. In 2014, NanoKTN was merged with another 15 KTN in the new organisation KTN Ltd.

In 2006, the Engineering and Physical Sciences Research Council issued its **Report of the Nanotechnology Strategy Group[557]** as an active response to the EPSRC 2005 Nanotechnology Theme Day Report that found that there were flaws in the structure for nanotechnology R&D in the UK. The report proposed, in conjunction with researchers and users, to identify a series of "grand challenges" in nano-science and nano-engineering, focused initially on areas such as energy, environmental remediation, the digital economy and healthcare, where an interdisciplinary, stage-gate approach spanning basic research through to application will be an integral part of the challenge of enabling nanotechnology to make an impact. The "grand challenges" were to be addressed via interdisciplinary consortia spanning the EPSRC research spectrum, and including collaboration with sister Research Councils (e.g. BBSRC).

In December 2007, the Research Councils announced a Cross-Council programme "**Nanoscience through Engineering to Application[558]**", with the objective of providing an additional GBP 50 million in areas where the UK nanotechnology research base could make a significant impact on issues of societal importance such as healthcare. These societal or economic Grand Challenges wanted to be addressed in a series of calls for large-scale integrated projects. They were led by the Engineering and Physical Sciences Research Council, in collaboration with stakeholders including other Research Councils, industry, the Technology Strategy Board (TSB) and the Nanotechnology Research Coordination Group.

Government announced its intention to develop a UK Strategy for nanotechnologies in its 2009 response to the Royal Commission on Environmental Pollution's report, Novel materials in the Environment: The case of Nanotechnology.

The **Nanoscale Technologies Strategy 2009-2012[559]** was launched in October 2009 by the TSB and targeted the ways by which nanotechnologies could address major challenges facing society such as environmental change, ageing and growing populations, and global means of communication and information sharing. Its objective was to provide the framework for future applied research predominantly through activity inspired by the needs of wider technologies and challenge-led calls.

In 2010, the Ministerial Group on Nanotechnologies, the Nanotechnology Research Co-ordination Group (NRCG), and the Nanotechnology Issues Dialogue Group (NIDG) issued the UK **Nanotechnologies Strategy - Small Technologies, Great Opportunities[560]**. This Strategy defined how Government will take action to ensure that everyone in the UK could safely benefit from the societal and economic opportunities that these technologies offer, whilst addressing the challenges that they might present.

In 2012 the Department for Environment, Food and Rural Affairs (DEFRA) launched the **Nanotechnology Strategy Forum (NSF)**[561] in order to facilitate discussion and engagement between Government and stakeholders in matters referred to the responsible advancement of the UK's nanotechnologies industries. The NSF is an advisory body formed by *ad hoc* expert with a

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[556] https://connect.innovateuk.org/web/nanoktn
[557] https://www.epsrc.ac.uk/newsevents/pubs/report-of-the-nanotechnology-strategy-group/
[558] https://www.epsrc.ac.uk/newsevents/pubs/nanotechnology-programme/
[559] http://www.nibec.ulster.ac.uk/uploads/documents/nanoscaletechnologiesstrategy.pdf
[560] http://www.steptoe.com/assets/htmldocuments/UK_Nanotechnologies%20Strategy_Small%20Technologies%20Great%20Opportunities_March%202010.pdf
[561] https://www.gov.uk/government/groups/nanotechnology-strategy-forum

membership drawn from industry, regulators, academia and NGOs (non-governmental organisations and it is jointly chaired by the Minister of State for Universities and Science (BIS) and the Parliamentary Under-Secretary for DEFRA and is supported by a small secretariat based in DEFRA.

The UK **Enabling Technologies Strategy 2012-2015**[562] also addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.

562 https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015

ANNEX 6: PRODUCTS FOR NANOTECHNOLOGY AND ENVIRONMENT

This Annex is divided largely into the same categories as used in the main body of the report:

- Soil remediation
- Water remediation
- Air remediation
- Sensors

1 Soil remediation

Product Name	Description	Producer
Magnetic Foam	AMT&C Ltd conducts research and developments in the field of liquid and solid foams containing magnetic submicron and nano-size particles. Such foams reveal magnetic properties and can be used for collection of oil or other hydrophobic pollution from water or solid surface.	Advanced Magnetic Technologies & Consulting Group Ltd
NANOFER STAR	NANOFER STAR is a NEW AIR-STABLE nZVI powder, consisting of Fe(0) surface stabilized nanoparticles, which has been developed in collaboration with Regional Centre of Advanced Technologies and Materials, Czech Republic	NANO IRON, s.r.o.
NANOFER 25S: nZVI slurry for groundwater remediation	Aqueous dispersion of Fe(0) nanoparticles with special surface modification which is based on combination of a biodegradable organic and inorganic stabiliser. Due to the narrow size distribution of nanoparticles and sophisticated stabilisation process, the product exhibits a high reactivity with a large scale of pollutants and very low degree of agglomeration, which implies for excellent migration and sedimentation properties. It is designed especially for groundwater remediation.	NANO IRON, s.r.o.
FAST-ACT	FAST-ACT® (First Applied Sorbent Treatment Against Chemical Threats), is a family of products for containment and neutralisation of a wide range toxic chemicals including chemical warfare agents.	NanoScale Corp.

2 WATER REMEDIATION

Product Name	Description	Producer
Anfiro™	Anfiro™ is a water technology addressing global freshwater scarcity. Using self-assembling polymers to create chlorine resistant and high permeability reverse osmosis (RO) membranes that vastly outperform current membrane technology. Significantly reduce the cost of desalinating and purifying water, enabling clean and affordable water for a better tomorrow.	Anfiro Inc.
NanoCeram®	Argonide's NanoCeram® patented filter media features a thermally - bonded blend of microglass fibres & cellulose infused with nanoalumina fibres in a non-woven matrix that creates an electropositively charged depth filter media. When assembled into a pleated cartridge, all NanoCeram® filters provide a unique combination of efficiency, capacity, flow rate & low pressure drop. In addition, all NanoCeram® filter cartridges are assembled using only FDA-compliant materials.	Argonide
Picohelix™	The Picohelix™ is based on a patented process that uses DNA to make a nano-ceramic coating to provide faster filtration at high purity. The Picohelix™ can purify solutions through an energy efficient process in a wide range of conditions, making it a robust technology for the process filtration industry. The DNA template provides nanoscale features allowing for highly efficient separations.	Cerahelix Inc.
NMX™	Crystal Clear Technologies (CCT), using nano-coating technology, has created proprietary filter media with high absorption capability and capacity, producing results at lower costs. CCT's proprietary filter media, branded NMX™, can be optimised for different contaminants and applications by bonding different nano-coatings onto the substrate. CCT's "self-extending" nano-coating media gives it exceptional capacity, lifetime and cost effectiveness over conventional media.	Crystal Clear Technologies Inc.
NanoClear™	NanoClear™ clean water systems and delivers high quality desalination and wastewater treatment with high selectivity and zero environmental ill-effects	DAIS analytics

Product Name	Description	Producer
Filmtec NF 200B membrane	The Filmtec NF 200B membrane permits the treatment of large quantities of water at low energy costs and also ensures the removal of pesticides, organic matter, related chlorine by-products and transmission of sufficient calcium to meet the water quality standard. The nano-filtration membrane, like reverse osmosis, provides an efficient barrier to micro-organisms no matter what their size. The variable operating conditions for this membrane are entirely compatible with the treatment of large water flows from polluted rivers at seasonally changing temperatures.	Dow Chemical
AQUCAR™	Controls bacteria and reduces biofouling in various membrane system types (reverse osmosis ultra-filtration, nano-filtration and microfiltration) used for industrial water processing	Dow Chemical Corp.
MBCR - Moving Bed Ceramic Reactor	ItN Nanovation's MBCR Filtration Container (MBCR - Moving Bed Ceramic Reactor) is built up of MBBR with Ceramic Flat Membranes. It can be used for biological sewage treatment with plug and play convenience.	ItN Nanovation AG
Quantum Flux	LG NanoH2O's thin-film nanocomposite (TFN) Quantum Flux membranes lower the cost of desalination by improving energy efficiency and productivity. Qfx membranes feature benign nanomaterials incorporated into the thin-film polyamide layer of a composite membrane. This patent-pending technology significantly increases membrane permeability.	LG NanoH2O
Liquidity – PATH C1 compliant purification cartridge	Pleated filters with 0.2 µm nano-fibre membrane & virus media. Liquidity Nanotech Corporation's water purification cartridge for the PATH C1 counter-top format has superior flow rate, microbiological retention, and ease of use. It meets the U.S. EPA standard for microbial reduction.	Liquidity Nanotech Corporation
Bio-Lair	Bio-Lair is a highly-porous ceramic product for effective use in water cleaning systems.	MetaMateria
Nano Pure water purification system	Nano Pure water purification technology employs a chemical-free and energy-free approach to eliminating waterborne pathogens – effectively shifting the paradigm from traditional filtering, chemical	Nano Global

Product Name	Description	Producer
	disinfecting techniques and UV – to a bonded film fluid purification system.	
NnF MBRANE® (Polymer nanofibrous membranes)	With application in products such as nanofibrous polymeric membranes, which can be used as separation membranes for different products or filtration materials for water and air purification with very low-pressure drop and very high filtration efficiency. Nanofibrous membrane can be deposited on a supporting substrate with air permeating structure made of virtually any material.	Pardam nanotechnology
Nanomesh™	Nanomesh™ is built of fused nano-structured of non-woven material that is manufactured in a scalable process using functionalised CNTs, activated carbon, and nanofibres within base sheet material. Using the immense surface area made by a carbon nanotube-based Nanomesh, this combines a large filtration area and excellent adsorption capability and this results in a facile, flow-through filter that brings maximum purification at low pressure loss.	Seldon Water
Dual Media SX Filters	The filters are free standing self-contained units with the ability to remove organic compounds up to 2 ppm. It can filter electrolytes up to 10 microns.	Spintek Filtration Inc.
CoMatrix Filters	These filters provide excellent recovery of organic compounds. It has five times the flow rate of SX filters. Fine electrolyte filtration down to 10 microns.	Spintek Filtration Inc.
Matrix Towers	Designed to provide organic recovery of up to 75% from the electrolyte solution. It uses hydrophobic matrix plates for coalescing. It has no moving parts.	Spintek Filtration Inc.
Aqualescer	The product is an aqueous coalescer for electrolyte and raffinate streams. It enhances the performance of dual media filters. It also reduces backwash frequency and minimises costs.	Spintek Filtration Inc.

3 AIR REMEDIATION

Product Name	Description	Producer
Hydrotect	Hydrotect, developed by AgroBuchtal is mainly used on ceramic floor tiles with its longterm guarantee. Surface of Hydrotect tiles contains a coating of titanium dioxide (TiO_2) this is baked onto the tiles at high temperatures ensuring the bonding of the materials with the tile surface. When light is captured by each tile the titanium dioxide activates oxygen from the atmosphere, the organic dirt on the surfaces is broken down due to the photocatalytic process.	AgroBuchtal
Air Oasis nano HTC™ Induct	The Air Oasis nano HCT™ Induct is an air purifier designed to be duct mounted in a HVAC (Heating Ventilation and Air Conditioning) system. The nano HCT Induct is capable of cleaning the air in every area supplied by the HVAC system, making this unit more efficient than standalone or countertop air purifiers that only cover a single room. For areas from 1000 to 5000 square feet. Similar to how hydrogen peroxide cleanses and disinfects wounds, the Air Oasis nano HCT™ Induct will cleanse and sanitise the air and surfaces.	Air Oasis LLC
PhotoScrub®	PhotoScrub® is a fibreglass material coated with a photocatalyst based on nanocrystalline anatase allotrope of titanium dioxide. Use of such materials assures negligable volatile compound emissions and better environmental sustainability.	Applied Nanotech, Inc.
Ultra-Web® filters	For dust collection	Donaldson Torit
Spider-Web® filter	For gas turbine air filtration,	Donaldson Torit
Donaldson Endurance™ air filters	For heavy-duty engines	Donaldson Torit
exceed ® Filters	exceed ® air filters comprise of high efficiency, low pressure-drop HVAC air filters with specially-designed nanofibre based media. It has been documented that exceed ® uses much lower energy compared to other commercially available filters thereby resulting in environment-friendly green technology.	eSpin Technologies
nWeb™ air filter media	eSpin manufactures nWeb™ air filter media for a variety of air filtration applications. Air filter media are designed for a wide range of efficiency ratings from ASHRAE MERV 11, MERV 13, MERV 14, and MERV 15.	eSpin Technologies

Product Name	Description	Producer
Gens Nano™	Gens Nano™ is a next generation of air purification technology, which can treat air pollution caused by more than 85% of harmful gases such as car exhausts NOx, formaldehyde, benzene, VOCs.	Green Earth Nano Science Inc.
TA2219 Indoor / Air Purification	TA2219 is a photocatalytic coating of surfaces. The coating is able to decompose organic compounds on a molecular level just by means of light.	Nadico Technologie
Nano Pure Air purification system	Traditional air purification systems work through capturing airborne bacteria and viral particles using mechanical and electrostatic filtration. Capable of being coated onto any air filtration device from clothing to industrial machines that filter airplane exhaust or eradicate warehouse carbon monoxide, Nano Pure technology eliminates unwanted microbes from the air supply.	Nano Global
NS Gold™	For emissions control in diesels vehicles. The emissions reduction was obtained due to the pioneering use of gold nanoparticles as a catalyst. The implementation of this particular catalyst enabled emissions reduction by 20%.	Nanostellar
MAXIT Airfresh plaster	MAXIT Airfresh Plaster is a plaster which can be applied on ceilings and walls. Making use of nano-sized TiO_2 particles and the photocatalytic effect, it eliminates unwanted odours, air pollutants and organic volatile compounds.	Saint-Gobain Weber GmbH

4 SENSORS

Product Name	Description	Producer
Industrial Ion Selective Sensors	Industrial ion selective sensors which can be used in air filtration.	Advanced Sensor Technologies, Inc.
AST-DO(-T) Submersible Galvanic Dissolved Oxygen Sensors	Industrial grade galvanic dissolved oxygen (DO) sensor which can detect biological and chemical oxygen demand imbalances and monitor for marine life.	Advanced Sensor Technologies, Inc.
FDEC FET nanosensors	For industrial leak detection applications where trace gas detection of few parts-per-billion or below is required. Applications include detection of low concentrations of gases such as hydrogen, oxygen in integrated fuel cell systems and other process control applications.	INanoBio LLC
Molecular Property Spectrometer™ (MPS™)	NevadaNano's Molecular Property Spectrometer™ (MPS™) provides high-value chemical information with minimal size, cost, power, and mass.	Nevada Nanotech Systems, Inc.
OndaVia analysis system	The OndaVia analysis system consists of a small, transportable instrument, and disposable, chemical-specific cartridges. These two components improve analysis time from days to minutes, while providing laboratory-grade detection capabilities in the field. For rapid, on-site chemical testing at the necessary accuracy and detection limits.	OndaVia Inc.

ANNEX 7: HUMAN HEALTH AND SAFETY

INTRODUCTION

Not much is known about exposure of humans to nanomaterials in the environment sector. No subsectors were identified within the NanoData project. CNT was identified for use in water filtration systems and nanosensors implemented to monitor environmental parameters. Also other nanomaterials (e.g. Ni, Pt, Au, Si, InP, GaN) are used in nanosensors. Nanosensors were evaluated as part of the ICT sector, and are therefore not further discussed here. Furthermore, nanoremediation was identified as an important environmental application. Various nanomaterials, such as nanoparticles, tubes, wires, fibres, function as adsorbents and catalysts and their composites with polymers are used for the detection and removal of gases (e.g. SO2, CO, NOx), chemical contaminants (e.g. arsenic, iron, manganese, nitrate, heavy metals), organic pollutants (aliphatic and aromatic hydrocarbons) and biological substances, such as viruses, bacteria, parasites and antibiotics (Khin et al., 2012). Examples of nanomaterials applied are cobalt manganese oxide nanoparticles, synthesized in situ in pressurised reactors for the supercritical water oxidation process to clean waste water of organics; zero-valent iron in permeable reactive barriers and silver, iron, gold, iron oxides and titanium oxide in polymeric membranes to remove metals and other contaminants form wastewater; nanofibres (silica, dendrimers, CNTs) in nanofibre media and membranes used for filtration; nanozeolites and dendrimers functionalised with inorganic nanoparticles, used as sorbents to remove heavy metals from wastewater (Khin et al., 2012). Another nanomaterial used in remediation, is nano-calcium peroxide, which is applied in in situ chemical oxidation (ISCO) of contaminated ground water, sediment or soil in order to destroy the contaminants by converting them to innocuous compounds (Khodaveisi et al., 2011).

Basis for the evaluation will be the "Stoffenmanager Nano" application developed by TNO (Van Duuren-Stuurman, et al. 2012). In short, Stoffenmanager Nano is a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios. This tool combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. "Stoffenmanager Nano" does not contemplate the dermal and oral routes of exposure.

The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries (ECHA, 2012). In view of the nature of the products in this sector, oral exposure of consumers is also considered to be minor.

The dermal route may be the main route of exposure for some substances or exposure situations, and cause local effects on the skin or systemic effects after absorption into the body (ECHA, 2012). However, nanoparticles as such are very unlikely to penetrate the skin (Watkinson et al., 2013), and consequently nanospecific systemic toxicity via the dermal route is improbable. Therefore, when evaluating nanorisks for the respiratory route, the most important aspects of occupational and consumer safety are covered.

Currently version 1 of Stoffenmanager Nano is being updated with recent data and insights. The hazard of six metal oxide nanoparticles has been reassessed and their hazard bands have been updated. This revision is based on more recent toxicity data to attribute the hazard bands according to the methodology described in the ISO guideline on the use of the control banding approach in occupational risk management of engineered nanomaterials . It has been published in a TNO-report (Le Feber, et al. 2014). Hazard bands for the nanoparticles listed in the table below are taken by preference from this report and, if not available in that report, from van Duuren-Stuurman et al. (2012). If a nanoparticle in the list has not been evaluated in either publication, data were collected from public literature to derive its hazard band, as described in the section hazard assessment below.

HAZARD ASSESSMENT

INTRODUCTION

In the ISO guidelines, the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). In essence, it applies the toxicity classification rules of the Globally Harmonised System (GHS) (UN, 2015) to establish the hazard band. The table below lists the criteria to allocate hazard bands per toxicity endpoint.

Table 1: Allocation of hazard bands per toxicity endpoint to nanomaterials insoluble in water

Table modified from the ISO guidelines (ISO, 2013)

Toxicity category	Hazard band				
	A No significant health hazard	B Slight Hazard	C Moderate Hazard	D Serious hazard	E Severe hazard
Acute toxicity: LC_{50} inhalation 4H (mg/m^3) (Aerosols/particles)	Low >5000	Acute tox 4 1000-5000	Acute tox 3 500-1000	Acute tox 1-2 <500	-
Severity of acute (life-threatening) effects		STOT SE 2-3; Asp. Tox 1	STOT SE 1	-	-
Respiratory Sensitisation	Negative	-	-	-	Prevalent moderate to strong respiratory allergic reactions Resp. sens. 1
Mutagenicity/ genotoxicity	Negative	-	-	-	Muta 2, Muta 1A- 1B
Irritant/ corrosiveness[a]	None to Irritant Eye Irrit.2: skin Irrit 2 EUH 066	-	Severe irritant skin/eyes Irritant to respiratory tract STOT SE 3: Eye Dam. 1 Corrosive Skin Cor. 1A-1B	-	-
Carcinogenicity in combination with mutagenicity[b]	Negative	Negative	Some evidence in animals Carc. 2	-	Confirmed in animals or humans. Carc. 1A-1B
Carcinogenicity without mutagenicity[b]	Negative	Negative	Some evidence in animals Carc. 2	Confirmed in animals or humans. Carc. 1A-1B	-
Developmental/ reproductive toxicity	Negative	Negative	Negative	Reprotoxic defects in animals and /or suspected or proved in humans Repr. 1A/B or 2	-
Likelihood of chronic effects Adverse effects per respiratory route (mg/m^3/6 h/day) (90 day chronic	Unlikely No adverse effects seen at C < 200[e]	Unlikely No adverse effects seen at C < 200[e]	Possible, STOT RE 2 Adverse effects seen at 20 < C ≤ 200	Probable, STOT RE 1[c] Adverse effects seen at C ≤ 20	-

study with dusts/mists/ fumes)[d]					

a According to the ISO approach just informative since focus is only on inhalation exposure (ISO, 2013), but in this report used as a proxy for possible irritation of the airways and lungs and included as a criterion to attribute hazard bands.
b The ISO guidelines do not discriminate between threshold and non-threshold carcinogenic effects, although, implicitly, they reserve hazard band E for non-threshold effects. Therefore, le Feber et al. (2014) have allocated different hazard bands to threshold and non-threshold carcinogens as specified in this table.
c Erroneously listed as STOT RE 2 in the ISO guidelines (ISO, 2013).
d The ISO guidelines only mention the cut-offs for dermal and oral studies for informative purposes, in this report the GHS cut-offs for respiratory studies are applied (UN, 2015).
e Not mentioned in the ISO guidelines (ISO, 2013), but follows logically from the approach applied
Asp. = aspiration, Carc. = carcinogenic, dam. = damage, EUH 066 = hazard statement: Repeated exposure may cause skin dryness or cracking, Irr. = irritant, MNO = manufactured nanoparticle, Muta = mutagenic, RE = repeated exposure, Repr. = reprotoxic, resp. = respiratory, SE = single exposure, sens. = sensitiser, STOT = specific target organ toxicity, tox = toxicity.

The highest toxicity endpoint hazard for a given nanomaterial is attributed to that material.

When the nanomaterial concerned is soluble in water, its hazard banding is based on its bulk material equivalent. In this report, Stoffenmanager as described by Marquart et al. (2008) is applied to that purpose. Stoffenmanager uses the hazard bands as defined in COSHH Essentials, the control banding tool used by the UK Health Safety Executive (HSE) .

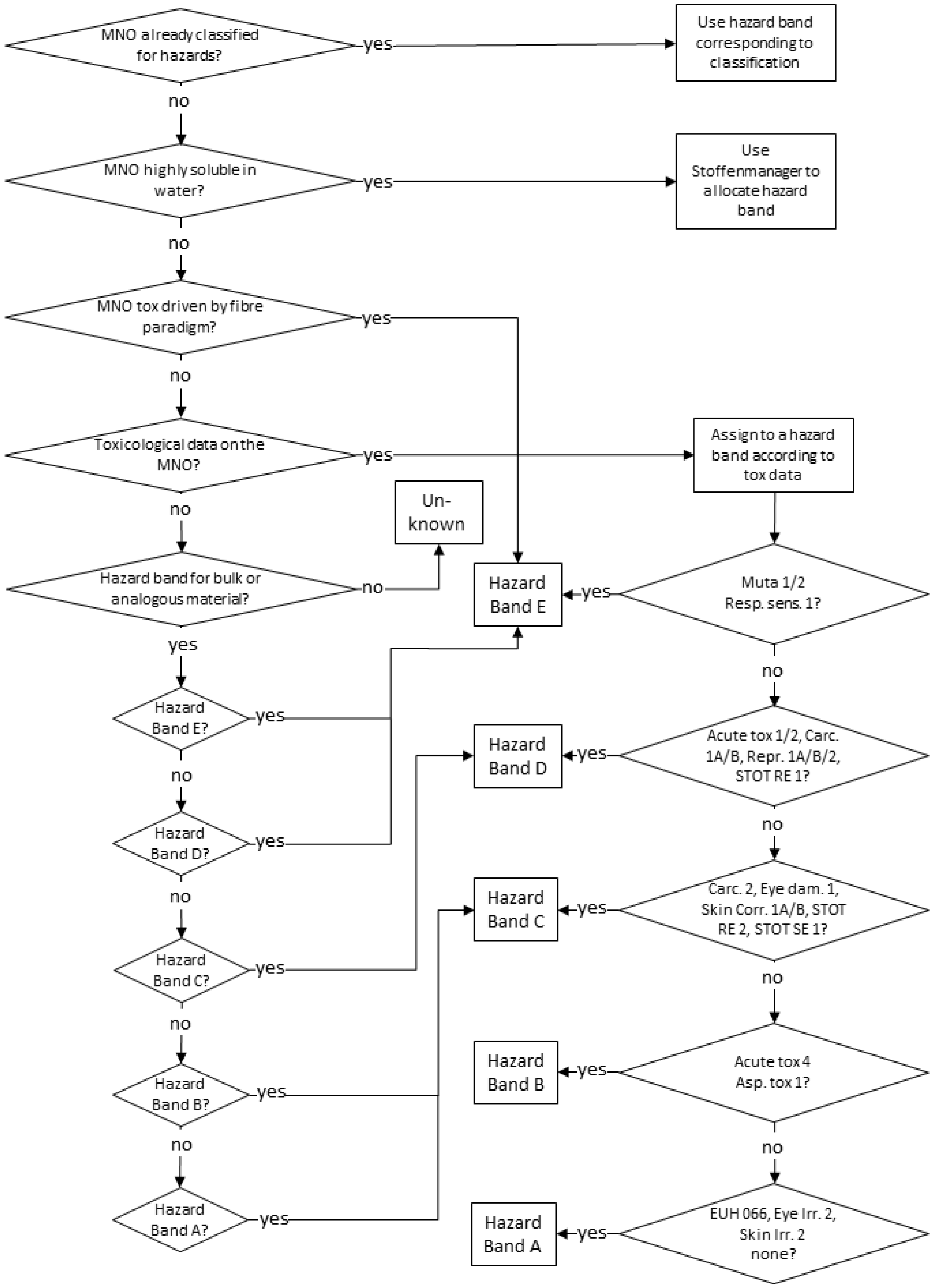

Figure 1: The stepwise approach of hazard banding of Stoffenmanager Nano (Van Duuren-Stuurman, et al. 2012)

C = carcinogenic, +C = and carcinogenic, M = mutagenic, -M = and not mutagenic, MNO = manufactured nanoparticle, R = reprotoxic, resp. = respiratory, T = toxic, T+ = very toxic

Stoffenmanager refers to the non-nano version of Stoffenmanager as described by Marquart et al. (2008)

The criteria used to allocate the different hazard bands are listed and described in a guidance document published on the internet , and are shown in the table below. Contrary to Stoffenmanager Nano, which uses hazard classifications as criteria, COSHH Essentials uses the hazard (H)-statements.

Table 2: Allocation of GHS H-statements to Hazard Band

(adapted from HSE (2009))

H-statements	Hazard Group
H303, H304, H305, H313, H315, H316, H318, H319, H320, H333, H336 and all H-numbers not otherwise listed	A
H302, H312, H332, H371	B
H301, H311, H314, H317, H318, H331, H335, H370, H373	C
H300, H310, H330, H351,H360, H361, H362, H372	D
H334, H340, H341, H350	E

When no or insufficient toxicity data are available for the specific nanomaterial, classifi¬cation or toxicity data of the corresponding bulk material or another, similar nanomaterial are used to allocate the hazard band using the criteria listed in table 'Allocation of hazard bands per toxicity endpoint to nanomaterials insoluble in water'. The hazard band thus found will be increased with one, except when the alternative material has been allocated band A, in which case hazard band C will be attributed to the nanomaterial concerned (ISO, 2013). This allocation may be mitigated using motivated expert judgement (Le Feber et al., 2014). When no classification nor toxicity data are available for either the nanomaterial concerned or likely similars, the ISO approach attributes hazard band E, as a precautionary measure (ISO, 2013). Since in this report the goal of hazard banding is not control banding to enable occupational risk management measures but prioritisation for governmental policy purposes, based on risks, the hazard band for such a nanomaterial is designated as "Unknown". The approach is summarised in the figure 'The stepwise approach of hazard banding' above.

Calcium peroxide nanoparticles

In contact with water, CaO2 dissolves to form H2O2 and Ca(OH)2, liberating a maximum of 0.47 g H2O2/g CaO2 (Khodaveisi et al., 2011). The rate at which it decomposes is higher for nano-calcium peroxide than for micro-calcium peroxide (Khodaveisi et al., 2011). No data on the toxicity of the nanoform have been found in public literature, and since it decomposes into soluble compounds in water, its hazard should be evaluated using Stoffenmanager for bulk compounds. Calcium peroxide is not classified for toxic hazards by the EU, but the majority of REACH registrants has classified it with Skin Irrit. 2 (H315), Eye Irrit. 2 (H319) and STOT SE 3 (H335). Based on the last classification calcium peroxide is allocated hazard band C.

Carbon nanotubes, single- and multi-walled (CNT)

Carbon nanotubes have often been demonstrated to have severe toxicity; however, this seems to be largely dependent on the dose, the degree of agglomeration and the route of administration. Differences in toxicity are also expected between single and multi-walled CNTs and are presumably dependent on their aspect ratio (El-Ansary, et al. 2013).

Upon inhalation, single walled carbon nanotubes (SWCNTs) have shown various chronic inflammatory responses in rat and mice (El-Ansary, et al. 2013, Zhao and Castranova 2011). SWCNTs have been shown to be genotoxic in mice after inhalation exposure as well as in mouse lung epithelial cells and lung fibroblasts (El-Ansary, et al. 2013, Zhao and Castranova 2011). SWCNTs have shown to be genotoxic in rats after oral administration (Zhao and Castranova 2011). Multiwalled carbon nanotubes (MWCNTs) have shown systemic immunological and inflammatory responses after short-term inhalation exposure (El-Ansary, et al. 2013, Yildirimer, et al. 2011). In the case of short to medium term pulmonary exposures to SWCNTs or MWCNTs in rodents, no tumours were reported. Cellular responses and gene expressions in these studies showed significant effects associated with lung cancer (Zhao and Castranova 2011).

Several studies have shown the potential for MWCNTs to act like the persistent fibres of asbestos, causing thoracic inflammation and fibrosis (NIOSH 2013, USEPA 2013). Additionally, MWCNT have been shown to penetrate into the alveolar region of the lung and to cause inflammation due to accumulation of alveolar macrophages. These biological events have been shown to lead to mesothelioma, although MWCNT have not been demonstrated to de facto cause mesotheliomas. Still the weight-of-evidence for certain types of MWCNT (e.g., those with high aspect ratios) is increasing: mice injected with long (> 15 µm) MWCNT or asbestos showed significantly increased granulocytes in the pleural lavage, com¬pared with the vehicle control at 24 hours post ex¬posure. Long MWCNT caused rapid inflammation and persistent inflammation, fibrotic lesions, and mesothelial cell proliferation at the parietal pleural surface at 24 weeks post exposure. Chronic in vitro exposure (4 months) of human mesothelial cells to MWCNT induced proliferation, migration and invasion of the cells similar to those observed with crocidolite asbestos as well as a similar up-regulation of a key gene involved in the process of cell invasion (matrix metalloproteinase-2) (Lohcharoenkal, et al. 2013). As a matter of fact, at the same mass exposure (0.02 µg/cm2) MWCNT caused a higher fold increase in cell migration and invasion than crocidolite asbestos (c. 3- and 2-fold, respectively). Also asbestos and rigid, high-aspect-ratio CNT activated the NLRP3 inflammasome to the same extent (Palomäki, et al. 2011). The NLRP3 believed to play a central role in inflammatory diseases (Abderrazak, et al. 2015). Frustrated phagocytosis is believed to be the trigger for the chain of events leading to mesotheliomas; in order to be able to cause this phenomenon fibres need to be biopersistent and longer than 5 µm (Donaldson, et al. 2013). Concluding, flexible, rigid, high-aspect-ratio MWCNT may cause cancer in a similar fashion as asbestos and may be as potent in this respect.

Based on the data summarised above, there are indications that carbonanotubes are mutagenic and carcinogenic while some can be classified as persistent fibres. Therefore, they are consigned to the highest hazard band, E.

Cobalt manganese oxide nanoparticles

These particles are formed in situ and react in situ in closed reactors (see the introduction above) and as such will not constitute a human safety issue and are therefore not further discussed here.

Cobalt-platinum nanocatalyst (Co Pt alloy)

No data on the toxicity of the alloy, be it in bulk or nanoform, have been found in public literature, hence it will be evaluated based on the properties of its constituent metals. The table below lists the classifications published by ECHA: cobalt has a globally harmonised classification and platinum only self-classifications. The most serious classification is that of cobalt for respiratory sensitisation code 1, on which basis the nanoparticle is attributed hazard band E.

Table 3: Classification of cobalt and platinum for human health hazards as listed by ECHA

Hazard class and code	Hazard statement code	Cobalt (GHS) classification?	Platinum (self-classification) # classified/total notifiers
Skin Sens. 1	H317	yes	56/317
Resp. Sens. 1	H334	yes	9/317
Skin Irr. 2	H315	no	1/317
Eye irr. 2	H319	no	1/317

Source: http://echa.europa.eu/information-on-chemicals/cl-inventory-database

Copper tungstate (CuWO4)

No toxicity data on copper tungstate, be it in the bulk or nanoform, have been retrieved from public literature. Copper tungstate is virtually insoluble in water (Grobler and Suri, 1980). Nanocopper tungstate is used for its photocatalytic activity (Gouma and Lee, 2014) and has a band gap energy of 3.5 eV (Jovanović et al., 2012). In a number of respects it is comparable to titanium dioxide, namely it is also insoluble in water, is photocatalytic and has a similar band gap energy of 3.0 (rutile) or 3.2 eV (anatase) (Li et al., 2016). Therefore, tentatively and in view of the uncertainties of this read-across, copper tungstate is attributed one hazard band higher than titanium dioxide, i.e. band D.

Dendrimers

The most successful early dendrimeric constructs were synthesised using classical linear, random coil polymers, such as polyethylene glycol (PEG), N-(2-hydroxypropyl)methacrylamide (HPMA) copolymers, poly(glutamic acid) (PGA), poly(ethyleneimine) (PEI) and dextrin (a-1,4 polyglucose), while more recently polyamidoamine (PAMAM;Starburstk) dendrimers and poly(propylenemine) (also called PPI, DAB; AstramolR) dendrimers have gained commercial success (Surekha, et al. 2012).

Many in vitro studies have shown toxic effects for almost all of dendrimeric nanopolymers, depending on particle size, shape, coating and many other factors (Duncan and Izzo 2005, Jain, et al. 2010). When they display clear toxicity, it is mostly associated with cationic dendrimers disrupting the cell membrane, e.g. the 5.0G PPI dendrimer has a 24h-EC50 for HEPG2 cells between appr. 10 and 1 µg/mL and a 72h-EC50 < 1 µg/mL (Jain, et al. 2010). At concentrations around 1 mg/mL, also clear haemolytic effects were observed in vitro (4 h incubation) with uncoated dendrimers, but not with coated ones (Jain, et al. 2010). Via the i.p route LD50 of 7.0 G PAMAM dendrimers is between 40 and 160 mg/kg in mice, while subchronic administration of 2.5 and 10 mg/kg bw did not result in mortality nor in renal damage. Based on the available data, no clear conclusion can be drawn with respect to dendrimer toxicity, but based on their membrane disruptive effects, it cannot be excluded that they may cause serious health effects, especially after respiratory exposure. Since there is no indication of mutagenic effects, and they also do not seem probably as these polymers destroy the cell membrane thus killing the cell, this nanoparticle is assigned the one but highest hazard band, D.

Fullerenes (C60)

Classified by Stoffenmanager Nano in hazard band D (Van Duuren-Stuurman et al., 2012).

Graphene and graphene oxide

Graphene is composed of sp2-hybridised carbon atoms arranged in a two-dimensional structure. The various forms of graphene include few-layer graphene, reduced graphene oxide, graphene nanosheets and graphene oxide (GO) (Seabra et al., 2014); these different forms may also be functionalised, that is chemically modified to enhance certain properties (see e.g. Nezakati et al., 2014; Yang et al., 2011). The toxicity profiles of graphene and graphene oxide (GO) nanoparticles remain difficult to separate, since their characterisation, bulk and chemical composition are very similar at the nanometre length scale (Nezakati et al., 2014).

The UK government body, the Medicines and Healthcare Products Regulatory Agency (MHRA), and the US Food and Drug Administration (FDA) are currently reviewing all forms of graphene and functionalised graphene oxide (GO) because of their poor solubility, high agglomeration, long-term retention, and relatively long circulation time in the blood (Begum et al., 2011 cited in Nezakati et al., 2014).

Currently, limited information about the in vitro and in vivo toxicity of graphene is available (Seabra et al., 2014).

In vitro graphene has been demonstrated to be cytotoxic, be it overall to a lesser degree than carbon nanotubes (Seabra et al., 2014). However, the reliability of this conclusion can be doubted since Seabra et al. stated that graphene showed an inverse dose-relationship, being more cytotoxic than carbon nanotubes at low concentrations. The only elaborate comparative study reported by Seabra et al., refers to genotoxicity towards human fibroblast cells. GO proved to be the most potent genotoxic agent compared to iron oxide (Fe304), titanium dioxide (Ti02), silicon dioxide (Si02), zinc oxide (ZnO), indium (In), tin (Sn), core—shell zinc sulphate-coated cadmium selenide (CdSe(3)ZnS), and carbon nanotubes.

Intratracheal instillation of 50 µg GO in mice caused severe pulmonary distress causing excessive inflammation, while the amount of non-functionalised graphene instilled did not (Duch et al., 2011). Single intravenous (i.v.) injection of graphene oxide into mice at a dose of 10 mg/kg bw accumulated in the lung resulting in pulmonary oedema and granuloma formation, with a NOAEL of 1 mg/kg bw (Zhang et al., 2011). Furthermore, surface functionalised graphene (PEGylated) appears to be far less toxic: no toxic effects after single i.v. injection of 20 mg/kg bw (Yang et al., 2011). In mice, PEGylated GO materials showed no uptake via oral administration, indicating limited intestinal absorption of the material, with almost complete excretion. In contrast, upon i.p. injection in mice, PEGylated GO was found to accumulate in the liver and spleen (Yang et al., 2013, cited in Seabra et al., 2014).

The toxicity of graphene is dependent on the graphene surface (the chemical structure or the nature of the functionalised coatings), size, number of layers, and synthesis methods and generalisations are therefore hard to make (Seabra et al., 2014).

Based on the scarce available evidence, it cannot be excluded that some forms of graphene will be as potent a toxicant as carbon nanotubes. Therefore, graphene and graphene oxide are assigned to hazard band E.

Iron nanoparticles

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm) (Van Duuren-Stuurman et al., 2012). Since the size distribution of the iron nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

Iron oxide nanoparticles

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm) (Van Duuren-Stuurman et al., 2012). Since the size distribution of the iron oxide nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

Gold nanoparticles

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm) (Van Duuren-Stuurman et al., 2012). Since the size distribution of the gold nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

Micelles

Micelles in aqueous environments are globular aggregates of amphipathic molecules with their hydrophobic tails facing inwards and their hydrophilic heads facing outwards (Stryer, 1988). In the environment nanomicelles may be used to clean polluted water from metals and organic pollutants (Noh et al., 2008). There are many chemically different nanomicelles, that may differ in toxicity. However, most likely in the application envisaged here their toxicity may principally depend on the pollutants they sequester and concentrate inside themselves. Therefore, it is not feasible to derive a hazard band for nanomicelles in general without taking into account their chemical composition and the pollutants they are supposed to remove from the environment.

Nanoclay

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm, and in band C for sizes >50 nm (Van Duuren-Stuurman et al., 2012). Since the size distribution of the nanoclay nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

Nanoporous materials

The description of the state of the art of nanotechnology for environmental purposes in chapter .. mentions the use of nanocrystals to capture carbon dioxide. Sneddon et al. (2014) reviewed the use of nanoporous materials, amongst others materials with a crystalline structure, in carbon dioxide capture. None of these are already applied at an industrial scale and it is doubtful that they ever will be in view of their higher costs in comparison to the absorbent usually applied in the capture and subsequent geological storage of carbon dioxide (Sneddon et al., 2014). Technically, metal-organic frameworks (MOFs) and mesoporous silicas and ordered mesoporous activated carbon functionalised with amine groups are the most likely candidates for carbon dioxide capture. Since all these materials themselves are not nano-sized, but only contain nano-sized pores, their toxicological properties will be mainly determined by their bulk chemical properties. MOFs often contain toxic metals (e.g. Cu) and/or heterocyclic or aromatic organic compounds, making it likely more hazardous than e.g. mesoporous silicas and activated carbon. However, the nature of amine compounds ligated to the silicas and activated carbon in order to confer carbon dioxide capturing properties to them, may introduce hazardous properties to these rather inert bulk chemicals. Concluding, based on the scant information available and great variety in materials applied, no realistic estimate of the hazard band to be attributed to nanoporous materials can be made.

Nanocoated hydrophobic sand

The description of the state of the art of nanotechnology for environmental purposes in chapter .. mentions nanocoated hydrophobic sand to create an artificial water table in the soil in order to address water scarcity. Since the sand will consist of macroscopic grains and is chemically inert, possible toxicological hazards of this material will depend on the nature of the nanocoating used and human exposure to it will largely depend on the ease with which it may get detached from the sand when coming in contact with the skin. Due to lack of information in these respects, no realistic estimate of the hazard band to be attributed to nanocoated hydrophobic sand can be made.

Silicon nanowires

Silicon nanowires are high-aspect ratio filamentary crystals of silicon, which implicates these nanowires may cause asbestos-like toxicity upon inhalation (Roberts et al., 2012). Fibres may induce lung inflammation and fibrosis that progress over time after exposure and may eventually lead to tumour formation. Whether this process occurs will depend on the dimensions of the fibres (length and width), and their durability (biopersistence). Particles less than 3 μm in width deposit more readily in the respirable region of the lung; long fibres with lengths greater than 15 μm frustrate phagocytosis and clearance by alveolar macrophages. Roberts et al. (Roberts et al., 2012) performed an in vivo experiment in rats to test whether silicon nanowires do cause asbestos-like toxicity. They found indications for the fibre paradigm being valid for these nanowires, but the evidence was not conclusive, a.o. because of the scarcity of long fibres ultimately reaching the alveoli. In view of the physical properties of the silicon nanowires and the fact that some evidence points to them following the fibre paradigm, hazard band E is attributed to them, in accordance with the Stoffenmanager Nano approach (Van Duuren-Stuurman, et al. 2012).

Silver nanoparticles

In an update on silver and some metal oxide nanoparticles hazard band D was attributed to nanosilver (Le Feber et al., 2014).

Single enzyme nanoparticles (SENs)

The description of the state of the art of nanotechnology for environmental purposes in chapter 2 mentions the use of SENs in water remediation. Immobilizing enzymes on nanoparticles will allow increased concentrations of the enzyme and convey a broader working pH and temperature range and a higher thermal stability (Ansari and Husain, 2012). Many different nanoparticles may be used, like alumina nanoparticles, cellulose-coated magnetite nanoparticles, Fe_3O_4 nanoparticles, gold nanoparticles, poly-methyl methacrylate (PMMA) nanoparticles, polystyrene nanoparticles, silica coated nickel nanoparticles, silica nanoparticles, zeo¬lite-gold nanoparticles and ZnO nanoparticles (Ansari and Husain, 2012), as well as single and multi-walled carbon nanotubes and graphene oxide nanomaterials (Campbell et al., 2014). Not only the nature of the nanoparticles employed but also that of the enzyme immobilised on it will determine the hazardous properties of single enzyme nanoparticles, since enzymes are bioactive compounds. Concluding, based on the scant information available and great variety in nanoparticles and enzymes applied, no realistic estimate of the hazard band to be attributed to SENs can be made.

Titanium dioxide nanoparticles

In an update on some metal oxide nanoparticles, hazard band C was attributed to titanium dioxide nanoparticles (Le Feber et al., 2014).

EXPOSURE ASSESSMENT

For the environmental applications for which some information on the application process or conditions is available, the nanomaterials are either present in a closed system or in a solid matrix (e.g. membrane, filter, grid). For such applications the exposure potential during the use phase is low (1). It may be assumed this is also the case for the other applications mentioned. However, a number of applications mentioned are still being investigated at the laboratory scale only, and consequently their exact use condition at an environmental scale are yet uncertain. Furthermore, during the production phase of these systems or matrices the exposure potential may be higher (3). Also during the end-of life phase, exposure is not expected to be very high, but somewhat higher than during the use phase (2).

RISK ASSESSMENT

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table *Priority bands in the Stoffenmanager*. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures or to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 2: Priority bands in the Stoffenmanager

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Risks based on the hazard and exposure banding applied to the environmental sector are listed in the table below. Carbon nanotubes, dendrimers, graphene and graphene oxide have a high priority (1), indicating the need to apply exposure control methods or to assess the risks more precisely. All other materials have an intermediate priority, except calcium peroxide and titanium dioxide in the in-use phase, for which they have a low priority.

Table 3: Priority bands for the nanotechnology environment sector

		Exposure band	
		In use exposure	End-of-life exposure
Nanoparticle	Hazard Band	1	2
Calcium peroxide	C	3	2
Carbon nanotubes, single- and multiwalled	E	1	1
Cobalt manganese oxide	n/a	n/a	n/a
Cobalt platinum catalyst	E	1	1
Copper tungstate (CuWO4)	D	2	2
Dendrimer	E	1	1
Fullerenes (C60)	D	2	2
Gold	D	2	2
Graphene and graphene oxide	E	1	1
Iron	D	2	2
Iron oxide	D	2	2
Micelles	n/a	n/a	n/a
Nanocoated hydrophobic sand	n/a	n/a	n/a
Nanoclay	D	2	2
Nanoporous materials	n/a	n/a	n/a
Silicon nanowires	E	1	1
Silver	D	2	2
Single enzyme nanoparticles (SENs)	n/a	n/a	n/a
Titanium dioxide (titani, rutile, anatase)	C	3	2

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