European Commission

NanoData Landscape Compilation

Construction

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EXECUTIVE SUMMARY

Background

This report offers a snapshot of the status of the environment for nanotechnology in the context of construction. The construction industry covers the building, maintaining and repairing of buildings and infrastructures for living, working and transport, including providing materials for those purposes. The sector is a major consumer of raw materials, chemicals, energy and intermediate products such as electrical equipment, as well as services.

Role of nanotechnology

Nanomaterials can be found in many ordinary construction materials and products such as cement, mortar and concrete, paints, coatings, insulation materials and glass. The nanomaterials (including polymers, particles, carbon nanotubes, quantum dots and thin films) can be used on their own or, more typically, in combination with other materials. Their functions include self-cleaning and non-wetting, photocatalytic cleaning, weight reduction, energy efficiency, safety, longevity, fire resistance and thermal stability.

Currently, nanotechnology is largely applied only to niche markets in the construction industry and much of its potential is not yet being used, the construction industry being rather conservative in nature. There are applications of nanotechnology in various areas of the construction industry, including coatings, insulation materials, fire-resistant materials and cement-based products, but the penetration of these products on the market is limited.

Policies

National policies to support nanotechnology tend to be generic at Member State level in that they may support nanotechnology within broad science and technology initiatives (e.g. Innovate UK in the United Kingdom, which funds across the board) or support it as a designated priority but usually do not single out construction specifically (e.g. NanoNext in the Netherlands).

European supports are concentrated in the EU RTD Framework Programmes (see below) as these have the greatest role in EU funding of nanotechnology R&D. Other policies include those for industry and for construction. There are many examples of collaborative and co-ordination mechanisms at European level including ERA-NET[1]s, European Technology Platforms and Networks of Excellence, not least, for construction the ERA-NETs ERABUILD and ERACOBUILD and the EeB public-private partnership (for energy-efficient buildings), NANOFUN-POLY and EPNOE, looking at polymer-based materials for applications including construction.

In terms of available data, this report tracks research and development activities through projects, publications and patents to products and markets in the context of the wider socio-economic environment.

EU R&D projects

For projects at the European level, nanosciences and nanotechnologies (NT) were first provided for at a significant level in FP6, taking about 10% of the budget (EUR 1,703 million for nanotechnology out of EUR 16,692 million for FP6) mainly under the headings of NMP (EUR 870 million), Information Society (EUR 346 million) and Life Sciences (EUR 54 million), as well as Human Resources and Mobility (Marie Curie Actions, EUR 219 million).

65 projects (80% in FP7) were found to be related to nanotechnology and construction, approximately 2% of all nanotechnology projects in the two Framework Programmes. They received EUR 192 million in funding, EUR 49 million in FP6 and EUR 143 million in FP7. The largest proportion of funding by theme was under the NMP theme of the Co-operation Programme in both FP6 (88%) and FP7 (80%).

Participants from Germany (16%), Spain (15%), the United Kingdom (11%) and Italy (10%) received more than half (52%) of total nanotechnology and construction funding throughout FP6 and FP7.

Research organisations dominate (32% of funding), followed by SMEs (27%), higher education

[1] Also ERA-NET plus

establishments (22%) and large companies (16%). This is in contrast to the case of nanotechnology projects and overall FP6-FP7 projects, where higher education institutes are those that receive the highest shares of funding (47.5% and 41.8% respectively) followed second by research organisations and third by enterprises (both SMEs and larger private companies).

In terms of individual organisations in the EU28, the countries of Germany (Fraunhofer Gesellschaft) and Spain (Tecnalia and Acciona Infraestructuras S.A.) are strongly represented. The top ten participants also include more than one organisation per country from each of Italy and Sweden. Switzerland is the strongest non-EU28 country represented in the top ten organisations.

Looking at companies by funding, Acciona Infraestructuras S.A. of Spain and D'Appolonia Spa of Italy participate in 14 projects (EUR 14.5 million) and 8 projects (EUR 3.28 million) respectively, the next highest participating in three (c. EUR 1 million).

Publications

Of 1.8 million publications globally related to nanoscience and nanotechnology (NST) between 2000 and 2014, about 17,000 were related to construction, around 1% of total output.

The strongest publishing countries in 2014 were China and the US, followed by Spain, France, the United Kingdom and Korea. Of the EU28, the strongest in publications in 2014 after Spain, France and the United Kingdom were Germany, Italy and Portugal.

Six of the top ten publishing organisations were in China. Of the top ten, six were from China and one each from the United Kingdom, Portugal, Spain and Korea.

Looking at EU&EFTA organisations in 2014, these are led by the University of Sheffield (UK), the University of Aveiro (PT) and the Polytechnical University of Valencia (ES). However, there has been no normalisation of the data to take into account factors influencing publication output such as the number of researchers/technicians/students or the research budgets. The companies with the most nanotechnology and construction publications globally in 2014 were SINTEF Building and Infrastructure, Lafarge Group, Zeobond PTY Ltd, HeidelbergCement AG and Daewoo E&C.

Patenting

The US dominates patenting in terms of patent applications, followed by Japan and Germany. Using patenting families[2] as the measure, the top EU28 countries for construction nanotechnology patenting between 1993 and 2011 were Germany (with over 200), and the Netherlands, France, and the United Kingdom (with over 50 each).

The top ten countries by number of applications are the same as the top ten countries by patents granted to applicants for EU and EFTA countries in the same order (DE, NL, FR, UK, IT, CH, SE, DK, BE, FI and AT). It is noteworthy that, of these, only the United Kingdom is in the top ten for publications on nanotechnology and construction and that Spain is missing despite its strong performance in both FP projects and publications.

Globally, the leading EU organisation for patents on nanotechnology and construction (by patent families) was the CEA[3] in France in third place globally after the University of California and MIT, with the Fraunhofer Gesellschaft (DE), the Leibniz Materials Institute (DE) and the CNRS[4] (FR) also in the top ten. Four out of the top ten organisations filing patents were in the US, and one each from China and Japan.

Of the top 15 universities and research organisations ranked by the highest number of EPO patents granted between 1993 and 2011, three are from the EU28/EFTA countries (KU Leuven (BE), University of Munster (DE) and ETH Zurich (CH) (ranked 2nd, 3rd and 4th respectively). The other organisations are all from the US.

Of the top ten companies with the highest number of patent families (with percentages for PCT, US and EP applications), three are in the United States and two are in Japan. Germany (two companies, Evonik Degussa and Merck in 8th and 9th places) and the Netherlands (one company, Degussa, in 4th

[2] At the European Patent Office, US Patent and Trademark Office or World Intellectual Property Office
[3] Commissariat à l'énergie atomique et aux énergies alternatives
[4] Centre national de la recherche scientifique

place) are the only EU28 countries that feature. It should be noted that some companies may be holding companies rather than research-performing companies or manufacturers.

While the numbers are very low, it is worth noting that Evonik Degussa (DE) ranks first amongst companies with highest number of patents granted by the EPO. Wacker Chemie (DE) and Rhodia Chemie (FR) are also in the top ten. Sorting the data by US patents, ASML (NL) is highest of the EU country companies in 3rd place while Evonik Degussa (DE) ranks 8th.

Products and markets for construction through nanotechnology

The global market for products[5] in nanotechnology and construction is expected to grow from USD 1.8 billion in 2013 to USD 4.7 billion in 2019. Most of the growth is expected to come from products that already exist in some form.

Nanotechnology can be used in construction in the form of particles, films and coatings, composites, etc. Global sales estimates show that solid nanoparticles accounted for the largest share (65%) by type of nanomaterial in 2013, with a decrease (to 33%) forecast to 2019, while sales of nano-scale thin films and nano-structured monolithics are expected to almost double their share by 2019, from c. 15% to c. 27%. Sales of nanocomposites are projected to almost triple in relative share (4.3% to 11.7%). Carbon nanotubes are currently forecast to play only a marginal role in terms of shares of sales.

95 building and construction-related products using nanotechnology have been identified as being commercially available on the market. About one quarter of those are in the area of lighting (organic light-emitting diodes (OLEDs), 16%, and light-emitting diodes (LEDs), 11%), and one fifth in the area of coatings (photocatalytic coatings, 11%, and anti-stick coatings, 9%). Paints, coatings and adhesives account for 17% of products and insulation products 16%.

Regulation and standards

European regulations for nanotechnology are well-advanced with definitions and many regulatory documents. Nanomaterials used in construction must comply with the overarching regulatory framework in place for chemical substances: REACH - the *Registration, Evaluation, Authorisation and restriction of CHemicals*.

The use of nanotechnology in construction has implications for three main areas of regulation: construction products; occupational health and safety aspects of construction work; and compliance with environmental performance legislation for new construction. In Europe, construction products are covered by the Construction Products Regulation (CPR) 305/2011. This regulation evaluates the environmental impact of construction products but does not specifically cover nanomaterials. Under occupational health and safety legislation, specifically the European Framework Directive on Safety and Health at Work (Directive 89/391 EEC), employers are required to assess and manage the risks of nanomaterials for their workers. While nanomaterials are not expressly covered by the Directive, the European Agency for Safety and Health at Work (EU-OSHA), dedicates part of its work to nanomaterials.

Some European Member States have put in place additional ways to regulate nanotechnologies, e.g. using databases and reporting schemes for nanomaterials. Non-EU countries have their own controls under which nanotechnology and construction may fall. In general, marketing authorisations have to be applied for on a country-by-country basis. No country has currently developed specific legislation to cover the use of nanomaterials in construction.

The International Organisation for Standardisation (ISO) technical committee on nanotechnologies, ISO/TC 229 Nanotechnologies, has not directly addressed construction in its work. However, a number of technical committees cover areas linked to construction e.g. ISO/TC 59 Buildings and civil engineering works. Standards covering construction developed in these and other technical committees are gathered under the International Classification for Standards (ICS) code 91: Construction materials and building. At the moment, these do not provide for the use of nanotechnologies in these products.

In Europe, the European Committee for Standardisation (CEN) committee on nanotechnology

[5] Sources including BCC Research

(CEN/TC 352) is currently working on a technical report dealing with the construction sector and, in total, over 80 CEN technical committees are dealing with construction. However, these have not yet produced standards dealing with the use of nanotechnology in construction.

Environment, health and safety

Exposure to nanomaterials in the construction sector may be quite diverse during the four-stage life cycle of construction materials: production, building, use and demolition. Since the industry does not manufacture the nanomaterials itself, the building phase generates the highest exposure and the use phase the lowest, with the demolition phase intermediate. Due to the high expected exposure, all nanomaterials reach the highest risk priority during the building phase.

In the use phase, all nanomaterials are contained in a solid matrix, meaning exposure will be negligible and thus health risks will be low. Amorphous silicon dioxide, titanium dioxide, spherical silicon carbide and zinc oxide nanoparticles have a low risk priority while carbon nanotubes, molybdenum, nano-scale graphite, silicon carbide fibres and whiskers, crystalline silicon dioxide, tungsten oxide and vanadium pentoxide have the highest risk priority and the remainder of the nanomaterials have an intermediate risk priority in their risk management.

In the demolition phase, building materials containing carbon nanotubes, molybdenum, nanoscale graphite, silicon carbide fibres and whiskers, crystalline silicon dioxide, tungsten oxide and vanadium pentoxide should receive the highest priority, while amorphous silicon dioxide and zinc oxide have a low risk priority in their risk management.

1 BACKGROUND

The ability to measure and manufacture at the nanoscale is opening up many new avenues within industry and across society including construction.

This report is a Landscape Compilation of facts and figures related to nanotechnology and construction. It offers a snapshot of the status in 2016 of the environment for nanotechnology in the context of construction.

This document reports on past and current policies and programmes for nanotechnology (in particular but not exclusively those relating to construction); the outputs of research (projects, publications and patents) and how those outputs are used in the application of nanotechnology to construction (products and markets). Being a landscaping of nanotechnology, it does not provide detailed analysis of the data or its trends or draw policy conclusions.

The outline of this report is as follows:

- Introduction to construction and the role of nanotechnology;
- Policies and programmes for nanotechnology and construction;
- Research projects, the EU Framework Programmes;
- Publications in nanotechnology and construction;
- Patenting in nanotechnology and construction;
- Industry and nanotechnology for construction;
- Products and markets for construction through nanotechnology; and
- The wider environment for nanotechnology and construction (regulation and standards, environmental health and safety, communication and surveys).

The next section introduces both construction as a sector and the role of nanotechnology as it relates to that sector.

2 INTRODUCTION TO CONSTRUCTION AND THE ROLE OF NANOTECHNOLOGY

2.1 Introduction to construction

The construction industry is about building, maintaining and repairing buildings and infrastructures for living, working and transport, including providing materials for those purposes. The construction sector is described in the European Nomenclature of Economic Activities (NACE)[6] in the following way:

I. Construction of buildings:
   a. Development of building projects.
   b. Construction of residential and non-residential buildings.
II. Civil engineering:
   a. Construction of roads and motorways.
   b. Construction of utility projects (for fluids, for electricity and for communications).
   c. Construction of other civil engineering projects.
III. Specialised construction activities:
   a. Demolition and site preparation.
   b. Electrical, plumbing and other construction installation activities.
   c. Building completion and finishing.
   d. Other specialised construction activities.

Construction is one of the secondary sectors of the economy, as it consists of the manufacture of finished products from raw materials, primary sectors relating more directly to the production of raw materials. It is a key sector in the development of countries as it provides the basic infrastructure on which the rest of the economy depends. As a major consumer of services, energy and intermediate products such as raw materials, chemicals and electrical equipment, the construction sector impacts many other sectors[7]. Although the relative share of construction in Europe's economic activity has declined over recent years, construction is still of high importance for European economies. Currently, it accounts for more than 5% of value added in the EU28, supports around 20 million jobs and contributes about 10% of the EU‵s GDP[8].[9] [10]

The construction sector is a stable, cost-driven and traditional sector, not a strongly technology-driven one. The firms in the sector are typically distant from science-based research and the innovations applied are often produced in other industries such as the chemical industry, material manufacturing or instrumentation[11]. Technology advancements in this sector do not necessarily lead to drastic changes in the final products or to a significant increase in consumer demand[12]. Consequently, the industrial R&D investments of the sector are rather modest, the largest European companies showing, on average, a 0.6% R&D intensity in 2014[13].

In contrast to the manufacturing sector, mass production is still rather scarce in construction, although the volume of pre-fabricated modules is gradually increasing. Construction projects tend to be one-off and typically have an identifiable private or public client for whom the work is highly customised. They generally involve large-scale investments that are expected to produce ‘goods’ that have a long lifetime. This long end-use life-time of buildings and civil works is one of the reasons for the slow pace of adoption of new technologies. All construction works must result in buildings

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[6] Eurostat (2008) Statistical classification of economic activites in the European Community. NACE Rev. 2.
[7] http://ec.europa.eu/growth/sectors/construction/index_en.htm
[8] Gross domestic product
[9] Eurostat Construction Production (Volume) Index Overview, data from 2016: http://ec.europa.eu/eurostat/statistics-explained/index.php/Construction_production_(volume)_index_overview
[10] EC, DG GROWTH (2016) The European construction sector - A global partner. http://eurocodes.jrc.ec.europa.eu/showpublication.php?id=333
[11] Arora et al. (2014) Drivers of technology adoption — the case of nanomaterials in building construction. Technological Forecasting & Societal Change, 87, pp. 232-244.
[12] ObservatoryNano (2009) Economical Assessment, Construction sector, Final report, June 2009.
[13] European Commission, JRC/DG RTD (2014) The 2014 EU Industrial R&D Investment Scoreboard. The Scoreboard reports data on the world's top 2500 companies including a sample of 38 EU based companies in construction sector.

and other infrastructure that perform to specification over the entire life cycle of the building or civil engineering works and the users of the technologies must have confidence in them. Thus, there is a reluctance to adopt new technologies, to be the first to apply a new process or use a new material in construction.

The construction sector is affected in the EU by several policies including environmental protection, energy efficiency, work safety, taxation and public procurement[14]. The European strategy for the sustainable competitiveness of the construction sector to 2020[15] is focused on five key objectives:

I. Stimulating favourable investment conditions, the financial crisis having significantly affected the construction sector with a severe drop in demand for new building projects.
II. Improving the human-capital basis of the construction sector, as there is a need for skilled labour in the sector.
III. Improving resource efficiency, environmental performance and business opportunities. Construction industry is intensively resource consuming, starting from the manufacture of construction materials like concrete and steel, to the energy needed in heating and cooling systems in existing buildings.
IV. Strengthening the internal market for construction, as it is a highly-regulated sector at many levels and it is important that the legal framework is as clear and predictable as possible.
V. Fostering the global competitive position of EU construction enterprises, as they cannot compete on equal terms with non-EU companies that are often subject to less social and environmental requirements and that may also benefit from state aids.

Initiatives in EU countries on energy efficiency can create significant potential for employment in the sector. Energy consumption in buildings in the EU accounts for around 40% of total energy consumption and generates around 37% of overall carbon emissions[16]. It has been estimated that, by 2050, three quarters of current buildings will be still in place while one quarter will be new buildings constructed from today onwards. Therefore, energy consumption in buildings became an essential part of all strategic lines of the EU's energy policy in terms of energy security, competitiveness and environmental and climate concerns[17]. The production of cement alone is estimated to represent 5% of worldwide CO_2 emissions[18]. Similarly, the volume of waste generated by construction and demolition is among the highest in the EU, representing approximately 25%-30% of the total waste[19], resulting in a clear challenge for the sector to achieve improvements in waste management. The largest drivers of the innovation in the construction sector are therefore environmental and energy-efficiency aspects across the whole value chain (from materials to building lifetime).

2.2 Role of nanotechnology in construction

Nanotechnology is a tool with the potential to enable the construction sector to respond to a broad range of challenges. Nanomaterials can be found in many ordinary construction materials and products such as cement, mortar and concrete, paints, coatings, insulation materials and glass. The nanomaterials can be used on their own or typically in combination with other materials, to achieve weight reduction or improved functionalities such as higher durability, fire resistance, thermal stability, self-cleaning and/or photocatalytic properties[20]. With improved properties over conventional materials, they can increase energy efficiency (in manufacture and use) and help to address environmental and safety aspects.

Currently however, nanotechnology applications are still occupying only niche markets in the construction industry and many of the envisaged benefits are yet to be realised. Despite the fact that the research sector has been reporting intensively about new nanotechnology developments

[14] http://ec.europa.eu/growth/sectors/construction/competitiveness/index_en.htm
[15] EC (2012) Action Plan "Construction 2020"Document COM(2012)433 final
[16] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[17] https://www.theparliamentmagazine.eu/articles/feature/energy-consumption-buildings-essential-eu-energy-policy
[18] IEA (2009) Cement Technology Roadmap 2009 - Carbon emissions reductions up to 2050.
[19] http://ec.europa.eu/environment/waste/construction_demolition.htm
[20] Scaffold project: Nanomaterials in the Construction Industry - Guidance for Protecting and Monitoring Health of Workers. http://scaffold.eu-vri.eu/

related to construction, in reality nanotechnology currently plays only a subordinate role in the industry[21].

2.3 Benefits, barriers and drivers of the application of nanotechnology to the construction sector

Some notable potential functionalities for construction offered by nanotechnology include the following:

- Improving the primary properties of materials traditionally used in construction like concrete, steel and glass. The use of nanotechnology-enabled materials is associated with benefits related to decreased use of natural resources (raw materials and energy), and to reduced generation and increased recyclability of waste.
- Adding new features to existing construction materials by means of coatings or paints (e.g. to add properties such as self-cleaning, self-repairing, antimicrobial, antireflective, fire resistance and pollution degradation).
- Introducing new materials that help to provide solutions to some existing problems like insulation or steel corrosion.

The use of nanotechnology materials and applications in the construction industry should be considered not only for enhancing material properties and functions but also in the context of enhanced energy efficiency of both the construction process (e.g. concrete and steel manufacturing) and along the life cycle of buildings. This is a particularly important issue since, as it has been said before, commercial buildings and residential houses account for 40% of all energy consumption in the EU (counting both residential and non-residential buildings and applications such as heating, lighting, and air conditioning[22]). New construction materials and methods, many of them nanotechnology-based, have been estimated to have a potential for energy savings of between 13% and 22% of the energy consumption of buildings in the next two decades[23].

Despite the potential benefits, there are several barriers to the wider introduction of nanotechnology in construction:

- High material costs not yet justified by the benefits achieved[24]. Nanomaterials and nano-products for the construction sector are still considerably more expensive than the conventional alternatives, largely due to the cost of the production technology[25]. As construction materials are generally used in large amounts, small price differences in materials can enormously increase the overall costs when considering the total volume of material used for construction of a building.
- Lack of availability of good quality nanomaterials in large volumes[26]. The construction sector is a very important industry in terms of the scale of material use, traditional materials and nanomaterials alike. Industrial production processes need to be improved in order to obtain an enhanced quality of large scale production of nanomaterials. Many of the current processing technologies of nanomaterials have not yet been shown to be suitable for large scale production. Construction can, however, be considered to have a critical "gate-keeper" role in the diffusion of nanotechnology. As construction uses such large volumes of materials, where it adopts a nanomaterial the volumes will be large. Thus, the need for large quantity of nanoparticles for construction may lead to a significant scaling-up in nanoparticle production and result finally in a significant reduction in market prices of nanoparticles.
- There is no mandatory labelling of nanomaterials used in construction sector[27] and it is often not clear whether nanotechnology is being applied, for the following reasons:

[21] http://www.nanowerk.com/nanotechnology/reports/reportpdf/report162.pdf
[22] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[23] Waide et al., The scope for energy and CO2 savings in the EU through the use of building automation technology, June 2014. Cited from EC (2015) Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation.
[24] Arora et al. (2014) Drivers of technology adoption — the case of nanomaterials in building construction. Technological Forecasting & Societal Change, 87, pp. 232-244.
[25] van Broekhuizen et al. (2011) Use of nanomaterials in the European construction industry and some occupational health aspects thereof. Journal of Nanoparticle Research.
[26] ObservatoryNano (2009) Economical Assessment / Construction sector, Final report. June 2009.
[27] Jones, W. et al (2015) Nanomaterials in construction and demolition – how can we assess the risk if we don't know where they are? Journal of Physics, Conference Series 617.

  - Nanoparticles may be used in some phases of the material fabrication process but are not traceable in the final product.
  - Some companies may not publicly identify the use of nanotechnology in their final products due to business secrecy.
  - Some companies may market their products under a "nano" label while there are no advanced functional properties resulting from the use of nanotechnology.

This means that most workers, and their employers, in the construction sector are not necessarily aware that they work with manufactured nanomaterials and nano-enabled particles. As a consequence, it is difficult to conduct a proper risk assessment and organise a safe workplace for the construction sector employees.

- Lack of industry and public awareness about the possibilities of nanotechnology applied to the sector[28].
- There are not enough data to evaluate the toxicity of the nanomaterials used in construction as many of them are not supposed to be biologically inert[29]. This is a very important concern not only in the production of these materials and the construction/demolition processes but also in the lifecycle of the infrastructure (many of which are for the purposes of habitation).
- Resistance to change in the construction industry. Construction projects are typically economically large-scale investments that are expected to have a long lifetime of the end product. The responsibility of the constructor is not unimportant as the ultimate goal is the functionalities and value offered to the end-user over a long period of time. The long end-use life-time of buildings and civil work is part of the reason why the adoption pace of new technologies in general, and nanotechnology in particular, is slower than in other industries. The technology must provide the agreed functionalities over the entire life cycle of the infrastructure.

However, there are also some important drivers for the adoption of nanotechnology applications in the sector:

- Sustainability legislation may drive a more rapid uptake of innovative technologies and novel materials in the construction sector, than that expected based on improved materials alone. Climate change and energy efficiency regulations and policy in particular may act as an important driver of market uptake of novel technologies in the sector, and may create new business opportunities, especially for SMEs[30].
- Decreasing the weight of construction materials to enable easier handling at the construction site and easier transportation[31], as well as reduced energy consumption and a smaller carbon footprint.
- If the service life of construction materials can be increased, the costs of maintenance and replacement of deteriorated construction components will be reduced. For example, in the case of concrete, the most common building material, even small improvements in its quality and durability (e.g. nano-enabled self-healing concrete) can lead to large savings in the costs of maintenance of buildings[32].
- As knowledge about the actual level of risk associated with the use of nanomaterials increases, and assuming that risk is relatively low, increased application of nanotechnology may result. There have already been studies and initiatives (and more are underway)[33] to assess the risks associated with the handling of nanomaterials in different scenarios. The aim of these is to produce resources for the diagnosis, implementation and audit of nano-risk management in construction enterprises.

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[28] Hanus and Harris (2013) Nanotechnology innovations for the construction industry. Progress in Materials Science, Volume 58, Issue 7, August 2013, pp. 1056–1102.

[29] Lee et al. (2009) Potential Environmental and Human Health Impacts of Nanomaterials Used in the Construction Industry. Nanotechnology in Construction: Proceedings of the NICOM3.

[30] EC (2014) Communication on Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy. 520 final. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52014DC0520

[31] ObservatoryNano (2009) Economical Assessment / Construction sector, Final report. June 2009.

[32] van Breugel (2012) Self-Healing Material Concepts as Solution for Aging Infrastructure. 37th Conference on Our World in Concrete & Structures: 29 - 31 August 2012, Singapore.

[33] e.g. FP7 funded project Scaffold: Innovative strategies, methods and tools for occupational risks management of manufactured nanomaterials in the construction industry.

- The customer is continuously seeking greater comfort and functionality in their home and workplace. This is another innovation driver for the construction sector, with nanotechnology bringing new innovative solutions to the market[34].

2.4 Main nanotechnology application areas in construction

There are several ways of classifying the nanotechnology application areas in construction industry. As nanotechnology in the construction sector is mainly related to materials, these will be taken as the basis for the sector. Thus, construction application areas of nanotechnology (with the related nanotechnology property) include[35]:

- Surface coatings: Production of low-maintenance coatings and paints with e.g. self-cleaning or pollution absorption properties;
- Lighting: Light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs);
- Cement-based materials: The use of nanomaterials to increase the strength and durability and decrease the weight of cementitious composites;
- Thermal insulation: Production of thermal insulation materials with a lower thermal transfer rate and better insulation performance compared to current commercial options;
- Energy recovery systems: Using nanotechnology in heat exchange systems;
- Sensors and self-healing materials: Production of nano-sensors and materials with sensing and self-repairing abilities;
- Nano-modified steel and nano-additions to steel: Production of cost-efficient corrosion-free steel; and
- Composites: Composite materials with surfaces that are hydrophobic and oleophobic.

2.4.1 Surface coatings

Currently, surface coatings form the most promising area of nanotechnology applications in the construction sector - but it is also the area with the most heterogeneous group of nano-enabled products in the building industry. The coatings can be for domestic or professional use, and products can either be supplied by the manufacturer with the nano-coating already incorporated on the surfaces of construction products (e.g. roofing tiles), or the coating can be applied afterwards (e.g. wall paints). The most widely-used nano-coatings in the construction industry fall into three broad categories[36]:

- Silica-based coatings, for water and/or fire resistance, or anti-graffiti properties.
- Titanium based coatings, to enable ease of cleaning and for pollution absorption.
- Coatings incorporating nanoscale silver as an anti-microbial agent.

Nanotechnology based coatings are applied to surfaces to improve their performance in terms of, for example, durability, strength, stability and weather resistance, and to add new properties or functionalities to the material they are applied to, including self-cleaning properties, water-, fire- or scratch-resistance. A wealth of nanotechnology-based products for various surfaces are already on the market. The main focus is on dirt-, fire- and water-repellent coatings, as well as self-cleaning coatings. These include facade paints, window panes, roof tiles, surface protection for construction materials against corrosion, water penetration, mosses, algae or mould, and anti-fingerprint coatings.

In relation to coatings, special mention must be made of glass as one of the materials most commonly used in buildings. Glass is used in construction sector on the exterior surface of buildings. The control of light and heat entering through such glazing is considered to be a major sustainability issue. Coated window glass is currently among the most widely used nano-enabled construction material and the large majority of new buildings incorporate windows with nano-coated surfaces to improve their thermal insulation[37]. Nanotechnology coatings can also be applied to windows to block excess light and heat and/or act as thermal insulation[38]. Electrochromic windows consist of two glass panes (sandwich pane) with an electrically conductive, transparent coating. Applying a small electric

[34] http://www.nanowerk.com/nanotechnology/reports/reportpdf/report162.pdf
[35] W. Zhu, P. Bartos, A. Porro (2004) Application of nanotechnology in construction. Summary of a state-of-the-art report. RILEM TC 197-NCM, Mater Struct, 37 (2004), pp. 649–658.
[36] Ibid
[37] Ibid
[38] Nanoforum Report (2006) Nanotechnology and Construction

current this nano-structured coating changes colour and reduces the passage of sunlight through the laminated panel. This permits control of light and heat intake through windows[39]. Apart from heat and light control, another application area of nanotechnology in building glazing is related to so-called self-cleaning windows based on the photocatalytic properties of titanium dioxide nanoparticle coatings. Other nano-enabled applications for window glass, such as solar protection or anti-fogging, are currently less frequently used. The application of nanotechnology in glass, specifically in windows, is also seen in the concept of smart windows, windows with added and improved functionalities due to the application of nanotechnology.

In addition, nanotechnology is likely to find wide application in wood-based products for the construction sector in the future[40]. Wood at the nanoscale is constructed of nano fibrils called lignocellulose, fibres that are argued to be much stronger than steel and could offer new avenues for treating sustainable buildings. Nanotechnology-based coatings applied to wood material, or wood composites are also being used to improve the properties (durability, water resistance, fungi resistance) of wood as a construction material. These products range from coatings to high-performance composites of wood and wood fibre.

2.4.2 Lighting

Light-emitting diodes (LEDs) have substituted light bulbs already in an increasing number of lighting applications. Unlike conventional incandescent lamps, which need to convert the electricity into thermal energy first and then to light, LED illumination is achieved when a semiconductor crystal is activated so that it directly produces visible light in a desired wavelength range[41]. Nevertheless, a low-cost, mass-market white-light diode with the potential to replace conventional incandescent bulbs and fluorescent tubes seems currently still out of reach for LED researchers and manufacturers.

One possible solution is the use of nanophosphors (i.e. semiconducting nanoparticles that emit light under excitation) in white LEDs. If the phosphor particles are smaller than 20 nm in diameter, according to Mie theory, there will be less scattering of light waves and thus greater optical and energy efficiency[42].

Organic light-emitting diodes (OLEDs) emit soft diffused light, the closest light source to natural light with the exception of incandescent lamps[43]. An OLED 'light bulb' is a thin film of material that emits light. OLED is the only technology that can create large area lighting panels (as opposed to point or line lighting enabled by LEDs and fluorescent bulbs). OLEDs can be used to make flexible and transparent panels, and can also be colour-tuneable.

Organic light-emitting diodes (OLEDs) are also expected to grow in use for flexible, high-resolution and low-energy consumption displays. They are still in development and a large potential market is envisaged. Developments in OLED technology are increasing the potential for extremely high-resolution, low-energy thin and flexible displays. OLEDs have a longer lifetime than regular LEDs and the flexibility of the material lends itself to distinctive designs.

2.4.3 Cement-based materials

Concrete is the most used material in the construction industry. Concrete is a cement composite material and made up of three basic components: water, aggregate (rock, sand, or gravel) and cement as a binding agent[44]. Cement is "a hydraulic binder, i.e. a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens"[45]. This hydraulic hardening is primarily due to the formation of calcium silicate hydrates as a result of the reaction between water and the constituents of the cement. Clinker, the main component of cement, is obtained from

[39] MIT Technology Review (2015) Smart Windows Just Got Cooler. https://www.technologyreview.com/s/539946/smart-windows-just-got-a-lot-cooler/

[40] Zev, A. and Ezel, M. (2014) Nanotechnology Innovations for the Sustainable Buildings of the Future. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering. Vol 8.

[41] LED inside: Advantages and Weaknesses of LED Application, December.20, 2007

[42] Zachau M, Konrad A (2004), Nanomaterials for Lighting, Solid State Phenomena Vols. 99-100 (2004): 13

[43] http://www.oled-info.com/oled-light

[44] Portland Cement Association (PCA) (2016) How Concrete is Made. Available: http://www.cement.org/cement-concrete-basics/how-concrete-is-made

[45] European Standard, EN 197-1, Cement - Part 1: Composition, specifications and conformity criteria for common cements, June 2000.

calcination of limestone[46]. This process requires high temperatures and is also major source of carbon dioxide emissions[47]. That is why supplementary cementitious materials (SCMs), such as blast-furnace slag, a by-product from pig iron production, fly ash from coal combustion, or silica fume from silicon manufacturing present a viable solution in concrete mixtures as a replacement of a portion of clinker in cement or as a replacement of a portion of cement in concrete[48]. This practice is favourable to the industry, often resulting in concrete with lower cost and lower environmental impact[49]. Accordingly, the European standard defines 27 distinct cement products and requirements for their constituents and performance in terms of mechanical, physical and chemical parameters[50].

Nanotechnology can improve cement-based materials in two main ways[51]:

- Nanotechnology can be used in the *measurement and characterisation* of the structures of cement-based materials (e.g. using advanced characterisation techniques and molecular modelling). Advances in the field of instrumentation and in computational materials science have made it possible to enhance the understanding of the structure of concrete, permitting improved prediction, design and control of material properties and performance[52].
- The *manipulation of structures* at the nanoscale to develop a new generation of tailored, multifunctional, cementitious composites with superior mechanical performance and durability[53]. The application of nanotechnology in the manufacture of cement is a rapidly progressing area, at least in terms of scientific research. Materials such as nano-silica (SiO_2), nano-titanium oxide (TiO_2), carbon nanotubes and nano-alumina (Al_2O_3) are being combined with cement (as additives) in order to improve properties of cementitious materials[54] such as structural efficiency, durability and strength which can thereby improve the quality and life-cycle of the building structures. Photocatalysts such as TiO_2 can be incorporated into cement-based products (e.g. internal and external surfaces of buildings, roads and motorway tunnels) creating air-purifying surfaces in the built environment[55]. In addition, the use of nanoscale industrial waste-based cement replacements (such as blast furnace slag or fly ash) can reduce carbon dioxide emissions associated with concrete production[56]. Nanoparticles can also act as interfaces for cement, enhancing cement hydration due to the high reactivity of nanoparticles or as fillers densifying the cement structure leading to reduced porosity.

Although the addition of nanoparticles can result in various benefits, there are some significant challenges to be addressed in order to access of the full potential of nanotechnology-enhanced cementitious materials. These include the effective dispersion of the nanoparticles; the current high cost-benefit ratio; and the lack of large-scale implementation of laboratory-level results[57]. A recent study concluded that concrete is now used only to a limited extent in nano-enabled forms and that the presence of nanoparticles in cured concrete is relatively low[58].

There are however some examples of nanotechnology enabled products in the context of civil infrastructure:

- The Gärtnerplatzbrücke, a bridge inaugurated in 2007 over the Fulda River in Kassel (Germany),

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[46] Moya, J. A., Pardo, N., Mercier, A. (2010) Energy Efficiency and CO2 Emissions: Prospective Scenarios for the Cement Industry, JRC Scientific and Technical Reports.
[47] Ibid; Amato (2013) Green cement: Concrete solutions, Nature 494, 300–301 (21 February 2013).
[48] Juenger, M., and Siddique, R. (2015) Recent advances in understanding the role of supplementary cementitious materials in concrete. Cement and Concrete Research, Volume 78, Part A, December 2015, Pages 71–80.
[49]Doneliene, J. et al (2016) The Effect of Synthetic Hydrated Calcium Aluminate Additive on the Hydration Properties of OPC. Advances in Materials Science and Engineering, Volume 2016 (2016), Article ID 3605845.
[50]European Standard, EN 197-1, Cement - Part 1: Composition, specifications and conformity criteria for common cements, June 2000.
[51] Sanchez, F., Sobolev, K. (2010) Nanotechnology in concrete – A review. Construction and Building Materials.
[52] Ibid.
[53] Porro A, Dolado J, Campillo I, Erkizia E, De Miguel Y, De Ybarra Y et al. Effects of nanosilica additions on cement pastes. In: Proceedings of the international conference on applications of nanotechnology in concrete design; 2005. p. 87–96.
[54] Raki et. Al (2010) Cement and Concrete Nanoscience and Nanotechnology. Materials, 3(2), 918-942.
[55] http://www.tecnalia.com/images/stories/10_PhotocatalyticProducts_v2.pdf
[56] Hanus and Harris (2013) Nanotechnology innovations for the construction industry. Progress in Materials Science, Volume 58, Issue 7, August 2013, pp. 1056–1102.
[57] Sanchez, F., Sobolev, K. (2010) Nanotechnology in concrete – A review. Construction and Building Materials.
[58] Jones, W. et al (2015) Nanomaterials in construction and demolition – how can we assess the risk if we don't know where they are? Journal of Physics, Conference Series 617.

and the Wild-Brücke in Völkermarkt (Carinthia, Austria), inaugurated in October 2010 and worldwide the first medium-sized road bridge whose main support structure was made of Ultra High Performance Concrete (UHCP). Recent overview lists another 17 examples of applications of UHCP in the context of civil engineering (e.g. pedestrian bridges, columns, sewer pipes and wind turbine foundations) around the world[59]. The article does not however specify whether the UHCP applied utilised nanoparticles in the concrete mixture.
- Several new trial applications have been initiated e.g. in Belgium and Italy in recent years to assess the real-life behaviour of photocatalytic coatings with cement-based products in road tunnels and road pavements for NOx emission reduction (e.g. Leopold II tunnel of Brussels; side roads of main entrance axis in Antwerp and industrial zones of Wijnegem and Lier, block pavement in Bergamo and tunnel pavement in Rome)[60,61]. Similarly, some real-life cases exist in the case of buildings with photocatalytic coatings applied to cement-based materials.

2.4.4 Thermal insulation materials

The use of nanotechnology in thermal insulation for buildings results in the same or improved thermal resistance using thinner, usually porous, insulation material. 'Nano insulation materials' (NIMs) are based on modifying the material properties at the nanoscale by minimising the pore size within the insulating material in order to achieve decreased level of thermal conductivity. Applications include aerogels, vacuum insulation panels, and coatings (including, for example, Phase Change Materials (PCM) and electrochromic windows)[62] as follows:

- Aerogel applications in insulation are rapidly growing field. Aerogel is an insulating material composed of silica nanoparticles separated by nano-pores.
- Vacuum Insulation Panels (VIP) are thin panels made out of nanoscale silica, graphite or silicon carbide and laminated by synthetic material and aluminium. The challenge of VIPs is that they are costly to produce, they are very sensitive to mechanical friction and they do not permit cutting to size at the construction site.
- Phase change materials for buildings store and release thermal energy using changes in their physical state (e.g. from solid to liquid or from liquid to gas (although the latter is not commonly used in this application due to the large volume changes associated with the gas). The change depends on the temperature of the material. Construction materials with phase change thermal properties suitable for the construction sector include concrete, glass, or steel with PCM coatings and are used for temperature control in buildings.
- Electrochromic windows consist of two glass panes (sandwich pane) with an electrically-conductive, transparent coating. The internal space contains a sol-gel-layer[30] of tungsten trioxide. Applying a small electric current (up to 3 Volts) turns this nano-structured coating blue and reduces the passage of sunlight through the laminated pane.

Nanotechnology may also change the thermal insulation in buildings so that the construction material itself becomes a high performance thermally-insulating material.

2.4.5 Energy recovery

Energy recovery ventilation (ERV) uses the energy recovery process of exchanging the energy contained in the air of a normally-exhausted building or space and using it to treat (precondition) the incoming outdoor ventilation air in residential and commercial HVAC (heating, ventilation and air conditioning) systems. During the warmer seasons, the system pre-cools and dehumidifies while humidifying and pre-heating in the cooler seasons[63]. Potential locations for the use of such systems include all types of commercial and residential buildings, data centres, medical facilities, homes,

[59] Abbas, S., Nehdi, M. L. and Saleem, M. A. (2016) Ultra-High Performance Concrete: Mechanical Performance, Durability, Sustainability and Implementation Challenges. International Journal of Concrete Structures and Materials, September, 2016, Vol. 10, Issue 3, pp. 271-295.

[60] Boonen, E. and Beeldens, A. (2014) Recent Photocatalytic Applications for Air Purification in Belgium. Coatings, 2014, 4, 553-573.

[61] Guerrini, G. L. (2012) Photocatalytic cement-based materials: applications and new perspectives. Presentation of Italcementi at Photopaq Symposium, 14th- 17th May, 2012.

[62] Jelle, B. J. (2011) Traditional, state-of-the-art and future thermal building insulation materials and solutions – Properties, requirements and possibilities, Review Article, Energy and Buildings, Volume 43,

[63] Dieckmann, John. "Improving Humidity Control with Energy Recovery Ventilation" ASHRAE Journal. 50, no. 8, (2008)

cars, trains, buses, retail display coolers, refrigerated trucks and others[64]. Some systems precondition incoming air using nanostructured polymer filters. Others using nanotechnology increase the energy conversion efficiency and emission reduction for the heating of houses using a combination of a zeolite-water adsorption heat pump and a gas condensing boiler. The goal is the supply of useful heat at a higher temperature level by adding low-temperature heat to the work process.

2.4.6 Nano-modified steel and nano additions to steel

Steel is another typical material for the construction sector and is especially used in the structures of buildings, roads and bridges. The main challenges related to steel are fatigue and the effect of corrosion on steel, with resultant structural weaknesses. Nanotechnology can be applied in steel manufacturing in two ways[65]:

- Improving the structure of steel at the nanoscale. The modified structure is associated with higher strength, better fatigue resistance and lower weight (when compared to normal steel).
- Adding nanoparticles such as copper to reduce surface unevenness, resulting in less stress risers and reduced fatigue cracking.

Currently, nanotechnology-enhanced steel is mainly in the research phase, and there are many technological and cost barriers to overcome before the advances of nanotechnology can be fully leveraged in steel manufacturing by the construction industry[66].

2.4.7 Sensors and self-healing materials

Production of nanosensors and materials with sensing and self-repairing ability is another area where nanotechnology is expected to provide value-added in the field of construction. More advanced structural health monitoring (SHM) of buildings and infrastructures typically involves sensors such as fibre optic sensors, piezoelectrics, magnetostrictive sensors, self-sensing composite materials, etc. which possess capabilities of sensing various physical and chemical parameters related to the health of civil structures[67,68]. Structural health monitoring can be performed by: (i) attaching sensors to the surface of a structure, (ii) embedding sensors into material structures during construction or, (iii) by constructing structures or parts of structures using a material containing self-monitoring of strain and/or other properties[69].

The main bottleneck of current SHM technologies is that they are hardly scalable to large scale structures due to number of sensors needed for effective assessment and because of costs related to management and maintenance. Here, recent developments of nanotechnology may provide interesting avenues for SHM development. The inclusion of nanomaterial as functional fillers into cementitious matrices can transform concrete structures into self-sensing systems[70]. The nano-scale functional fillers such as carbon fibre, carbon nanotube, and nickel powder are dispersed into conventional concrete matrix to form an extensive conductive network inside the composite material, which allow the detection of strain, stress, crack or damage through measuring the electrical properties of the composite[71]. This technology has its potential not only in the field of SHM but can also be used e.g. for traffic detection, corrosion monitoring of rebar, and structural vibration control of buildings and infrastructure[72]. However, there are still issues to be resolved before large-scale

[64] BCC Research (2014), Nanotechnology, a realistic market assessment, p.77
[65] Hossain K. and Rameeja, S. (2015) Importance of Nanotechnology in Civil Engineering, European Journal of Sustainable Development.
[66] Shi, X. et al. (2013) The use of nanotechnology to improve the bulk and surface properties of steel for structural applications. In Nanotechnology in Eco-Efficient Construction.
[67] Rana, S., Subramani, P. Fangueiro, R. and Gomes Correia, A. (2016) A review on smart self-sensing composite materials for civil engineering applications. AIMS Materials Science, 2016, 3(2): 357-379.
[68] Hanus and Harris (2013) Nanotechnology innovations for the construction industry. Progress in Materials Science, Volume 58, Issue 7, August 2013, pp. 1056–1102.
[69] Ibid
[70] D'Alessandro, A., Rallini, M., Ubertini, F. Annibale Luigi Materazzi, A. L. and Kenny, J. M. (2016) Investigations on scalable fabrication procedures for self-sensing carbon nanotube cement-matrix composites for SHM applications. Cement and Concrete Composites, 65 (2016), 200-213.
[71] Han, B., Ding, S. and Yu, X. (2015) Intrinsic self-sensing concrete and structures: A review. Measurement 59 (2015) 110–128.
[72] Ibid

deployment of such a sensing technology can be achieved. According to a recent overview, more research is still needed to develop self-sensing systems that can identify the location of damage, to study the effects of different environmental and usage conditions on the self-sensing performance and especially in respect to cost reduction of nanomaterials to make the self-sensing materials more affordable[73].

Ultimately, the objective is to develop construction materials that are not only able to monitor but also to regulate, adapt and repair themselves without external intervention[74]. The so-called "self-healing materials" are mimicking nature and have the built-in capability to repair the early stage damage that would finally lead to material failure[75]. Self-healing mechanisms that have recently shown promise in concrete include 1) enhancing the concrete properties to self-healing, 2) microcapsules that contain a repair agent, bacteria that precipitate calcite, 3) shape memory polymers that shrink when triggered, and 4) vascular flow networks that circulate a healing agent[76]. Since the material defect generally emerges at very small scale, nanotechnology plays an important role in advances of self-healing materials[77]. For example, there are on-going research activities in UK[78] on a new generation of smart concrete and other cement-based construction materials looking at the benefits of combining several self-healing technologies for the same piece of concrete mimicking the skin healing processes[79].

2.4.8 Composites

Composite materials using nanotechnology are common and have many uses. One area of application for construction is the use of composites with specific surface properties. These properties are similar to those achieved using coatings and thin films based on nanotechnology as discussed previously under coatings. However, it is reported that self-organising nanocomposite materials, for use in construction, are being created by breaking down a composite material consisting mainly of alcohol and sand into nanoparticles that form a composite, the surface of which is both hydrophobic and oleophobic.

Nanotechnology in construction is also used in fibres, cables, wire sheathing, and many other areas. The purpose of nanotechnology in construction products currently on the market is further discussed in the section on *Products and Markets*, later in this report.

The next section considers the policies and programmes in place for nanotechnology and construction.

[73] Rana, S., Subramani, P. Fangueiro, R. and Gomes Correia, A. (2016) A review on smart self-sensing composite materials for civil engineering applications. AIMS Materials Science, 2016, 3(2): 357-379.
[74] Lark et al. (2013) Biomimetic Multi-Scale Damage Immunity for Construction Materials: M4l Project Overview
[75] http://theconstructor.org/building/smart-materials/self-healing-materials-civil-engineering/5868/
[76] Kapsali, V. and Toomey, A. (2014) CM1. Self-healing Materials. Available: https://www.changemakers.com/sites/default/files/cm1_self_healing_materials_report_.pdf
[77] De Rooij, M., Van Tittelboom, K., De Belie, N. and Schlangen, E. (Eds.) (2013) Self-Healing Phenomena in Cement-Based Materials: State-of-the-Art Report of RILEM Technical Committee.
[78] University of Cardiff, University of Cambridge and University of Bath joined forces in a UK Engineering and Physical Sciences Research Council funded project.
[79] University of Cambridge (2015) Press release: Health-conscious concrete. Available: http://www.cam.ac.uk/research/features/health-conscious-concrete

3 EU POLICIES AND PROGRAMMES FOR NANOTECHNOLOGY AND CONSTRUCTION

Support for public sector research and development (R&D) in the European Union is funded by Member States either directly through national programmes or indirectly via the programmes administered by the European Commission and its agencies. In addition, research and development are 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), on Member State funding and on the outputs of industry funding of its own R&D.

EU funds for research and innovation are provided through dedicated programmes. In 2014-2020, these include the Framework Programmes (currently Horizon 2020), covering all research fields and fully dedicated to funding research and innovation activities; sectoral research programmes (nuclear energy, coal and steel, space); and the European Structural and Investment Funds. These programmes are complemented by five other EU programmes with links to research and innovation activities: The Third Health Programme[80], Life[81], Erasmus+[82], COSME[83] and the Connecting Europe Facility[84].

This section will first consider the EU Framework Programmes.

3.1 The EU Framework Programmes: supports for nanotechnology

The construction sector is Europe's largest industrial employer, a major source of revenue from exports and an evident contributor to the quality of life for all citizens. Continued research and development is vital to provide a sound basis for recovery from the effects of economic downturn and to address the global problems of climate change and population growth.

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. Support specifically named as being for nanosciences and nanotechnologies was first provided at a significant level in the Sixth Framework Programme (FP6, 2002-2006)[85]. Within FP6 funding, nanotechnology construction projects were mainly funded under NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) (88%, EUR 43 million), most of the rest of the funding being for human resources and mobility as well as horizontal research involving SMEs.

Nanotechnology funding in FP6 was followed up with targeted funding in the Seventh Framework Programme (FP7, 2007-2013). The largest part of funding for construction and nanotechnology was under the Co-operation Programme and specifically NMP - "Nanosciences, Nanotechnologies, Materials and new Production Technologies (NMP)" with 80% of funding (EUR 115 million). Funding also went to Environment (under Co-operation) and Research for the benefit of SMEs (under Capacities) (both with almost 6%, EUR 8 million) and Marie Curie Actions (under People) (2.5%, EUR 3.6 million). This is covered in much greater detail later in this chapter.

Within the NMP Theme of FP7, research for the construction sector included two topics identified as priorities in consultation with the Member States and the European Construction Technology Platform:

- "Resource-efficient and clean buildings", to reduce significantly the consumption of materials and encourage the wider use of renewable resources.
- "Innovative value-added construction product services", for retro-fitting and maintenance of buildings, which was identified as a key activity for the 2.5 million SMEs in the construction

[80] Preventing diseases, protecting EU citizens from cross-border health threats, contributing to innovative health systems, and facilitating better access to healthcare.

[81] For environment, biodiversity and climate change.

[82] Supporting relocation for education and training purposes.

[83] Supporting the creation and expansion of companies, especially by expanding their research and innovation activities.

[84] Improving trans-European infrastructure for transport, energy and telecommunications.

[85] 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.

sector.

Mechanisms for collaboration on nanotechnology and construction, *inter alia*, include the ERA-NETs, Networks of Excellence and ESFRI, as outlined below. Later in the report, there is coverage of EUREKA's Eurostars; the European Technology Platforms; and the Joint Technology Initiatives (and Joint Undertakings).

The ERA-NET scheme began under FP6 to support collaboration between and co-ordination of national research programmes. Networks supporting construction included, for example, the activities of the ERA-NET ERABUILD[86] (2004 – 2007) for research on sustainable development in the construction and operation of buildings, particularly energy and environment research. Under FP7, the work of the network continued through a second ERA-NET, ERACOBUILD[87] (2008 -2012), with 34 partners from 21 Member States, and a total EC contribution of EUR 2.3 million. It focused on the sustainable renovation of buildings and on value-driven construction processes and it applied technologies including nanotechnology. ERACOBUILD was a network of national R&D programmes and aimed to develop synergies between national programmes by sharing strategies and establishing joint programmes and projects. It defined two thematic frameworks for transnational co-operation: "Sustainable Renovation" and "Value Driven Processes". The ERA-NET ERACOBUILD was well in line with the "Energy-efficient Buildings" (EeB) Public-Private Partnership[88] Initiative, funded with a total of EUR 1 billion in the period 2010-2013, and included as part of the "European Economic Recovery Plan" (2008)[89].

Under FP7, the ERA-NET scheme continued to develop and strengthen the co-ordination of national and regional research programmes through ERA-NET Plus actions - providing, in a limited number of cases with high European added value, additional EU financial support to facilitate joint calls for proposals between national and/or regional programmes. For example, ERANET+ projects targeting construction were funded through MATERA+[90] (ERA-NET Plus on Materials Research). The MATERA+ call was launched in March 2009 with financial resources from the European Commission and 20 national and regional Funding Agencies from 14 different countries and was a follow-up to the MATERA. The focus of MATERA+ was on projects for multi-functional materials; engineering structural materials; and bio-based and bio-inspired materials.

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. The intended long-term impact was to create efficient organisations operating at the European level, thereby eliminating wasteful duplication of research effort and, by facilitating joint planning and resource sharing, overcoming any inadequacies faced by individual institutes in terms of human resources, expertise, equipment and infrastructure. These bottom-up initiatives are led by consortia targeting specific research or technological challenges. Two Networks of Excellence mentioned target nanotechnology for the construction sector:

- NANOFUN-POLY[91]: under FP6, aiming to generate a Network of Excellence designed to become a European centre of nanostructured polymers and polymer-based nanocomposite materials, strengthening the scientific, technological and training excellence in all the disciplines that contribute to the development of the field; and
- The European Polysaccharide Network of excellence "EPNOE[92]": a research, education and knowledge transfer network connecting companies, academic and research institutions working or interested in polysaccharides.

The main objective of European Network of Excellence (NoE) Nanostructured and functional polymer-based materials and nanocomposites (NANOFUN-POLY) project was to form the European Centre for Nanostructured Polymers (ECNP). The major aim of the centre is the co-ordination and the joint carrying-out of activities and operations, particularly with regard to polymer nanotechnologies,

[86] https://www.era-learn.eu/network-information/networks/erabuild
[87] https://www.era-learn.eu/network-information/networks/eracobuild
[88] http://ec.europa.eu/research/industrial_technologies/energy-efficient-buildings_en.html
[89] http://ec.europa.eu/economy_finance/publications/publication13504_en.pdf
[90] http://www.materaplus.net/
[91] http://acletters.org
[92] http://www.epnoe.eu/

principally for the sake and in the interests of the partners of the NoE NANOFUN-POLY project. The attainment of this objective presupposed the form of a transdisciplinary partnership which consists of a hundred and twenty scientists. Applications which pertain to NANOFUN-POLY materials concern strategic industrial sectors which can become competitive only by implementing advanced technologies, such as optoelectronics and telecommunications, packaging, agriculture, building construction, automotive and, biomaterials, etc.

EPNOE (European Polysaccharide Network of Excellence) for research on polysaccharides (such as cellulose and starch) that are fully biodegradable and renewable raw materials produced by nature on a large scale (1000 times of the amount of synthetic polymers). The network was initially funded with a total of EUR 5 million over 4 years from 2005 within the thematic priority "Nanotechnologies and Nanosciences-Multifunctional Materials, Processes and Production. It was founded by sixteen member organisations across nine Member States formally in 2005 but also has business and associated members. EPNOE aims to organise and integrate the European scientific community in order to promote the use of polysaccharide materials as industry feedstocks for the manufacturing of advanced multifunctional materials. The materials can be used in the pulp and paper industries, as well as for fibres, textiles, construction and packaging materials.

Other mechanisms to support research and innovation in nanotechnology and construction 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).

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

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

3.2.1 Overview

Project-related data was extracted from the eCorda database for the EU Sixth Framework Programme (FP6) and the EU Seventh Framework Programme (FP7)[93]. 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"[94] in the title or abstract of the project. Thus, nanotechnology projects form approximately 10% of total FP projects. The share of nanotechnology projects increased slightly between FP6 (9.1%) and FP7 (10.4%).

74.4% of the 3.544 nanotechnology projects were FP7 projects and 25.6% were FP6 projects. The relative shares of nanotechnology projects were similar to those found for FP projects in general (71.6% in FP7 and 28.4% in FP6).

[93] Extraction of data from eCorda January 2015.

[94] 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".

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)		10.0%	10.4%	9.1%

Number and share of construction nanotechnology projects

The number of projects (in FP6 and FP7 together) that were related to both construction and nanotechnology was determined by a keyword search[95] to be 65, less than 2% of the total number of FP6 and FP7 projects related to nanotechnology. The percentage of construction-related nanotechnology projects as a proportion of all nanotechnology projects was slightly higher in FP7 (2.0%) than it was in FP6 (1.4%). This is an indication that the relevance of construction has slightly increased within nanotechnology FP-activities from FP6 to FP7.

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

	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
Construction nanotechnology FP projects	65	52	13
	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%
NT construction FP projects	100%	80%	20%
NT construction projects as % of all NT projects	1.8%	2.0%	1.4%
NT construction projects as % of all FP projects	0.2%	0.2%	0.1%

Projects in FP7 comprised 80% of all construction nanotechnology with 20% of projects being in FP6. This share of FP7 projects is higher than those corresponding to nanotechnology projects (74%) or FP projects (72%).

Funding of construction nanotechnology projects

The 65 construction-related nanotechnology projects received a European contribution of EUR 191.8 million. European funding to construction projects was EUR 48.7 million (25.4%) in FP6 and EUR 143.1 million (74.6%) in FP7. In FP6, construction-related nanotechnology projects took 2.9% of total European funding for nanotechnology projects whereas in FP7 it was 3.1%, indicating a very small relative increase of construction-related funding within European nanotechnology funding, as shown in the figure below.

[95] See Annex for details

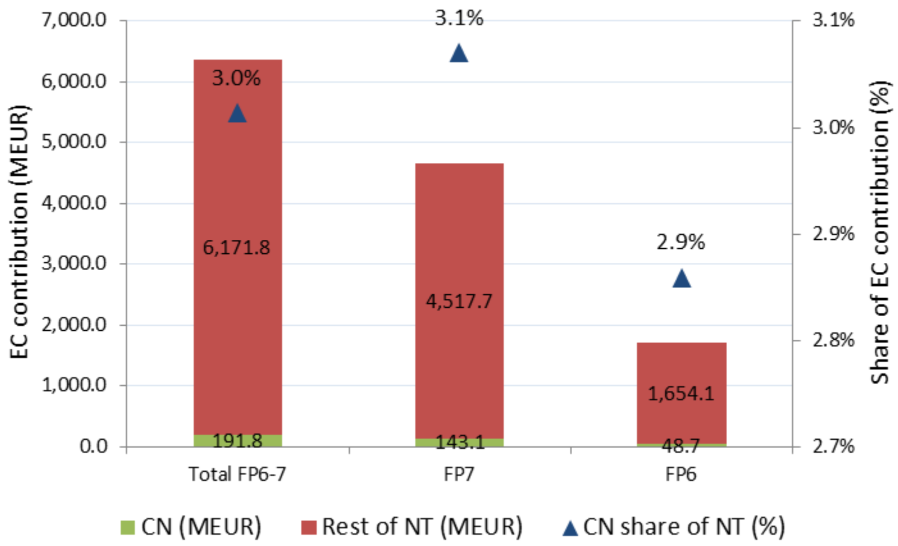

Figure 3-1: Funding of construction nanotechnology for FP6 and FP7 together, for FP7 and for FP6

3.2.2 Activities by programme and sub-programme

3.2.2.1 FP6 construction nanotechnology activities

There were 908 nanotechnology projects in FP6, 9.1% of the total number of projects in FP6. Thirteen of them were identified as being construction-related, 1.4% of FP6 nanotechnology projects and 0.1% 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, projects specific to nanotechnology and construction made up approximately 2.5% of all nanotechnology activities as measured by EC funding allocation (EUR 48.7 million). They took place mainly under the priority of Focusing and integrating the ERA. In fact, 93.4% of all funding for construction activities under FP6 came from this priority, specifically for:

- NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had 88.2% of the total (EUR 42.9 million) for eight projects; and
- Horizontal research involving SMEs had the remaining construction activities in FP6, with three projects and EUR 2.5 million of EC funding (5.2% of total).

The remaining 6.6% of funding came from Structuring the ERA, specifically:

- Human resources and mobility, which had two projects accounting for EUR 3.2 million, or 6.6% of funding.

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

FP6 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP6	FP6 NT	FP6 CN	FP6	FP6 NT	FP6 CN	FP6	FP6 NT	FP6 CN
I Focusing and Integrating ERA	**4,735**	**455**	**11**	**13,445.0**	**1,383.6**	**45.5**	**80.5%**	**81.3%**	**93.4%**
Thematic Priorities	3,374	389	8	12,027.5	1,314.8	42.9	72.1%	77.2%	88.2%
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	0	3,798.9	346.1	0.0	22.8%	20.3%	0.0%
3. NMP	444	271	8	1,534.2	870.1	42.9	9.2%	51.1%	88.2%
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	0	2,300.9	30.5	0.0	13.8%	1.8%	0.0%
7. Citizens and Governance	143	3	0	236.6	2.4	0.0	1.4%	0.1%	0.0%
Specific Activities	1,361	66	3	1,417.5	68.8	2.5	8.5%	4.0%	5.2%
Policy Support	520	29	0	604.2	40.7	0.0	3.6%	2.4%	0.0%
Horizontal Research Involving SMEs	490	29	3	463.1	24.7	2.5	2.8%	1.4%	5.2%
International Co-operation	351	8	0	350.3	3.4	0.0	2.1%	0.2%	0.0%
II Structuring the European Research Area	**5,096**	**449**	**2**	**2,744.2**	**303.1**	**3.2**	**16.4%**	**17.8%**	**6.6%**
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	2	1,723.1	219.2	3.2	10.3%	12.9%	6.6%
Research Infrastructures	147	17	0	717.6	74.3	0.0	4.3%	4.4%	0.0%
Science and Society	163	9	0	79.5	5.8	0.0	0.5%	0.3%	0.0%
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	13	16,692.3	1,702.7	48.7	100.0%	100.0%	100.0%

3.2.2.2 FP7 construction nanotechnology activities

With 52 projects, nanotechnology and construction comprised 2% of FP7 nanotechnology projects and 0.2% of all FP7 projects[96]. In terms of funding, they comprised 3.1% of nanotechnology FP funding and 0.3% 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 nanotechnology construction is seen under the Co-operation Specific Programme with EUR 125.6 million (87.8% of total nano construction funding in FP7) and 34 projects. Within this Co-operation Specific Programme, the NMP thematic area has the highest funding (EUR 114.9 million, 80.3%), followed at a distance by Environment (EUR 8.2 million) and Transport (EUR 2.5 million).

[96] Data extraction January 2015

The Capacities Specific Programme, with a share of 8.1% of FP7 funding and EUR 11.5 million comes second. There are two activities funded under this Specific Programme, Research for the benefit of SMEs, with EUR 8.2 million, seven projects, and 5.8% of funding, and Research Potential with EUR 2.3 million, two projects and 1.6% of funding.

Marie-Curie Actions, under the People Specific Programme, has the next highest funding with EUR 3.6 million (2.5%) for 7 projects.

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

FP7 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP7	FP7 NT	FP7 CN	FP7	FP7 NT	FP7 CN	FP7	FP7 NT	FP7 CN
COOPERATION	7,834	756	34	28,336.3	2,803.8	125.6	63.1%	60.2%	87.8%
Health	1,008	33	0	4,791.7	157.0	0.0	10.7%	3.4%	0.0%
Food, Agri and Bio	516	25	0	1,850.7	97.1	0.0	4.1%	2.1%	0.0%
ICT	2,328	175	0	7,877.0	561.3	0.0	17.5%	12.0%	0.0%
NMP	805	412	30	3,238.6	1,595.6	114.9	7.2%	34.2%	80.3%
Energy	368	24	0	1,707.4	81.5	0.0	3.8%	1.7%	0.0%
Environment	494	10	3	1,719.3	26.9	8.2	3.8%	0.6%	5.7%
Transport	719	12	1	2,284.2	61.5	2.5	5.1%	1.3%	1.8%
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	0	1,295.5	14.1	0.0	2.9%	0.3%	0.0%
General Activities	26	0	0	312.7	0.0	0.0	0.7%	0.0%	0.0%
Joint Technology Initiatives	736	46	0	1,966.4	177.0	0.0	4.4%	3.8%	0.0%
IDEAS	4,525	572	1	7,673.5	1,026.1	2.3	17.1%	22.0%	1.6%
European Research Council	4,525	572	1	7,673.5	1,026.1	2.3	17.1%	22.0%	1.6%
PEOPLE	10,716	1,158	7	4,777.5	579.9	3.6	10.6%	12.4%	2.5%
Marie-Curie Actions	10,716	1,158	7	4,777.5	579.9	3.6	10.6%	12.4%	2.5%
CAPACITIES	2,025	149	10	3,772.0	249.9	11.5	8.4%	5.4%	8.1%
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	7	1,249.1	86.1	8.2	2.8%	1.8%	5.8%
Regions of Knowledge	84	4	1	126.7	7.3	0.9	0.3%	0.2%	0.7%
Research Potential	206	27	2	377.7	55.1	2.3	0.8%	1.2%	1.6%
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	0	173.4	12.7	0.0	0.4%	0.3%	0.0%
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	52	44,917.3	4,660.8	143.1	100.0%	100.0%	100.0%

3.2.3 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 construction nanotechnology.

Table 3-5: Participations in FP6 and FP7 including funding and share of funding[97]

	Total FP6 and FP7			NT in FP6 and FP7			Construction NT, FP6 & FP7		
	Particip.	EC Funding MEUR	Share of Funding	Particip.	EC Funding MEUR	Share of Funding	Particip.	EC Funding MEUR	Share of Funding
HES	76,777	25,736.0	41.8%	7,671	3,019.5	47.5%	129	43.4	22.6%
REC	53,384	17,304.4	28.1%	4,696	1,778.1	28.0%	183	61.2	31.9%
PCO	25,067	7,021.3	11.4%	2,275	615.4	9.7%	145	30.6	16.0%
SME	29,428	6,882.6	11.2%	3,239	769.1	12.1%	249	51.8	27.0%
Other	24,961	4,626.8	7.5%	1,059	174.2	2.7%	35	4.8	2.5%
Total	209,617	61,571.1	100.0%	18,940	6,356.2	100.0%	741	191.8	100.0%

Research organisations (REC) received 31.9% of the EC contribution to nanotechnology and construction, as shown in the table above and the figure below. They are followed by small and medium-sized enterprises (SME, 27%), higher education institutes (HES 22.6%), large companies (PCO, 16%) and other organisations (OTH, 2.5%).

There are significant differences between the distribution of funding among different participant types in nanotechnology construction projects and both nanotechnology projects and FP6-FP7 projects in general. The highest shares of funding in the case of nanotechnology construction projects accrues to enterprises (SMEs and PCOs together account for 43% of funding) and research organisations (31.9%) while higher education institutes have the lowest share of funding (22.6%). In the case of nanotechnology projects and overall FP6-FP7 projects, higher education institutes are those that receive the highest shares of funding (47.5% and 41.8% respectively) followed second by research organisations and third by enterprises (both SMEs and PCOs). This seems to indicate that nanotechnology construction projects are closer to the market than either nanotechnology projects or FP projects as a whole.

[97] 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.

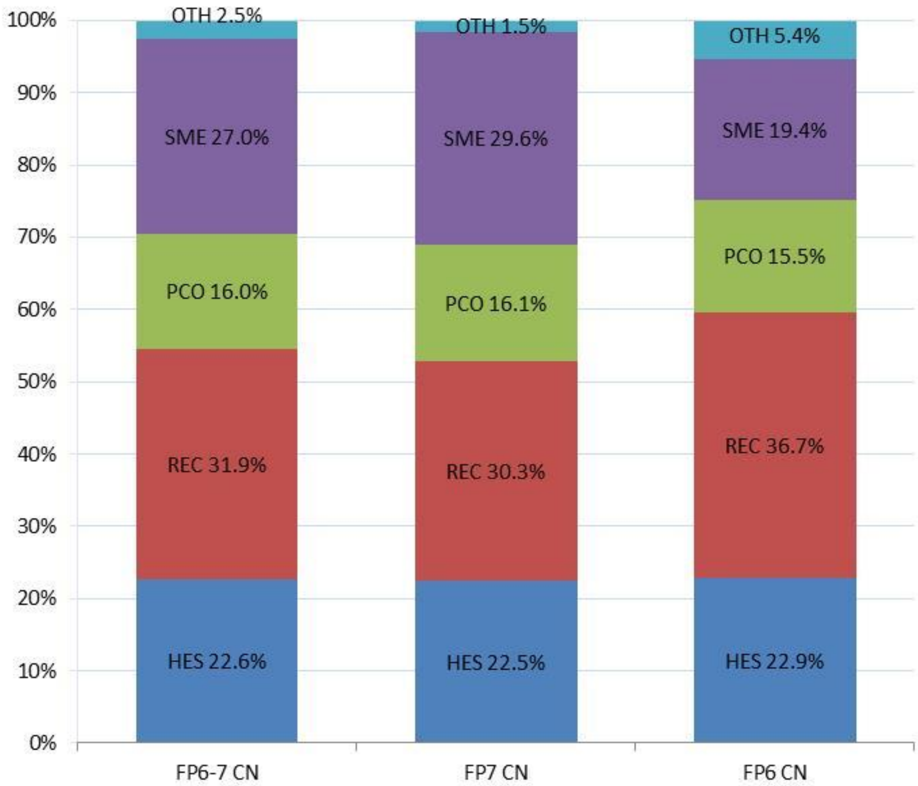

Figure 3-2: Shares of EC contribution by organisation type for nanotechnology and construction

Comparing FP6 and FP7, the most remarkable finding is that the share of funding going to SMEs rose from 19.4% in FP6 to 29.6% in FP7. There is also a rise (although a smaller one) in the share for PCOs from FP6 to FP7. However, the share for research organisations fell from 36.7% in FP6 to 30.3% in FP7. FP7 projects seem to have achieved greater involvement by enterprises maybe because of their higher proximity to market.

The proportion of funding going to organisations in the higher education sector (22.6%) is less than half of that corresponding to their share of nanotechnology funding (46.6%), and a bit over half of their share for FP funding overall (41.8%). The relative importance of HES fell slightly from 22.9% in FP6 to 22.5% of all construction funding in FP7.

3.2.4 Activity by organisations receiving funding

The organisations receiving the largest amounts of funding for nanotechnology construction activities were Fraunhofer[98] (DE) (EUR 6.96 million for 13 projects) and Tecnalia[99] (ES) (EUR 4.63 million, 12 projects) as well as the companies Acciona Infraestructuras S.A.[100] (ES) (EUR 4.54 million, 14 projects) and D'Appolonia SPA[101] (IT) (EUR 3.28 million, 8 projects).

Out of the top 25 recipients, thirteen were research organisations, seven were higher education institutions, and five were companies. The top ten organisations come from Germany, Spain, Italy, Sweden, Greece, the Netherlands and Switzerland.

[98] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. http://www.fraunhofer.de/en.html
[99] Fundacion Tecnalia Research & Innovation http://www.tecnalia.com/en/
[100] http://www.acciona-infrastructure.com/about-us.aspx
[101] http://www.dappolonia.it/en

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

	Construction - Top participants	Country	No. of Projects	EC Funding (MEUR)	Share of CN Funding
1	Fraunhofer-Gesellschaft[102]	DE	13	6.96	3.64%
2	Fundacion Tecnalia Research & Innovation	ES	12	4.63	2.42%
3	Acciona Infraestructuras S.A.	ES	14	4.54	2.37%
4	D'Appolonia SPA	IT	8	3.28	1.71%
5	Uppsala Universitet	SE	3	3.10	1.62%
6	National Technical University of Athens - NTUA	GR	6	3.07	1.60%
7	TNO	NL	5	2.96	1.55%
8	INSTM[103]	IT	2	2.23	1.17%
9	Eidgenoessische Materialpruefungs- und Forschungsanstalt[104]	CH	5	2.18	1.14%
10	SP Sveriges Tekniska Forskningsinstitut AB	SE	4	1.77	0.92%
11	Fundacion Tekniker	ES	4	1.69	0.88%
12	Innventia AB	SE	1	1.69	0.88%
13	University of Bath	UK	2	1.63	0.85%
14	EPFL[105]	CH	3	1.49	0.78%
15	Profactor GmbH	AT	1	1.37	0.71%
16	Eberhard Karls Universitaet Tuebingen	DE	1	1.35	0.70%
17	University of Belgrade	RS	1	1.30	0.68%
18	Teknologisk Institut	DK	2	1.26	0.66%
19	CEA[106]	FR	3	1.16	0.61%
20	Institouto Michanikis Ylikon Kai Geodomon AE[107]	GR	3	1.09	0.57%
21	Bundesanstalt fuer Materialforschung und -Pruefung[108]	DE	4	1.05	0.55%
22	Latvijas Valsts Koksnes Kimijas Instituts	LV	1	1.05	0.55%
23	Ncc Construction Sverige AB	SE	1	1.02	0.53%
24	Foundation for Research and Technology	GR	3	1.02	0.53%
25	Fundacion Inasmet	ES	1	1.02	0.53%

The table below indicates the most active companies in FP nanotechnology construction projects by funding. In this sector, eighteen of the most relevant companies were SMEs.

The Spanish company Acciona Infraestructuras S.A. received EUR 4.54 million for fourteen projects. D'Appolonia SPA (IT) followed with EUR 3.28 million and eight projects, and Profactor GmbH (DE) came next, at distance, with EUR 1.37 million and one project.

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[102] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[103] Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali www.instm.it
[104] https://www.empa.ch/web/empa
[105] École Polytechnique Fédérale de Lausanne, the Swiss Federal Institute of Technology in Lausanne www.epfl.ch
[106] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[107] Institute of Mechanics of Materials and Geostructures SA
[108] http://www.bam.de/en/ueber_uns/index.htm

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

	Construction - Top company participants	Country	SME	Number of projects FP6-7	EC funding (MEUR)
1	Acciona Infraestructuras S.A.	ES		14	4.54
2	D'appolonia Spa	IT		8	3.28
3	PROFACTOR GmbH	AT	SME	1	1.37
4	Institouto Michanikis Ylikon Kai Geodomon Ae (Institute Of Mechanics Of Materials And Geostructures SA)	GR	SME	3	1.09
5	Ncc Construction Sverige Ab	SE		1	1.02
6	Va-Q-Tec Ag	DE	SME	3	0.99
7	Babcock Support Services Limited	UK		1	0.98
8	Vento Nv	BE	SME	2	0.88
9	Siemens Schweiz Ag	CH		1	0.84
10	Advance Composite Fibres Sl	ES	SME	2	0.80
11	Exergy Ltd	UK	SME	2	0.79
12	UK Materials Technology Research Institute Ltd	UK	SME	3	0.72
13	Vertech Group Sarl	FR	SME	2	0.72
14	Obermayr Holzkonstruktionen GesmbH	AT	SME	1	0.71
15	Separex Sas	FR	SME	3	0.70
16	Integrated Environmental Solutions Limited	UK	SME	1	0.69
17	Bouygues Travaux Publics SA	FR		2	0.68
18	Nubiola Pigmentos Sl	ES	SME	1	0.67
19	Indosynt As	NO	SME	1	0.64
20	Farbe Spa	IT	SME	2	0.64
21	IBZ-Salzchemie GmbH & Co Kg	DE	SME	2	0.62
22	P3 - Digital Services GmbH	DE	SME	1	0.62
23	Acciona Inmobiliaria Sl	ES		1	0.61
24	Slovenski Gradbeni Grozd, Gospodarsko Interesno Zdruzenje	SI	SME	2	0.59
25	Pedrini S.P.A	IT	SME	1	0.58

3.2.5 Participation by country

In total, 36 countries took part in nanotechnology construction projects funded under FP6 and FP7. The top fifteen are shown in the table below, with funding and shares of funding for each country.

The top four countries (Germany, 16.28%; Spain, 14.74%; the UK, 10.61%; and Italy, 10.16%) accounted for more than half of the total EC funding for nanotechnology construction projects.

It is worth noting the presence of Spain ranking second in this list while it holds the 5th and 6th positions in the case of nanotechnology and overall FP6-FP7 projects. This is well in line with the relevance of the construction sector in the Spanish economy.

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

Rank	Country	CN NT funding (MEUR)	% of funding
1	DE	31.22	16.28%
2	ES	28.27	14.74%
3	UK	20.36	10.61%
4	IT	19.48	10.16%
5	SE	15.63	8.15%
6	FR	12.75	6.65%
7	EL	8.39	4.37%
8	CH	7.40	3.86%
9	BE	7.14	3.72%
10	NL	6.85	3.57%
11	AT	5.01	2.61%
12	FI	4.12	2.15%
13	PL	3.16	1.65%
14	CZ	2.99	1.56%
15	DK	2.90	1.51%
	TOTAL	**175.64**	**93.1%**

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

(Listed in order of received construction-related nanotechnology funding, highest at the top of the table)

	FP EC contribution			NT EC contribution			CN EC contribution		
	MEUR	%	Rank	MEUR	%	Rank	MEUR	%	Rank
DE	10,164.1	16.5	1	1,121.5	17.6	1	31.2	16.28	1
ES	4,200.6	6.8	6	481.0	7.6	5	28.3	14.74	2
UK	9,295.2	15.1	2	845.9	13.3	2	20.4	10.61	3
IT	5,046.5	8.2	4	505.2	7.9	4	19.5	10.16	4
SE	2,386.7	3.9	9	271.6	4.3	8	15.6	8.15	5
FR	7,319.3	11.9	3	760.9	12.0	3	12.8	6.65	6
GR[109]	1,425.5	2.3	12	128.5	2.0	14	8.4	4.37	7
CH	2,503.2	4.1	8	338.0	5.3	7	7.4	3.86	8
BE	2,518.0	4.1	7	258.4	4.1	9	7.1	3.72	9
NL	4,438.4	7.2	5	444.3	7.0	6	6.8	3.57	10
AT	1,612.2	2.6	10	156.9	2.5	10	5.0	2.61	11

Germany, the United Kingdom, France and Italy are the top countries both for nanotechnology projects and for FP projects. The table above and figure below show the top ten countries for nanotechnology construction, for nanotechnology and for FP projects by funding. In the table, Greece is in the top ten for nanotechnology construction but not for nanotechnology or for FP project funding overall. Austria is in the top ten for nanotechnology and for FP project funding, but not for nanotechnology construction.

[109] Greece is identified using the letters either GR or EL (Ellas)

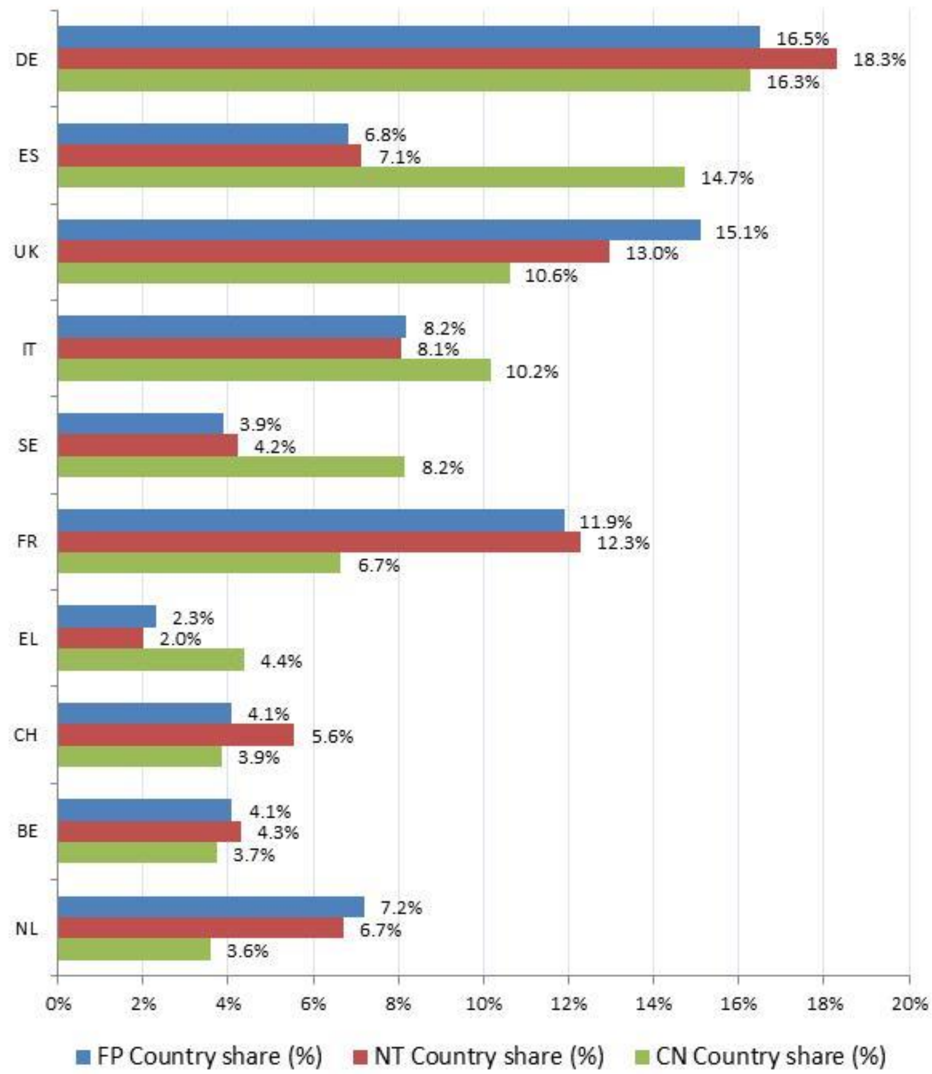

Figure 3-3: Percentage shares of FP funding by country in FP, in nanotechnology and in construction nanotechnology

From the figure above, in most cases, the share of funding for nanotechnology construction 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, such as Spain, Italy, Sweden and Greece, who have higher percentages of funding for construction nanotechnology. It is worth mentioning the case of Spain with a share of funding of nanotechnology construction projects which is double the share of nanotechnology projects funding. It can be concluded that these countries show a higher specialisation in the field of construction nanotechnology.

In the figure below (the EC funding for nanotechnology construction projects in FP6 and FP7 (bars) and the country shares (points or diamonds), three countries have increased their share of funding for nanotechnology construction projects from FP6 to FP7. These are Spain, the UK and Switzerland. Spain is the most significant case, as it increased its share of funding from 7.7% to 17.1% and also the United Kingdom with a rise from 4.8% in FP6 to 12.6% in FP7. Italy, on the other hand, reduced its share of funding from 14.2% in FP6 to 8.8% in FP.

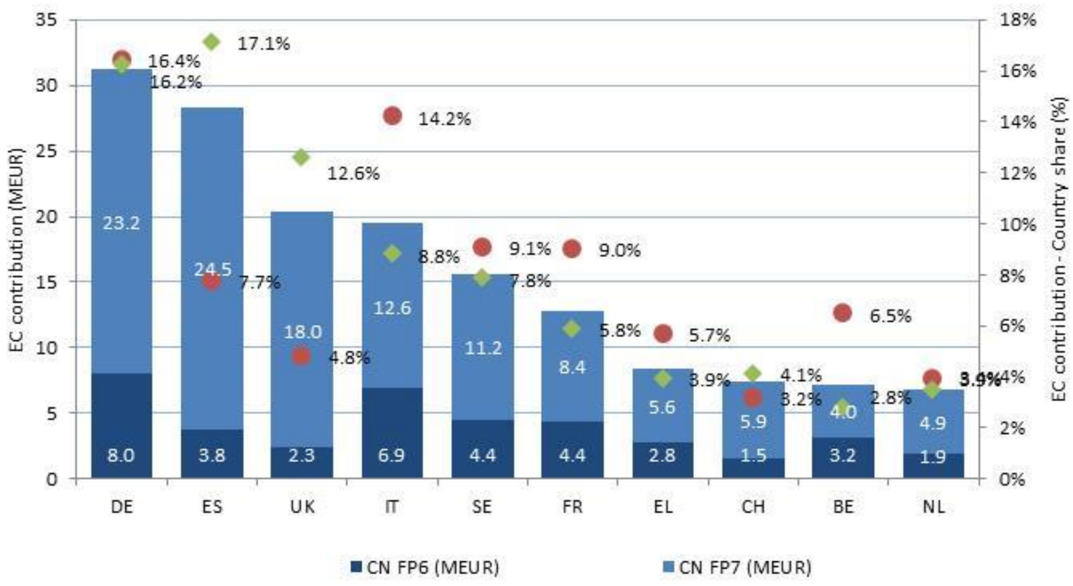

Figure 3-4: EC funding for construction nanotechnology activities in FP6 and FP7 in MEUR and country shares

3.2.6 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:

- 82% of projects had published work during the project, the total number of publications being 1783 and the average number being almost 17; and
- 32% of projects had applied for patents, a total of 73 patents having been applied for, an average of 0.7 per project. Of these, 18 have been applied for at the European Patent Office, 20 under the PCT at WIPO, 6 at the USPTO and 30 at other (national) patent offices.

Of the 106 projects, seven were classified by review as being related to construction and nanotechnology. Those seven projects reported outputs of:

- 57 publications, an average of eight publications per project, half that for nanotechnology overall; The project "Nanotechnology enhanced extruded fibre reinforced foam cement based environmentally friendly sandwich material for building applications" had many more publications than the average with 24 published papers.
- Four patent applications, an average of 0.07 per project, a tenth of that found for nanotechnology overall (0.6). Only two of the seven projects had patents:
    - "Development of Nanotechnology-based High-performance Opaque & Transparent Insulation Systems for Energy-efficient Buildings" had a total of 3 patents.
    - "Extended service-life and improved properties of wood products through the use of functional nanoparticles in clear coating and adhesive systems" resulted in one patent.

A workforce of 440 people was involved in the projects (with an average of 63 people per project).

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

3.3 Other EU policies and programmes

3.3.1 EU policies and programmes: Industry

Policies related to industry and economic development fall under the Framework Programmes and other EU measures (e.g. under the remit of DG Enterprise and Industry). Some, addressing construction, are identified below.

Under FP6 and FP7, the objective of construction research funding is to strengthen the science and technology base to the level of global leadership, to stimulate innovation and creativity in products, processes and services, and to enhance the use of construction for public benefit in society and the economy. Alongside the Framework Programmes, complementary mechanisms such as COST (European co-ordination in science and technology) and EUREKA provide additional funding for joint European research in the field of construction. Both are inter-governmental programmes for the coordination of nationally-funded research on a European level. COST encourages various national facilities, institutes, universities and private industry to work jointly on a wide range of research activities, while EUREKA focuses on market-oriented industrial R&D.

The EUREKA Eurostars initiative was established under Article 185 of the Treaty on the Functioning of the European Union (TFEU), in partnership between the EC, the Member States and the countries associated with the Framework Programmes. Eurostars supports SMEs in the EU to commercialise their research, bringing it to the market more quickly in the form 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 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. Under EUREKA scheme, the umbrella project EurekaBuild was initiated in 2006 to develop technologies for sustainable and competitive construction, in line with the Strategic Research Agenda of the European Construction Technology Platform (ECTP)[110].

European Technology Platforms (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 contribute to design, update and provide recommendations on the Strategic Research Agenda on the specific sector they are dealing with. ETPs now exist across the themes of construction, energy, environment, ICT, production and processes, transport and the bio-based economy.

The European Construction Technology Platform (ECTP) was launched in 2004, with the aim of mobilising all stakeholders around the stated objectives of 'meeting clients' and users' requirements, becoming sustainable and transforming the construction sector'. It has over 170 member organisations, and is mirrored by national platforms in most EU countries. It also maintains close links with other construction-related technology platforms. It has committees working across five areas:

- Active ageing and design
- Energy and efficient buildings (E2B)
- Heritage and regeneration
- Infrastructure and mobility
- Materials and sustainability

The European Economic Recovery Plan endorsed by the European Council in December 2008 includes public-private partnerships (PPPs) to support research into sustainable technologies for the EU construction sector as well as for the manufacturing and automotive industries. The 'Energy-efficient Buildings' (EeB) PPP is allocating EUR 1 billion of public-private funding to the development of energy-efficient systems and materials in new and renovated buildings with a view to reducing their energy consumption and CO_2 emissions.

Under Horizon 2020, a contractual Public-Private Partnerships on Energy-efficient Buildings will aim to develop affordable breakthrough technologies and solutions at building and district scale,

[110] http://www.ectp.org/about-us/

facilitating the road towards future smart cities. Up to the end of FP7 in 2013, a dialogue was going on between the Commission services and the Ad-hoc Industrial Advisory Group for the construction sector to develop a multi-annual roadmap of research priorities for the period. The multiannual roadmap for the years 2014-2020, prepared jointly with the Energy Efficient Buildings Association (E2BA), sets a vision and outlines routes towards a high-tech building industry, turning energy efficiency into a sustainable business. This roadmap proposes research and innovation priorities agreed amongst a wide community of stakeholders across Europe, after public consultation.

General objectives of the multi-annual roadmap are to:

- Develop technologies and solutions to speed up the reduction of energy use and GHG emissions;
- Develop energy efficiency solutions in order to turn the building industry into a knowledge-driven sustainable business, with higher productivity and better skilled employees; and
- Develop innovative and smart systemic approaches for green buildings and districts, helping to improve the competitiveness of the EU building industry by providing cost-effective, user-friendly, healthy and safe products for smart cities.

Specific objectives and key deliverables of the roadmap are:

- Innovative construction;
- Systemic, cost-effective, mass-customised, high-performing, and minimally invasive building retrofitting solutions, integrating innovative energy equipment and storage;
- Interactive sustainable buildings for energy neutrality/positivity in a block of buildings, for a further 15% energy and emission reduction at district and city scale; and
- Performance monitoring tools to ensure energy efficiency during service life.

3.3.2 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.

3.3.3 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)[111] aim to focus regional innovation policies on regional priorities based on existing areas of strength; competitive advantage; and potential for excellence in each

[111] 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.

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 next section considers Member State policies and programmes for nanotechnology and construction.

4 POLICIES AND PROGRAMMES IN MEMBER STATES FOR NANOTECHNOLOGY AND CONSTRUCTION

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 related to applications in construction, specific initiatives at Member State level, past or present, include:

Austria: The Austrian NanoInitiative[112] (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 trans-nationally 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, has been to invest in projects with considerable market potential and relevant to Austrian companies. NANO aimed to address the following issues that are relevant to construction: *"What is the best way for Austria to harness the opportunities in nanotechnology, for instance for the sake of environmental and energy technology, new resource-saving products or for small- or medium-sized enterprises?"* The type of activities begun under the programme are now continuing under the thematic areas FFG's research funding programmes. For example, since 2012, nanotechnology is supported, *inter alia*, via FFG's thematic research funding for *Production of the Future*.

France: The French Agence National de la Recherche (ANR) channels public funding into priority areas including Nanotechnologies and Manufacturing. Since 2006, the P2N programme[113] 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. P2N also addresses nanotechnology for sustainable development, relevant to construction. The objectives are to reinforce the partnerships between the industrial and scientific communities, and to improve the competitiveness of French technologies by fostering technological breakthroughs.

Germany: In 2011, the German Ministry for Education and Research (BMBF) published the Action Plan Nanotechnology 2015[114] outlining the strategy for responsible development, innovation and public dialogue on nanotechnology for the period 2010-2015. The plan included proposals for developing nanotechnology in five main areas including energy, being Nanomaterials for adaptive building technology a sub-area within energy (operation of buildings alone accounts for 40% of the energy consumption in Germany). In parallel, there are the Innovation Alliances[115], providing 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 industry is combined in a typical proportion of 1:5 (public: private).

The Netherlands: NanoNed (2004 – 2010, total funding of EUR 235 Million administered by the Dutch Ministry for Economic Affairs), the Nanotechnology R&D initiative in the Netherlands, has clustered the Dutch expertise on nanotechnology and enabling technology into a national network. The NanoNed programme was organised into eleven independent programmes, or flagships, amongst which were Bottom-up Nano-Electronics and Nano-Fabrication. In 2011, NanoNed was followed by NanoNextNL[116], a consortium of more than a hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities. Stakeholders collaborate

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[112] https://www.ffg.at/nano-das-programm
[113] http://www.agence-nationale-recherche.fr/en/projects-and-results/calls-for-proposals-2013/aap-en/nanotechnologies-and-nanosystems-p2n-2013/
[114] http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf
[115] https://ec.europa.eu/growth/tools-databases/kets-tools/sites/default/files/policy/germany.pdf
[116] http://www.nanonextnl.nl/

on fundamental as well as applied research through research projects. NanoNextNL is expected to grow into an open-innovation ecosystem, with new partners joining the consortium. Industry has committed to continue its support for NanoNextNL after 2015.

In addition, innovation in the Netherlands is organised under the *Top Sector Policy*[117] announced in 2010. Businesses, researchers and government work closely together in *Top consortiums for Knowledge and Innovation* (TKIs). The only policy objective that has been set specifically for the top sector policy is that public and private parties should participate in the TKIs for an amount of at least €500 million by 2015, 40% of which should be financed by trade and 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. 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 cost micro- and nanotechnology-based autonomous sensors and control systems with local intelligence).

Portugal: The International Iberian Nanotechnology Laboratory[118] (INL) was established as the result of a joint decision of the Governments of Portugal and Spain, in November, 2005. With a total investment of EUR 46.5 million (of which EUR 30 million came from the European Regional Development Fund, "Spain – Portugal" Operational Programme, 2007-2013). INL 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 (including nanofabrication facilities) for materials science at nanoscale, nano-electronics, nano biotechnology and nanomedicine. In addition to being a facility for researchers in Portugal and Spain, it hosts those from non-EU countries such as Brazil. Among the key research activities at INL is nano-electronics (including spintronics, MEMS and nano-devices).

Slovakia: The Ministry of Education, Science, Research and Sports (MESRS)[119] published the Action Plan for the Innovation Strategy for Smart Specialisation, 2014-2020[120]. 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 (about EUR 42 million) and information and communication technologies (about EUR 10 million).[121]

Spain: The Sixth National Scientific Research, Development and Technological Innovation Plan (2008-2011) included the Strategic Action for Nanoscience and Nanotechnology, New Materials and New Industrial Processes (SANSNT), which addressed seven priorities, amongst which were nano-electronics and molecular electronics, optoelectronics and photonics, and semiconductor nano-structures as well as magnetic information storage and magneto-electronics. Under the Spanish State Plan for Scientific and Technical Research and Innovation 2013-2016, endorsed in February 2013, a number of funding support instruments are available for the development and dissemination of Key Enabling Technologies, including nanotechnology.

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[122]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[123] and identified future potential growth sectors and commercialisation opportunities.

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[117] http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/smart-industry
[118] http://inl.int/
[119] https://www.minedu.sk/about-the-ministry/
[120] http://s3platform.jrc.ec.europa.eu/regions/SK
[121] http://s3platform.jrc.ec.europa.eu/documents/10157/511834/PPT_Slovakia_Dublin%20FINAL%2026%206%202014.pdf.
[122] https://www.gov.uk/government/organisations/innovate-uk
[123] https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative

The UK Enabling Technologies Strategy 2012-2015[124] also aims to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment by addressing four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT). Nanotechnology is identified as having a significant underpinning role across most of these technology areas.

Many of the Member State nanotechnology policies and programmes are identified in the table at the end of this section. 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. Most notable in such pooling of Member State resources and collaboration to address common issues are the Joint Programming Initiatives (JPIs) mentioned in the sections on European policies and programmes.

National websites also highlight the importance of nanotechnology in various sectors and some countries actively promote themselves as leaders in nanotechnology in areas including those relevant to ICT, electronics and photonics. For example:

- From France, the web site of Campus France[125] 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, 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."
- On the German Trade and Invest Agency[126] 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, nano-tools, nano-analytics, and nano-tool accessories (e.g. vacuum and cleanroom technology, plasma sources, etc.). They also manufacture and utilize nano-optimised components and systems, and they provide services in the areas of consulting, contract coating, technology transfer, and commissioned analysis and research …"

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

[124] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015
[125] http://ressources.campusfrance.org/catalogues_recherche/recherche/en/rech_nano_en.pdf
[126] http://www.gtai.de/

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[127] (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[128]	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[129]	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[130]	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[131]	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 Conquers Markets	2004-2006	Directly Targeting NT	Five leading-edge innovation programmes including NanoforLife – pharmaceuticals and medical	All	BMBF	24 over 3 years

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127 https://www.ffg.at/nano-aktuell ; https://www.ffg.at/11-ausschreibung-produktion-der-zukunft
128 http://innovationsfonden.dk/en/about-ifd
129 www.tekes.fi
130 https://www.anses.fr/fr/lexique/nanotechnologies
131 http://www.agence-nationale-recherche.fr/

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
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 Knowledge and Innovation (TKIs).	IND SME HEI PRO	Dutch Ministry for the Economy	Objective for public and private sector to participate for an amount of at least EUR 500 million by 2015, 40% of which from trade and industry.

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
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[132]	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 a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.	Business mainly	Innovate UK	GBP 20m a year in higher-risk, early-stage innovation across advanced materials; biosciences; electronics, sensors and photonics; and ICT

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

5 POLICIES AND PROGRAMMES IN OTHER COUNTRIES[133]

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)[134], 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)[135]. Managed by the Research Council of Norway[136], this large-scale programme is designed to further raise the level internationally of the Norwegian knowledge base in nanotechnology, micro-technology 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[137])[138].

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[139]) but this dropped to USD 2.6 billion (EUR 1.9 billion[140]) 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 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. Its research projects fall under six clusters and its activities are industry focused in sectors such as construction materials among others[141].

[133] 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)
[134] http://www.forskningsradet.no/prognett-nano2021/Artikkel/About_the_programme/1253970633592?lang=en
[135] http://www.forskningsradet.no/servlet/Satellite?c=Page&pagename=nano2021%2FHovedsidemal&cid=1253969916237&langvariant=en
[136] http://www.forskningsradet.no
[137] Currency conversion at the exchange rate of October 2015.
[138] Nanotechnology and Advanced Materials – NANO2021: Work Programme.
[139] Average yearly conversion rate, 2008-2009 (*source*: www.wolframalpha.com)
[140] Average yearly conversion rate, 2010 (*source*: www.wolframalpha.com)
[141] http://en.rusnano.com/upload/images/documents/RUSNANO_Strategy_2020.pdf

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 industry.

CTI funds the Swiss MNT network (micro and nanotechnology) as one of the core innovative themes of national and international importance[142]. 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[143]. 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[144], and Nano-Cluster Bodensee[145]. Most activities are strongly focused on R&D to support industry.

Some important measures target nanotechnology and their deployment in Switzerland - the “Micro and Nanotechnology” initiatives of CTI and the “National Centres of Competence in Research (NCCR)[146] Nanoscale Science”. Neither specifically targets nanotechnology in the construction sector, but they promote synergies between different sub-areas and sub-disciplines and solutions between various areas of application and industrial sectors by using nanotechnology, which can impact on construction.

5.2 The Americas

5.2.1 North America

5.2.1.1 Canada

Nanotechnology is promoted in Canada mainly 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. It is active in a wide range of fields such as energy and nano-enabled bio-materials.

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[147]) in market share for nano-enabled commerce by 2020.

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

[142] https://www.kti.admin.ch/kti/en/home/unsere-foerderangebote/Unternehmen/internationale-netzwerke-und-forschungskooperationen-neu/spezialthema-japan-schweiz1/foerderlandschaft-schweiz.html
[143] http://www.swissmntnetwork.ch/content/
[144] http://www.i-net.ch/nano/
[145] http://www.ncb.ch/wordpress_neu/
[146] http://www.snf.ch/en/funding/programmes/national-centres-of-competence-in-research-nccr/Pages/default.aspx
[147] Current conversion rates, October 2015

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[148] 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[149]). 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.

5.2.1.2 The United States of America (US)

The National Nanotechnology Initiative[150] 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 Global Issues in Nanotechnology; Nanotechnology Environmental & Health Implications; Nano-manufacturing, Industry Liaison, & Innovation; and Nanotechnology Public Engagement and Communications.

In February 2014, the National Nanotechnology Initiative released a Strategic Plan[151] 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 five Nanotechnology Signature Initiatives (NSIs) covered:

- nanotechnology for solar energy collection and conversion;
- nanoelectronics for 2020 and beyond (including the energy sector as an application area;

[148] http://www.nanoquebec.ca/media/plan-action_en1.pdf
[149] Current conversion rates, October 2015.
[150] http://www.nano.gov/
[151] http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf

- nanotechnology knowledge infrastructure (NKI);
- sustainable nano-manufacturing; and
- nanotechnology for sensors and sensors for nanotechnology.

The 2014 NNI Strategic Plan also identifies potential challenges in which nanotechnology can play a role. The Strategy mentions the different priorities and interests of Federal Agencies, many of which are relevant to energy and therefore to the built environment, for example:

- The Department of Commerce: Economic Development Administration sees nanotechnology in the energy sector among its funding priorities.
- The Department of Energy (DOE) views nanoscience and nanotechnology as having a vital role to play in solving the energy and climate-change challenges, particularly for solar energy collection and conversion, energy storage, alternative fuels, and energy efficiency.
- The Department of State consider nanotechnology important to face global challenges in the energy field.
- The Intelligence Community(IC) has several agencies that conduct nanotechnology R&D.
- The National Reconnaissance Office (NRO) has an R&D programme that focuses on nanomaterials, energy generation and storage using nanotechnologies, and nanoelectronics.
- NASA focuses R&D activities also on energy generation, storage, and distribution.

The NNI's budget supplement proposed by the Obama administration for Fiscal Year 2015 provided for USD 1.5 billion (EUR 1.2 billion[152]) of funding. Cumulative NNI investment since fiscal year 2001, including the 2015 request, totals almost USD 21 billion (EUR 17 billion[153]). Cumulative investments in nanotechnology-related environmental, health, and safety research since 2005 is nearly USD 900 million (EUR 680 million[154]). 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).

Some of the above-mentioned institutions (like NIST, with its main focus on measurement sciences and standards development) have areas dedicated to nanotechnology as well as to the built environment (having a specific portal dedicated to each of them)[155, 156]. NIST provides facilities to support production, through the Centre for Nanoscale Science and Technology (CNST)[157], established in 2007. The CNST facilitates the access to commercial state-of-the-art nanoscale measurement and fabrication tools. In addition, NanoLab gives the chance to researchers to collaborate through the Energy Research Group that develops instruments designed to reveal the nanoscale physical and chemical processes and properties critical to advances in energy conversion, transport and storage”[158]. One of the NanoLab focus areas is *energy storage, transport, and conversion* in the forms of: theory and modelling of materials for renewable energy; nanostructures for energy conversion; opto-electrical characterisation of nanostructured photovoltaic materials and devices; nanoscale functional and structural characterisation of thin-film inorganic solar cells; and nanostructured thermo-electrics.

The US Department of Energy (DoE) has established five Nanoscale Science Research Centres that provide facilities and instruments to the international academic, industry and government research community for successfully peer-reviewed research projects[159]. The centres are: Centre for Functional Nanomaterials (CFN), Centre for Integrated Nanotechnologies (CINT), Centre for Nanophase Materials Sciences (CNMS), Molecular Foundry (TMF) and Centre for Nanoscale Materials. The last one is a joint partnership between the DOE and the State of Illinois, is one of offices of the DoE[160] with the main goal of conducting basic research and instrumentation development in nanotechnology linked to energy-related research and development programmes[161]. The DOE programmes *EV Everywhere* (for electric vehicles) and *SunShot* (for solar energy) are using

[152] Average yearly conversion rate, 2015 (*source*: www.wolframalpha.com)
[153] Average yearly conversion rate, 2001-2015 (*source*: www.wolframalpha.com)
[154] Average yearly conversion rate, 2005-2015 (*source*: www.wolframalpha.com)
[155] http://www.nist.gov/nanotechnology-portal.cfm
[156] http://www.nist.gov/building-and-fire-research-portal.cfm
[157] http://www.nist.gov/cnst/index.cfm
[158] http://www.nist.gov/cnst/erg/index.cfm
[159] http://science.energy.gov/bes/suf/user-facilities/nanoscale-science-research-centers/
[160] http://www.anl.gov/cnm/about-us
[161] http://www.anl.gov/cnm/group/nanophotonics

engineered nanomaterials and nanoscale processes to collect and store energy.

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[162]) (FY 2015), funds approximately 24% of all federally-supported basic research (except for medical sciences) conducted by America's colleges and universities[163]. With relation to construction, NSF deals with energy through its Chemical, Bioengineering and Environmental and Transport Systems Division which has a programme on energy for sustainability. Current topics (many of which would address nanotechnology and energy) include: biomass conversion, biofuels & bioenergy; photovoltaic (PV) solar energy (particularly oriented to nanotechnology); advanced batteries for transportation and renewable energy storage; and wind energy[164]. The US Department of Defence contributes to nanotechnology research through its Defence Nanotechnology Research and Development programme[165]. This document is partially connected to construction via energy-related matters, for instance energy storage for thermal energy conversion.

In additional to these Federal initiatives, there exist several policy initiatives at State level[166]. Programmes for the promotion of nanotechnologies currently exist in 23 states. Notable examples are the Texas Emerging Technology Fund[167], the Oklahoma Nanotechnology Initiative[168], the Illinois Nanotechnology "Collaboratory"[169], and the Oregon Nanoscience and Micro-Technologies Institute (ONAMI)[170]. The State-level organisations typically undertake some or all of the following activities: fostering collaboration on nanotechnology topics and challenges between researchers and research centres; higher education/industry joint projects; education and outreach; access to technology experts and infrastructure; early-stage funding and investment opportunities; technology transfer and commercialisation; and awareness raising in the community.

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[171]) as a result of which four nanoscience and nanotechnology networks were approved in 2005, bringing 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)[172] 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

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162 Current conversion rate, November 2015 (*source*: www.wolframalpha.com)
163 http://www.nsf.gov/about/
164 http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501026
165 http://www.nano.gov/sites/default/files/pub_resource/dod-report_to_congress_final_1mar10.pdf
166 http://www.nano.gov/initiatives/commercial/state-local
167 http://gov.texas.gov/. As of October 2010, the Texas Emerging Technology Fund has given a total of UDS 173 million to 120 companies as well as UDS 161 million to educational institutions.
168 http://www.oknano.com /
169 http://nano.illinois.edu/collaboration/index.html
170 http://onami.us/
171 http://www.agencia.mincyt.gob.ar/frontend/agencia/fondo/agencia
172 http://www.fan.org.ar/en/

basic and applied science via public-private partnerships.

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 is focused on three general-purpose technologies (nanotechnology, biotechnology and ICT) addressing six strategic sectors, including industry. It addresses six strategic sectors: environment and sustainable development (including adaptation of individual and collective construction types to avoid temperature increases and greenhouse gas emissions), social development (including the improvement of conditions and quality of life of the population through the development of innovations in water and energy consumption and production, social housing (adapted to the territorial and climatic characteristics of each region) and design, planning and development of urban and rural areas), energy (including the development of materials oriented to reducing and rationalising energy consumption in daily life), industry, agroindustry and health[173].

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[174]) 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[175]) 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[176]) to c. USD 30 million (EUR 24 million[177]) 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 importance in the programmes were the development of qualified human resources, the modernisation of infrastructure and the promotion of university-industry co-operation.

In 2012, the Brazilian Ministry for Science, Technology and Innovation (MCTI) launched the SisNANO[178] 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[179]) for the 2013-2014 period. The implementation of IBN was an effort to further strengthen nanotechnology in Brazil by strengthening academic and industry

[173] http://www.argentinainnovadora2020.mincyt.gob.ar/?page_id=194
[174] Average yearly conversion rate, 2001(*source*: www.wolframalpha.com)
[175] Average yearly conversion rate, 2004-2007 (*source*: www.wolframalpha.com)
[176] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[177] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[178] Sistema Nacional de Laboratórios em Nanotecnologias ftp://ftp.mct.gov.br/Biblioteca/39717-SisNANO.pdf
[179] Average yearly conversion rate, 2013-2014(*source*: www.wolframalpha.com)

linkages thereby to promote the scientific and technological development of the nanotechnology sector.

Brazil has a collaboration with the International Iberian Nanotechnology Laboratory (INL)[180] 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[181] 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 Programme on Key Basic Research Project (973 Programme)" sought to strengthen basic research in line with national strategic targets[182]. 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. As the MLP is implemented in the context of the Five-Year Plan for S&T

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[180] http://inl.int/about-inl/what-is-inl

[181] 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.

[182] http://www.chinaembassy.bg/eng/dtxw/t202503.htm

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 ICT and nanotechnology, as well as manufacturing technology and materials, energy, 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)[183] in 2001 to JPY 97 billion (EUR 709 million[184]) in 2005.

In the subsequent STBP[185], 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)[186]. 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 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[187].

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

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

[185] https://www.jsps.go.jp/english/e-quart/17/jsps17.pdf

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

[187] http://www.jeupiste.eu/news/5th-science-and-technology-basic-plan-adopted

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)[188] 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[189]); phase 2, 277.2 billion Won (EUR 1,541.8 million[190]).

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[191] (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)[192]. In total, 24 nanotechnology-related centres now exist in Korea.

The Korean Institute of Science and Technology (KIST)[193] has a Nanophotonics Research Centre in its Material and Life Science Division. The centre focuses on solar cells, as well as optical devices, fibre optic devices and memory devices, using materials with various nano-structures such as quantum dots, quantum wells, nano wires and photonic crystals[194].

Under the Nanotechnology Development Promotion Act 2002, Korea also established in 2004 the Korean Nano Technology Research Society (KoNTRS)[195] 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-driven actions.[196]

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[197] 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

[188] http://www.nstc.go.kr/eng/
[189] Average yearly conversion rate, 2001-2005 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[190] Average yearly conversion rate, 2006-2010 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[191] http://www.kanc.re.kr/kancEnglish/center/center_overview.jsp
[192] https://www.ibs.re.kr/eng/sub02_04_03.do
[193] KIST is a science and technology institute. It was the first S&T research institute founded in Korea following the joint statement by the Presidents of Korea and the US on the "Establishment of a Korean Industrial and Applied Science R&D Institute" (1966) http://eng.kist.re.kr/kist_eng/?sub_num=728
[194] http://eng.kist.re.kr/kist_eng/?sub_num=728
[195] http://kontrs.or.kr/english/index.asp
[196] http://www.nanotechmag.com/nanotechnology-in-south-korea/
[197] http://www.nnpc.re.kr/htmlpage/15/view

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)[198] 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[199]) 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[200]) each.

5.3.1.4 Taiwan (Chinese Taipei)[201]

The National Nanoscience and Nanotechnology Programme[202] 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[203]) and actual expenditure estimated to be USD 625 million (EUR 486 million[204]) 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 in areas including applied materials.

The National Nanoscience and Nanotechnology Programme also co-ordinates the nanotechnology research efforts of government agencies mainly through the establishment of common core facilities 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 has supported nano-instrumentation, nano-optoelectronics, nano-electrics, energy and environmental nanotechnology, nano-materials and nano-biotechnology and applied nanotechnology in traditional industries.

[198] http://www.nanotech2020.org/download/english_brochure.pdf
[199] Current exchange rate, November 2015 (*source*: www.wolframalpha.com)
[200] Current exchange rate (November 2015) (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[201] http://www.twnpnt.org/
[202] http://www.twnpnt.org/english/g01_int.asp
[203] Average yearly conversion rate, 2002 (*source*: www.wolframalpha.com)
[204] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2768287/

5.3.2 Southern Asia

5.3.2.1 India[205]

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[206]) 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.

A capacity-building programme for nanoscience and nanotechnology (called Nano Mission)[207] 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 period 2012 to 2017[208]. 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:

- The Council of Scientific and Industrial Research (CSIR)[209] 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 electronics and instrumentation.
- 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.[210]
- 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[211].
- The MST's Science and Engineering Research Council (SERC)[212] supports frontier and interdisciplinary research. Support for nanotechnology projects has been provided through its R&D schemes for basic science and engineering science.

[205] 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
[206] Average yearly conversion rate, 2002-2006 (*source*: www.wolframalpha.com)
[207] http://nanomission.gov.in/;
[208] http://timesofindia.indiatimes.com/home/science/Govt-approves-Rs-650-crore-for-Nano-mission/articleshow/30722422.cms
[209] www.csir.res.in/
[210] http://www.csir.res.in/external/heads/collaborations/NM.pdf
[211] http://www.teriin.org/div/ST_BriefingPap.pdf
[212] www.dst.gov.in/about_us/ar05-06/serc.htm

5.3.2.2 Iran[213]

The Islamic Republic of Iran ranked 23rd in the world in nanotechnology in 2007, second to Korea in citations in Asia[214], but, by 2012, it had moved to 10th place[215, 216]. 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, renewable energies, environment, biotechnology, aerospace and information technology.

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)[217], 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[218] (EUR 9 million[219]).

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[220]. 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[221].

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 and regulations through the Iran Nanotechnology Standardisation Committee (INSC)[222], a body established in 2006 as a collaboration between the INIC and the Institute of Standard and Industrial Research of Iran (ISIRI)[223].

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[224].

5.3.3 South-Eastern Asia

5.3.3.1 Malaysia

The Second National Science and Technology Policy (STP II), launched in 2003, identified nanotechnology and photovoltaic (PV) solar cells as priority emerging technologies. Other products

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213 See also http://www.sciencedev.net/Docs/Iran_Nano.pdf (2010)
214 http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file11959.pdf
215 http://statnano.com/report/s29
216 http://www.nanotech-now.com/news.cgi?story_id=45237
217 http://nano.ir/index.php?lang=2
218 http://www.nanotech-now.com/news.cgi?story_id=36557
219 Average yearly conversion rate, 2004-2010 (*source*: www.wolframalpha.com)
220 http://blogs.scientificamerican.com/guest-blog/science-and-sanctions-nanotechnology-in-iran/
221 http://nano.ir/index.php?ctrl=static_page&lang=2&id=397&section_id=22
222 http://nanostandard.ir/index.php?lang=2
223 http://www.isiri.com/
224 http://statnano.com/strategicplans/1

and technologies that were also specified were nano-biochips and nano-biosensors, Li-ion batteries, photonics, 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)[225] 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[226] 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. Also in 2011, the Top-down Nanotechnology Research Grant (NanoFund) was introduced and NanoMalaysia Centres of Excellence created.

5.3.3.2 The Philippines[227]

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 identified five key sectors for the application of nanotechnology that also coincided with the priority areas of DOST for R&D support. These areas were: energy; environment; information and communications technology and semiconductors; health; and food and agriculture.

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[228] was developed. Thirteen technology scanning panels were established, including one on 'Exploiting Nanotechnologies'. There were also panels on energy, environmental technologies, materials and infrastructure, manufacturing, semiconductors, broadband, information storage, intelligent systems, 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[229], and the Roadmap (ITR5) of the Infocomm Development Authority[230]. 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 precision machinery, transportation machinery, engineering, ICT, electronics, chemicals, food, and environment. The Plan also indicates nanotechnology is fundamental and horizontal to these clusters.

Nanotechnology is one of six areas at the heart of clinical and translational research supported under the Biomedical Research Council, which is responsible for research related to the industrial sectors of pharmaceuticals, medical technology, biotechnology and healthcare services and delivery. Nanotechnology is also a key area for the Science and Engineering Research Council (SERC).

The main funding agency for nanoscience and nanotechnology (NST) in Singapore is the Agency for Science, Technology & Research (A*STAR)[231]. 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. A*STAR research institutes involved in NST

[225] http://www.mosti.gov.my/en/about-us/divisions-departments/national-nanotechnology-directorate-division-nnd/
[226] http://www.nanomalaysia.com.my/index.php?p=aboutus&c=whoweare
[227] http://www.techmonitor.net/tm/images/d/d1/10jan_feb_sf3.pdf
[228] https://www.mti.gov.sg/ResearchRoom/Pages/Science-and-Technology-Plan-2010.aspx
[229] www.edb.gov.sg
[230] www.ida.gov.sg
[231] www.a-star.edu.sg/

include the Institute of Materials Research and Engineering (IMRE)[232]. Its Advanced Energy Storage Laboratory and its Molecular Materials Laboratory are particularly relevant for energy. The former focuses its research on energy storage materials and battery device for application in renewable energy, smart grids, biomass, etc. The latter, a collaboration with the Department of Chemistry of the National University of Singapore, focuses on energy materials, molecular catalysis, biomimetic materials; and carbon materials.

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. In addition, the Sustainable Manufacturing Centre (SMC), directed by SIMTech, is active in local manufacturing industry and eco-performance and energy efficiency.[233]

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. NiMI concentrates "on the application of nanotechnology in the processes of forming, joining and coating", particularly for the electronics industry, nanocomposite physical vapour deposition (PVD) coatings and others. Characterisation is also a relevant part of the initiative.[234]

5.3.3.4 Thailand

Thailand has been active in nanotechnology since at least 2003 when it established NANOTEC[235] 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)[236] and the Nanosafety and Ethics Strategic Plan (2012-2016)[237] were approved by government for implementation by the Ministry of Science and Technology, and relevant agencies. The Framework has three primary goals:

- 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, including manufacturing industry and electronics, and defines seven flagship products including nano-electronics. 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 strategy in Thailand is largely to focus on product development through nanotechnology. To this end, NANOTEC is addressing national and NSTDA priorities under the Framework through seven flagship programmes to develop specific products.

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[232] www.a-star.edu.sg/imre
[233] www1.simtech.a-star.edu.sg/SMC/
[234] http://www.a-star.edu.sg/Media/News/Press-Releases/ID/1363/ASTAR-SIMTech-Nanotechnology-in-Manufacturing-Initiative-NiMI-to-Overcome-Challenges-to-Tap-Market-Potential.aspx
[235] http://www.nanotec.or.th/th/wp-content/uploads/2013/05/NANOTEC-brochure11.pdf
[236] http://www.nanotec.or.th/en/wp-content/uploads/2012/02/The-National-Nanotechnology-Policy-framework-exe-sum.pdf
[237] http://www.nanotec.or.th/en/

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)[238] in 2002 as a shared action of the Forum for National Infrastructures for Research & Development (TELEM)[239] and the ministry for the economy (now called the Ministry for Industry, Trade and Labour)[240]. 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[241] at the Office of the Chief Scientist.

Since the identification of nanoscience and nanotechnology (NST) as a national priority area in 2007, 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[242]) per annum for basic NST equipment plus another almost USD 10 million (EUR 8 million[243]) per annum for new infrastructure and facilities.[244] 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[245] 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[246]) 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[247, 248], in 2005 (before the official launch of the programme), the other five research universities receiving support in 2006.

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[249]. 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. The Mokari Research Group, for instance, focuses on energy-related applications[250].

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.

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238 http://www.nanoisrael.org/
239 http://www.trdf.co.il/eng/fundinfo.php?id=2846
240 http://www.economy.gov.il/English/Pages/default.aspx
241 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.
242 Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
243 Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
244 Figures for funding under the programme to 2012.
245 http://www.nanoisrael.org/category.aspx?id=1278
246 Average yearly conversion rate, 2006 (*source*: www.wolframalpha.com)
247 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.
248 Israel Institute of Technology http://www.technion.ac.il/en/
249 http://www.nanoisrael.org/category.aspx?id=13671
250 http://www.nanowerk.com/phpscripts/n_unis_c.php?page=3&country=South%20Korea&=%27U%27

They also gather statistics and market information on NST.

5.3.4.2 Saudi Arabia[251]

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 5-year strategic plans (missions) in eleven research areas prioritising nanotechnology and advanced materials, energy and environment as well as water, oil and gas, petrochemicals, biotechnology, information technology, electronics, photonics, space and aeronautics). The National Nanotechnology Programme (NNP) was established to deliver the plan in that area.

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[252]; and the CNT established in 2006 at the KAU[253]. 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 Nanomanufacturing Applications (CENA) was established in 2009 at KACST and the King Abdullah Institute for Nanotechnology (KAIN)[254] established in 2010 at the KSU in the Riyadh Techno Valley. The KAIN covers areas including energy, telecommunications, manufacturing of 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.

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) fuel cells and energy; (ii) nano-sized quantum information processing (iii) nanomaterials; (iv) nano-photonics, nano-electronics, nano-magnetism; (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[255] that nanotechnology received State support of about one billion Turkish Lira, or c. USD 500 million (EUR 367 million[256]). Over 20 nanotechnology research centres, departments and graduate schools have been established including Nano Tam[257] and Unam[258] (with research areas that includes energy) at Bilkent University; Sabanci University Nanotechnology Research and Application Centre (SUNUM)[259] (with a focus on renewable energy systems and energy applications); and the Micro and Nanotechnology Department at the Middle East Technical University[260].

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[251] A review of nanotechnology development in the Arab World, Bassam Alfeeli et al., Nanotechnology Review, 2013 (05/2013; 2(3):359-377)
[252] King Fahd University of Petroleum and Minerals, Riyadh
[253] King Abdul Aziz University, Jeddah
[254] http://nano.ksu.edu.sa/en
[255] http://www.issi2015.org/files/downloads/all-papers/0720.pdf
[256] Average yearly conversion rate, 2007-2014 (*source*: www.wolframalpha.com)
[257] http://www.nanotam.bilkent.edu.tr/eng/main.html
[258] http://unam.bilkent.edu.tr/?page_id=576
[259] http://sunum.sabanciuniv.edu/
[260] http://mnt.metu.edu.tr/

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 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[261]), 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[262] 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. The Research Strategy highlighted the importance of developing clean energy solutions, and highlighted among the selected areas of research *Nanostructured materials for clean energy* (hydrogen storage, lithium ion-batteries and fuel cells). In addition, the Strategy sees advances in computing infrastructure as helping to address the challenge of managing increased energy consumption. Materials design for clean energy applications, development of nanoporous membranes and fuel cells are also priorities, particularly since they all involve multiscale, multidisciplinary expertise.

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[263]. 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.

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[264]. 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[265]) funding for 2003-2006 from the Ministry of Education and, in early 2006, developed a "Nanotechnology Initiative for New Zealand"[266] identifying where capability in nanotechnology could be developed in the country. The Initiative identified six programmes for research in nanoscience and nanotechnology (NST): nanotechnology for energy; nano-photonics, nano-electronics and nano-devices; nano- and micro-fluidics; nanomaterials for industry; bio-nanotechnologies; and social impacts of nanotechnology.

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[261] Average yearly conversion rate, 2010-2013 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-aud.en.html)
[262] https://www.science.org.au/publications/national-nanotechnology-research-strategy
[263] http://www.ausnano.net/index.php?page=home
[264] http://www.macdiarmid.ac.nz/
[265] Average yearly conversion rate, 2003-2006 (*source*: www.wolframalpha.com)
[266] http://www.macdiarmid.ac.nz/a-nanotechnology-initiative-for-new-zealand/

Also in 2006, the New Zealand government released a Nanoscience and Nanotechnologies Roadmap (2006-2015)[267]. 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. Among the key sectors, some potential areas and type of applications were identified. One is dedicated to energy, namely *Energy and Industrial* (including applications like lubricants and fuel additives, energy storage, super-hard bearings and coatings, catalysts, energy generation and transmission). Three priority areas for public funding were identified: the creation of new materials, diagnostic devices; and tools and techniques. The Ministry of Science and Innovation was put in charge of policy actions to implement the Roadmap.

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 capability in knowledge-intensive activities, such as high-technology manufacturing and the services sector. Six priority areas were identified including high-value manufacturing and services, energy and minerals, health and society, as well as biological sciences, hazards and infrastructure, and the environment[268].

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)[269] 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)[270] by the Department of Science and Technology (DST);
- In 2005, the publication of the National Strategy on Nanotechnology (NSN)[271] 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).

South Africa launched its first nanotechnology innovation centres in 2007 at the CSIR[272] and MINTEK[273]. 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)[274], 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[275] enables joint projects and mobility[276] between S&T departments in those countries.

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

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[267] http://statnano.com/strategicplans/13
[268] http://www.mbie.govt.nz/
[269] http://www.sani.org.za/
[270] http://www.esastap.org.za/download/natstrat_advmanu_mar2005.pdf
[271] http://chrtem.nmmu.ac.za/file/35e56e36b6ab3a98fac6fc0c31ee7008/dstnanotech18012006.pdf
[272] http://www.csir.co.za/
[273] http://www.nic.ac.za/
[274] http://ls-ncnsm.csir.co.za/
[275] http://www.ibsa-trilateral.org/
[276] http://www.ibsa-trilateral.org/about-ibsa/areas-of-cooperation/people-to-people

6 PUBLICATIONS IN NANOTECHNOLOGY AND CONSTRUCTION

6.1 Overview

Around 1.8 million publications were identified[277] from the Web of Science as being related to nanoscience and technology (NST)[278] between 2000 and 2014. Of those, almost 17,000 were identified as relating to nanotechnology and construction. This volume of publications is equivalent to around 1% of all of the output for nanoscience and nanotechnology (NST).

The table below shows the publication output between 2000 and 2014. Almost 7,000 publications on nanotechnology and construction were produced in the EU28 plus EFTA countries (EU28&EFTA, here including only Switzerland and Norway), around 41% of the total World nanotechnology and construction publications throughout the time period.

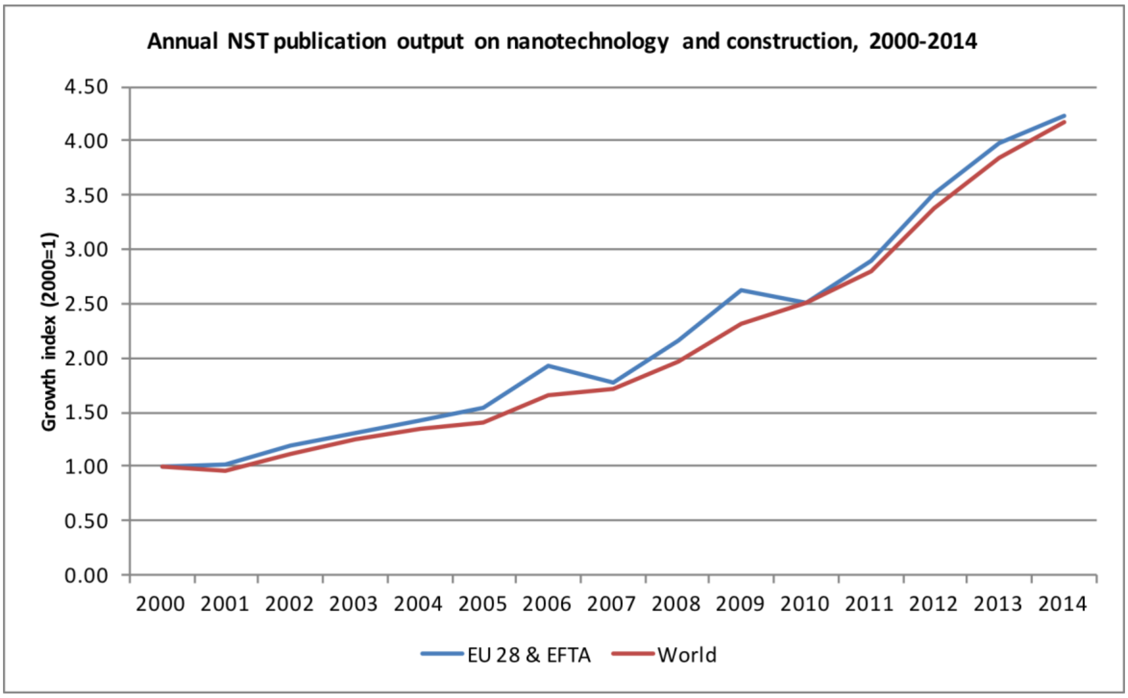
Table 6-1: Annual NST publication output for construction worldwide and in the EU28&EFTA, 2000-2014

Year	World	EU 28 & EFTA	
	npub	**npub**	**%**
2000	530	209	39.43%
2001	506	213	42.09%
2002	595	250	42.02%
2003	660	272	41.21%
2004	717	297	41.42%
2005	744	324	43.55%
2006	873	402	46.05%
2007	910	369	40.55%
2008	1047	450	42.98%
2009	1228	547	44.54%
2010	1334	523	39.21%
2011	1485	604	40.67%
2012	1789	735	41.08%
2013	2039	833	40.85%
2014	2210	886	40.09%
TOTAL	**16,667**	**6,914**	**41.48%**

Source: Derived from Web of Science

There has been a strong growth in nanotechnology and construction publications as indexed to the year 2000. There has been almost a four-fold growth during the period to 2014 for the World as well as for the EU28&EFTA.

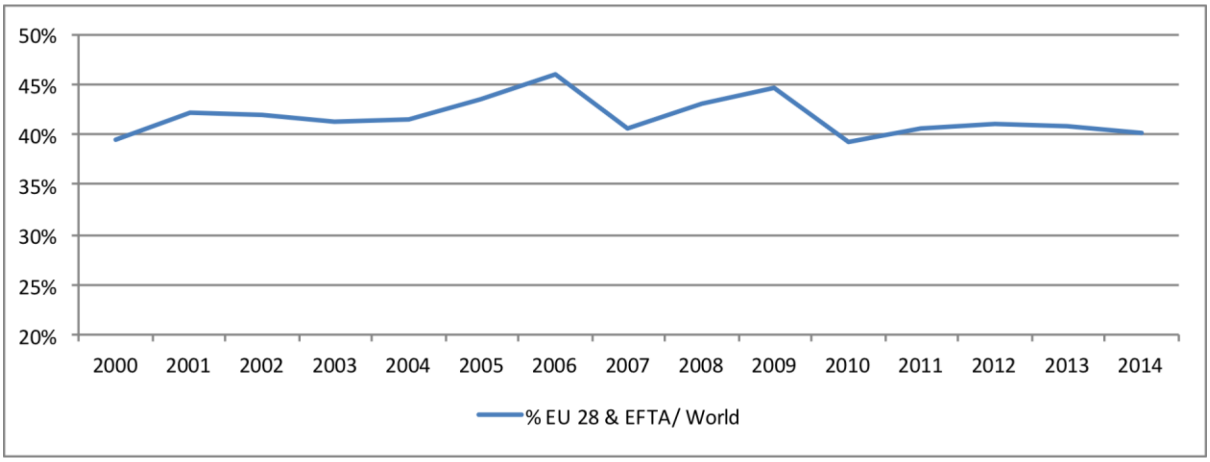
[277] http://www.vosviewer.com/Publications
[278] Search included all those publications having been produced with "nano" as a core term. The term "nanosecond" has been omitted as not being relevant to the study.



Source: Derived from Web of Science

Figure 6-1: Annual NST construction publication output, worldwide and EU28&EFTA, 2000-2014
(indexed to 2000(=1))

Looking at the EU28&EFTA proportion of world output on nanotechnology/construction, it is seen to remain a similar level over time, as shown below.



Source: Derived from Web of Science

Figure 6-2: NST construction publications as a percentage of NST World total, 2000-2014

The table below shows the journals in which researchers in this sector most frequently published their results. The results show a clear preference for the top two journals.

Table 6-2: Most common journals by numbers of NST construction publications (npub), 2000-2014

Rank	Journal	npub
1	Cement and Concrete Research	1,873
2	Construction and Building Materials	1,841
3	Cement & Concrete Composites	808
4	Materials and Structures	442
5	Journal of Materials in Civil Engineering	379
6	ACI Materials Journal	373
7	Magazine of Concrete Research	282
8	Advances in Cement Research	274
9	Journal of Wuhan University of Technology-Materials Science Edition	234
10	Journal of Thermal Analysis and Calorimetry	219

Source: Derived from Web of Science

6.2 Activity by region and country

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

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

Region	npub
EU28&EFTA	886
Asia	831
North America	320
Middle East	163
South and Central America	120

Source: Derived from Web of Science

The most prolific country for construction publications globally in 2014 was China (PRC), followed by the US, South Korea, Japan, Germany and India, as shown below.

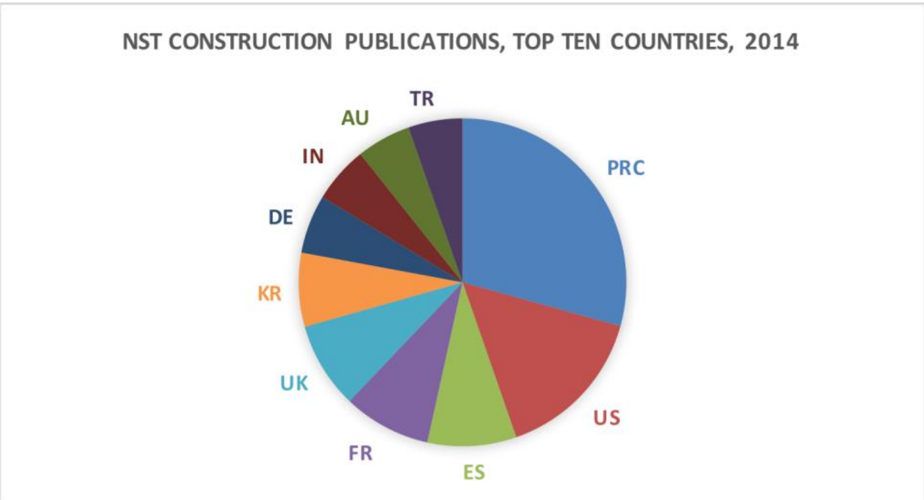


Figure 6-3: Number of NST construction publications by country (top 10), 2014

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

Country	Region	Npub
China (PRC)	Asia	471
USA	North America	247
Spain	EU28&EFTA	141
France	EU28&EFTA	139
United Kingdom	EU28&EFTA	137
South Korea	Asia	117
Germany	EU28&EFTA	93
India	Asia	90
Australia	Oceania	86
Turkey	Middle East	86
Canada	North America	85
Italy	EU28&EFTA	82
Malaysia	Asia	78
Brazil	South & Central America	63
Portugal	EU28&EFTA	61
Switzerland	EU28&EFTA	51
Poland	EU28&EFTA	45
Japan	Asia	44
Saudi Arabia	Middle East	42
Czech Republic	EU28&EFTA	40

Source: Derived from Web of Science

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

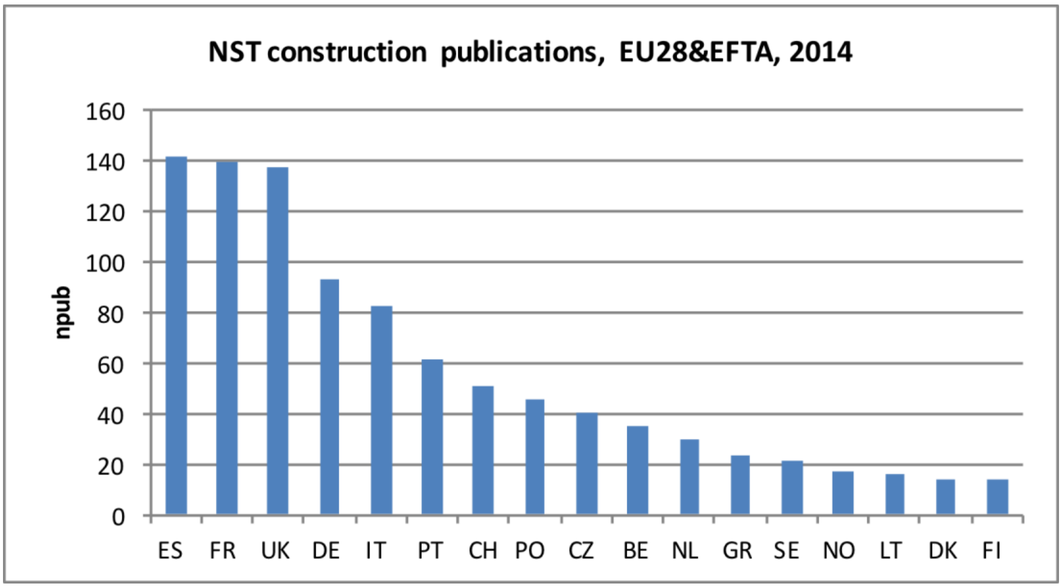


Figure 6-4: Number of NST construction publications by EU&EFTA countries, 2014
Data for the top NST construction publishing countries only

6.3 Activity by organisation type

The most active organisations in NST construction publications in 2014 are shown in the table below of the top 25 publishing organisations. The higher education organisations with the most nanotechnology construction publications globally in 2014 were mainly Chinese.

Table 6-5: Publication numbers for nanotechnology and construction for higher education and research organisations, 2014

Country	University/ Research Institute	npub
PRC	Wuhan University	38
PRC	Southeast University	33
PRC	Tsinghua University	32
PRC	Tongji University	28
PRC	Hong Kong University of Science and Technology	26
EU28&EFTA	University of Sheffield	25
EU28&EFTA	University of Aveiro	20
EU28&EFTA	Polytechnical University of Valencia	19
Korea	Hanyang University	19
PRC	Zhejiang University	18
EU28&EFTA	Delft University of Technology	18
EU28&EFTA	Swiss Federal Institute of Materials Research and Technology	17
EU28&EFTA	Brno University of Technology	16
PRC	Dalian University of Technology	16
USA	MIT	16
EU28&EFTA	University of Toulouse	15
USA	University of California Berkeley	15
PRC	Chinese Academy of Sciences of Science and Technology	15
EU28&EFTA	Swiss Federal Institute of Technology EPFL[279]	15

Source: Derived from Web of Science

The higher education organisations (EU28&EFTA) with the most nanotechnology and construction publications globally in 2014 were the University of Sheffield, the University of Aveiro and the Polytechnical University of Valencia, as shown in the table below of the top publishing organisations for nanotechnology and construction.

[279] École Polytechnique Fédérale de Lausanne

Table 6-6: Number of NST construction publications by EU&EFTA organisation (top twelve), 2014

Organisation	Country	npub
University of Sheffield	UK	25
University of Aveiro	PT	20
Polytechnical University of Valencia	ES	19
Delft University of Technology	NL	18
Swiss Federal Institute of Materials Research and Technology (EMPA)	CH	17
Brno University of Technology	CZ	16
University of Toulouse	FR	15
Swiss Federal Institute of Technology EPFL	CH	15
Swiss Federal Institute of Technology ETHZ	CH	14
University of Cambridge	UK	14
University College London	UK	14
Technical University of Lisbon	PT	14

Source: Derived from Web of Science

The companies with the most nanotechnology and construction publications globally in 2014 were Sintef (originating from Norway) and Lafarge Group (originating in France), as shown in the table of the top publishing companies below.

Table 6-7: Number of NST construction publications by company (top 5), 2014

Company	npub
SINTEF Building and Infrastructure[280]	9
Lafarge Group[281]	7
Zeobond PTY Ltd.[282]	5
HeidelbergCement AG[283]	4
Daewoo E&C[284]	4

Source: Derived from Web of Science

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

[280] https://www.sintef.no/en/about-us/
[281] http://www.lafarge.com/en
[282] http://www.zeobond.com/
[283] http://www.heidelbergcement.com/en
[284] http://www.daewooenc.com/eng/

7 PATENTING IN NANOTECHNOLOGY AND CONSTRUCTION

7.1 Overview

This section looks at the patenting activity in nanotechnology and construction by patent filings and patents granted over the period 1999-2011 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 sub-sector as appropriate)) and IPC (International Patent Classification) numbers. The IPC numbers used were both those for nanotechnology i.e. B82Y and those related to the sector under consideration (ICT, energy, etc.)[285]. 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[286] applications registered at WIPO are protected under the Patent Cooperation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[287] that are members of the treaty.

7.2 Number and evolution over time of nanotechnology and construction patent families

Using the above methodology, 45,127 (simple) nanotechnology patent families[288, 289] of granted patent and patent applications were found in the period 1993-2011[290]. All were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[291].

In the same period, the number of construction-related patent families identified among the nanotechnology patents is 1,611, 3.5% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EP and US do not sum to 100%. The highest percentage of applications relating to construction and nanotechnology is in the US (91.7%) while the figures corresponding to PCT (59,5%) and EPO (51%.4%) are considerably lower.

Table 7-1: Absolute numbers and percentages of patents on construction and nanotechnology

Nanotechnology and CN applications (1993-2011)	Absolute number	Percentage
Total patent families	1,611	100%
PCT applications	958	59,5%
EP applications	821	51%
US applications	1,478	91,7%

285 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.

286 http://www.wipo.int/pct/en/

287 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

288 We use the definition of simple family, 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.

289 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/

290 This year refers to the oldest year of the priority patents.

291 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.

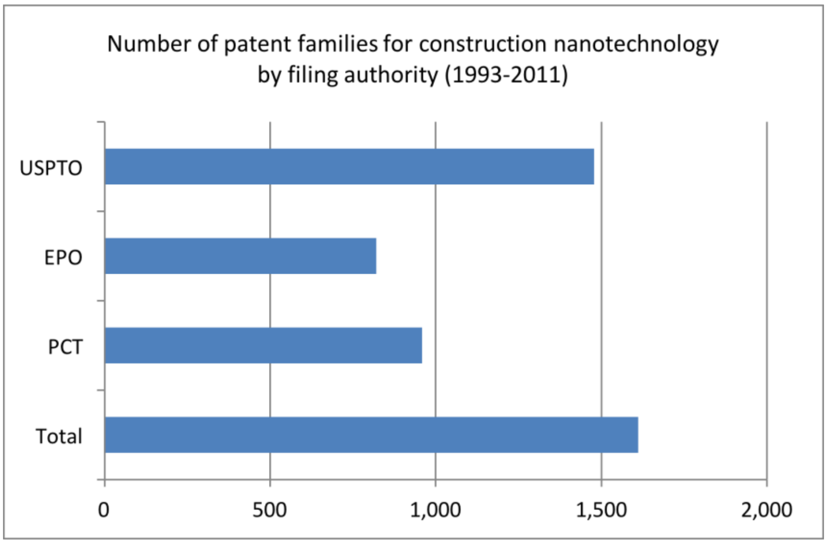


Figure 7-1: Number of patent families by filing authority (PCT, EPO, and USPTO)

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.

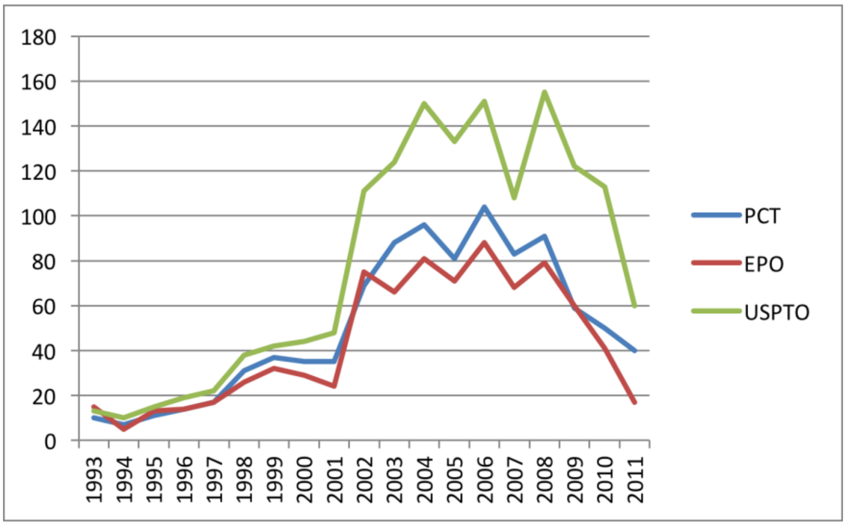


Figure 7-2: Evolution over time of WIPO (PCT), EPO and USPTO construction nanotechnology patenting

In this figure, it can be observed that the filings at EPO, USPTO and WIPO follow a similar pattern, where the number of filings increased slightly at the beginning of the period experimenting an important increase during the early 2000. The number of filings in the three patent authorities were quite stable during roughly the whole decade of 2000, concentrating in these years most of the patents in the construction sector. At the end of the decade all three patent authorities experimented a significant decline in the number of filings.

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 ten patent authorities through which PCT applications were filed are shown in the table, the US being by far the most prolific, followed by Japan, Europe (EPO) and the UK. The sum of the figures for the European patent offices in this top ten table and the EPO is just 427, considerably less than in the US. Even if all the remaining EU countries are allocated the figure of the lowest European country in the table (France, 59), the total for the EU28 plus the EPO is less than the US.

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

Receiving authority	No. of Patent families (1993-2011)
United States	434
European Patent Office (EPO)	161
Japan	156
United Kingdom	28
International Bureau (WIPO)	25
South Korea	22
France	22
Germany	19
Sweden	10
Singapore	9

7.4 Activity by country of applicant

PATENT APPLICATIONS

Within the group of 1,611 construction-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in roughly 30% of them while there is participation from the rest of the world in 95,5% 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 construction patent families	449	1,216
Percentage of nanotechnology and construction patent families	27.9%	75,5%

Applicants may file patents with more than one patent authority, e.g. at the USPTO and as a 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 with more than one authority (including 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, followed by Japan. Among the countries with the highest number of patent families there are some European countries like Germany (215), Netherlands (68), France (64) and UK (57).

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

World ranking	Country of applicant	No. of Patent Families	PCT	US	EP
1	United States	678	67.6%	99.4%	46.2%
2	Japan	333	48.9%	93.4%	47.4%
3	**Germany**	**215**	**74.9%**	**77.2%**	**78.6%**
4	South Korea	83	31.3%	95.2%	27.7%
5	**Netherlands**	**68**	**42.6%**	**86.8%**	**60.3%**
6	**France**	**64**	**59.4%**	**81.3%**	**73.4%**
7	**United Kingdom**	**57**	**77.2%**	**77.2%**	**59.6%**
8	Taiwan (Chinese Taipei)	52	0.0%	100.0%	7.7%

World ranking	Country of applicant	No. of Patent Families	PCT	US	EP
9	China	40	42.5%	92.5%	25.0%
10	Canada	27	59.3%	100.0%	55.6%
11	**Switzerland**	**26**	**76.9%**	**92.3%**	**88.5%**
12	**Sweden**	**20**	**85.0%**	**85.0%**	**85.0%**
13	**Italy**	**18**	**88.9%**	**88.9%**	**83.3%**
14	Singapore	17	82.4%	94.1%	41.2%
15	India	17	94.1%	76.5%	41.2%
16	**Belgium**	**12**	**66.7%**	**75.0%**	**83.3%**
17	**Denmark**	**11**	**100.0%**	**72.7%**	**72.7%**
18	Russian Federation	9	88.9%	55.6%	77.8%
19	**Spain**	**8**	**100.0%**	**75.0%**	**100.0%**
20	Australia	8	87.5%	87.5%	75.0%
21	**Finland**	**8**	**75.0%**	**87.5%**	**87.5%**
22	Israel	7	85.7%	71.4%	57.1%
23	**Austria**	**7**	**71.4%**	**85.7%**	**85.7%**
24	Brazil	7	71.4%	71.4%	57.1%
25	**Ireland**	**5**	**60.0%**	**100.0%**	**60.0%**

More than 99% of patents by US applicants are filed with the USPTO while roughly 70% are filed as PCTs. Less than 50% are filed by US applicants at the EPO.

Among the European applicants, it can be observed that the highest percentages of filings concentrate at the EPO and USPTO, with quite similar value, suggesting that both patent authorities seem to be the most relevant for European Applicants. In some cases, the PCT route seems to be important looking at the percentage of patents.

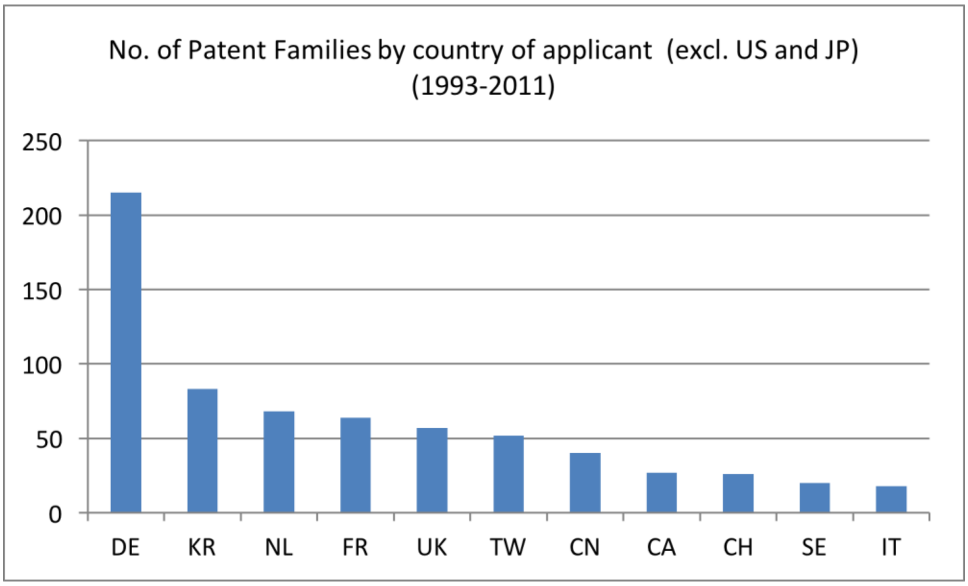


Figure 7-3: Number of patent families by country of applicant
(excluding the US and Japan)

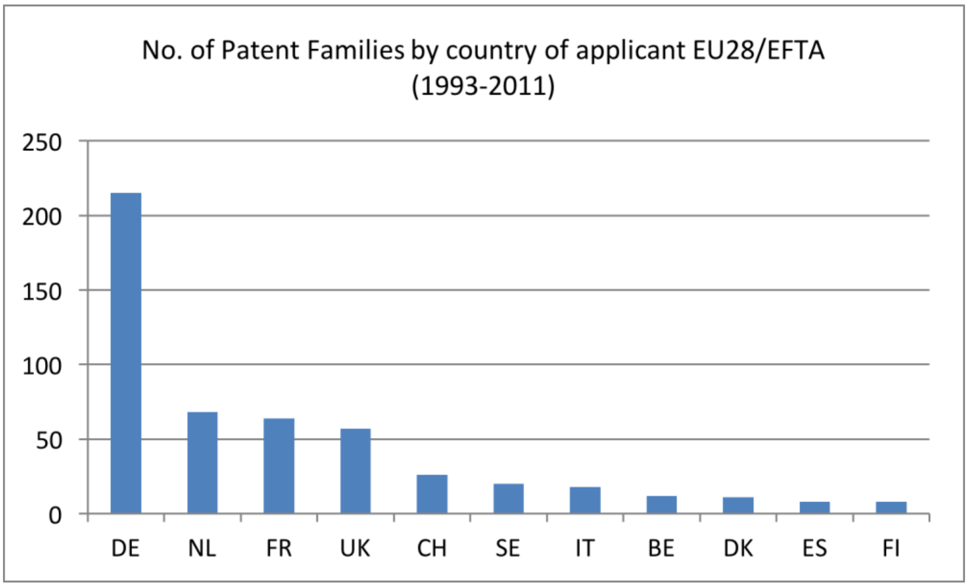


Figure 7-4: Number of patent families by country of applicant EU28/EFTA

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

World ranking	Country of applicant	No. of Patent Families	PCT	US	EP
3	Germany	215	74.9%	77.2%	78.6%
5	Netherlands	68	42.6%	86.8%	60.3%
6	France	64	59.4%	81.3%	73.4%
7	United Kingdom	57	77.2%	77.2%	59.6%
11	Switzerland	26	76.9%	92.3%	88.5%
12	Sweden	20	85.0%	85.0%	85.0%
13	Italy	18	88.9%	88.9%	83.3%
16	Belgium	12	66.7%	75.0%	83.3%
17	Denmark	11	100.0%	72.7%	72.7%
19	Spain	8	100.0%	75.0%	100.0%
21	Finland	8	75.0%	87.5%	87.5%
23	Austria	7	71.4%	85.7%	85.7%
25	Ireland	5	60.0%	100.0%	60.0%

Looking at the non-EU/EFTA and non-US countries of applicants, the filing patterns are quite homogeneous with a clear preference, among the patent authorities considered in this study, to filing most at the USPTO, like Japan and South Korea, the most active countries in patent applications.

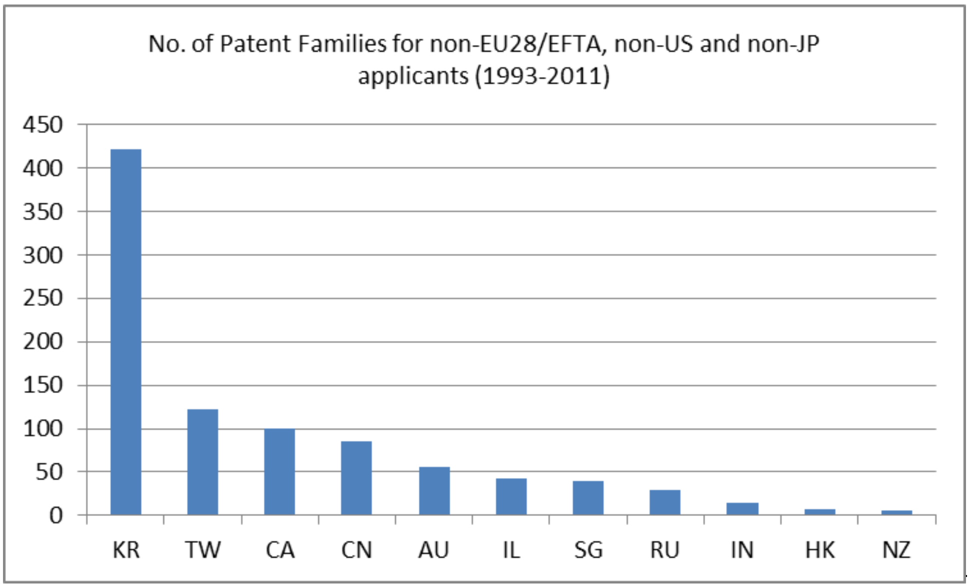


Figure 7-5: Number of patent families by country of applicant for non-EU28/EFTA (excluding the US and Japan)

GRANTED PATENTS

Applicants from the same EU and EFTA countries performing strongly in patents granted by the EPO are especially Germany, followed by France and Netherlands. Also Germany is by far the first country in patents granted by the USPTO, where also Netherlands, France and the United Kingdom show a strong performance, although lagging behind Germany.

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	56	76
2	France	9	23
3	Netherlands	8	35
4	Italy	7	8
5	Sweden	7	6
6	Switzerland	5	7
7	Denmark	4	6
8	United Kingdom	4	18
9	Austria	3	1
10	Finland	3	3
11	Spain	2	1
12	Ireland	1	3
13	Norway	1	0

While for many countries the amount of patents granted by EPO is similar to the amount of patents granted by the USPTO, some countries like Germany, France, Netherlands and United kingdom the number of patents granted by the USPTO is substantially larger compared to the EPO.

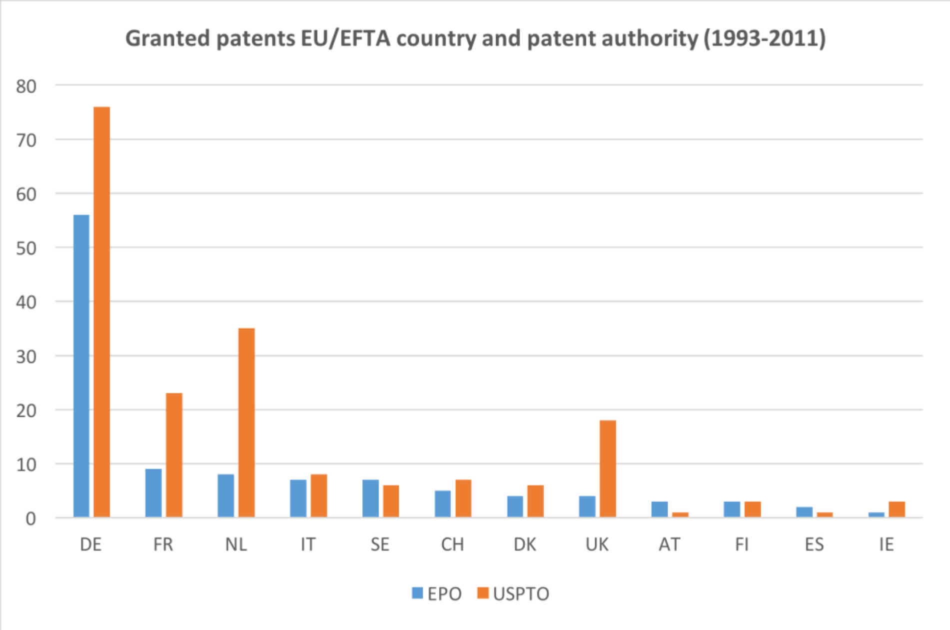


Figure 7-6: Granted patents by country of applicant for EU28/EFTA

The top ten countries by number of applications are the same as the top ten countries by patents granted to applicants for EU and EFTA countries, as shown in the table below.

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	215	1	DE	100
2	NL	68	2	NL	39
3	FR	64	3	FR	27
4	UK	57	4	UK	19
5	IT	18	5	IT	12
7	CH	26	7	CH	10
6	SE	20	6	SE	10
8	DK	11	8	DK	9
9	BE	12	9	BE	5
10	FI	8	10	FI	4
11	AT	7	11	AT	3

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[292]. This shows a high success rate for Denmark and Italy. The number in the left column is their overall ranking from the previous table.

[292] 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.

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

	Country of applicant	Granted/ Applied %
8	DK	81.8%
5	IT	66.7%
2	NL	57.4%
6	SE	50.0%
10	FI	50.0%
1	DE	46.5%
3	FR	42.2%
9	BE	41.7%
7	CH	38.5%
4	UK	33.3%

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	CA	FR	DE	JP	NL	CN	KR	TW	UK	US
APPL										
CA	25	1	4			1			1	10
FR		61	5		1	2			4	7
DE	3	7	205	2	8	4			10	19
JP			3	327		2			2	8
NL		7	10		51	2			5	5
CN		2	2	3	2	40		2	1	10
KR							80			7
TW						14		31		16
UK	2	2	7		3		1		47	8
US	14	13	25	10	1	12	5	1	7	647

7.5 Patenting activity by organisation type

7.5.1 Universities and public research organisations

PATENT APPLICATIONS

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

Looking at the top 25 performing universities and PROs for patent families, 12 out of 25 are from outside the US, 5 being from the EU28 or EFTA (from France, Germany and Spain). The tables below show the top ten 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 ten universities and PROs (1993-2011)

Rank	Country	Organisation	No. of Patent families	PCT	US	EP
1	US	University of California	22	68.2%	81.8%	18.2%
2	US	Massachusetts Institute of Technology	17	82.4%	76.5%	23.5%
3	**FR**	**CEA**	**12**	**50.0%**	**58.3%**	**41.7%**
4	US	Harvard College	11	63.6%	90.9%	27.3%
5	CN	Tsinghua University	10	0.0%	100.0%	0.0%
6	**DE**	**Fraunhofer Institute**	**10**	**70.0%**	**50.0%**	**90.0%**
7	JP	National Institute of Advanced Industrial Science and Technology (AIST)	10	80.0%	70.0%	30.0%
8	**DE**	**Leibniz Institut für neue Materialien**	**10**	**30%**	**0.0%**	**0.0%**
9	**FR**	**CNRS**	**9**	**66.7%**	**44.4%**	**77.8%**
10	US	Dartmouth College	8	0.0%	100.0%	0.0%

The table below shows the top ten performing universities and PROs for patent families in EU28/EFTA countries. French and German organisations perform strongly among this group of countries (the top four organisations).

Table 7-11: Number of patent families in the top 20 EU28/EFTA universities and PROs (1993-2011)

Rank	Country	Organisation	No. of Patent families	PCT	US	EP
1	FR	CEA	12	50.0%	58.3%	41.7%
2	DE	Fraunhofer Institute	10	70.0%	50.0%	90.0%
3	DE	Leibniz Institut für neue Materialien	10	30.0%	0.0%	0.0%
4	FR	CNRS	9	66.7%	44.4%	77.8%
5	ES	CSIC	4	25.0%	50.0%	100.0%
6	UK	University of Southampton	3	100.0%	0.0%	66.7%
7	UK	University of Bath	2	100.0%	0.0%	0.0%
8	BE	Universite Libre de Bruxelles	2	0.0%	100.0%	100.0%
9	DE	University of Dresden	2	50.0%	50.0%	0.0%
10	DE	Saarland University	2	100.0%	0.0%	0.0%

GRANTED PATENTS

Of the top 15 universities and research organisations, 3 are from the EU28/EFTA countries as shown in the table below which is ranked by the highest number of EPO patents granted between 1993 and 2011. All the remaining organisations are from the US.

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

Rank	Country	Organisation	EP	US
1	US	Harvard College	2	8
2	**BE**	**KU Leuven**	**1**	**1**
3	**DE**	**University of Munster**	**1**	**0**
4	**CH**	**ETH Zurich**	**1**	**0**
5	US	University of Texas	1	3
6	US	University of Texas	1	3
7	US	California Institute of Technology	1	2
8	US	Massachusetts Institute of Technology	1	9
9	US	Purdue Research Foundation	1	2
10	US	Oklahoma State University	1	1
11	US	University of Illinois	1	2
12	US	Dartmouth College	1	2
13	US	University of Central Florida	1	0
14	US	Wayne State University	1	1
15	US	Rice University	1	3

Ranking by the number of USPTO patents granted between 1993 and 2011, 11 of the top 15 universities and research organisations are in the US and three in the EU28/EFTA.

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

Rank	Country	Organisation	US	EP
1	**FR**	CEA	43	16
2	US	California Institute of Technology	34	2
3	US	University of California	31	1
4	JP	Japanese S&T Agency	30	5
5	KR	Electronics and Telecommunications Research Institute	24	1
6	US	MIT	21	1
7	**BE**	IMEC	19	7
8	TW	Industrial Technology Research Institute (ITRI)	15	0
9	**FR**	CNRS	13	12
10	KR	Korea Institute of Science and Technology (KIST)	12	1
11	US	Rice University	12	3
12	US	Standford University	11	2
13	JP	National Institute of Advanced Industrial Science and Technology (AIST)	10	0
14	US	Northwestern University	9	2
15	KR	Korea Advanced Institute of Science and Technology (KAIST)	8	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 six different countries. Germany (2) and Netherlands (1) are the only EU28 countries that features 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)

Rank	Country	Company	No. of Patent families	PCT	US	EP
1	US	Molecular Imprints INC	48	77.1%	97.9%	45.8%
2	JP	Canon	33	27.3%	97.0%	39.4%
3	TW	Hon Hai Precision Industry	30	0.0%	100.0%	0.0%
4	**NL**	**ASML**	**30**	**13.3%**	**93.3%**	**23.3%**
5	JP	Asahi Glass	25	88.0%	76.0%	68.0%
6	US	Corning	24	79.2%	29.2%	79.2%
7	KR	Samsung Electronics	22	4.5%	72.7%	18.2%
8	**DE**	**Evonik Degussa**	**18**	**38.9%**	**66.7%**	**66.7%**
9	**DE**	**Merck**	**17**	**82.4%**	**41.2%**	**76.5%**
10	US	3M	17	88.2%	76.5%	82.4%

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[293]. 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. Companies from the US and Japan are among the organisations with highest number of patents granted by the EPO. Evonik Degussa and Wacker Chemie (Germany) as well as Rhodia Chemie (France) are the only three companies located in the EU28/EFTA.

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

Country	Company	EP	US
DE	**Evonik Degussa**	**7**	**11**
JP	Canon	5	24
US	3M	5	11
US	Corning	5	7
US	Molecular Imprints INC	5	38
DE	**Wacker Chemie**	**5**	**2**
JP	Matsushita Electric	4	4
JP	Nissan Chemical	4	4
US	Rohm & Haas	4	3
FR	**Rhodia Chemie**	**4**	**1**

[293] 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
US	Molecular Imprints INC	38	5
JP	Canon	24	5
NL	**ASML**	**22**	**3**
TW	Hon Hai Precision Industry	18	0
JP	Asahi Glass	14	3
US	PPG Industries	13	2
JP	Toshiba	12	1
DE	**Evonik Degussa**	**11**	**7**
US	3M	11	5
JP	TDK Corporation	10	2

Interestingly, only three of the companies with the highest number of patents granted by the USPTO are from the US. The other seven companies are located in other countries. ASLM (Netherlands) and Evonik Degussa (Germany) are the two companies of the EU28 among these ten companies.

The next two sections look at the construction industry and construction nanotechnology products and global markets.

8 INDUSTRY AND NANOTECHNOLOGY FOR CONSTRUCTION

As a proxy for nanotechnology in the construction industry, this section presents wider economic data on the parts of the construction sector in which nanotechnology is most commonly found. Nanotechnology has found applications in different areas of the construction industry and already there are products on the market. However, penetration of these products on the market is limited and mainly applied in coatings.

This section indicates the value of the construction sector, as well as manufacturing sub-sectors that are relevant for the construction sector and in which nanotechnology is used. It focuses on the number of firms, turnover[294], production value and value added[295], production value[296] and value added[297], and employment numbers, as well as on expenditure on research and development (R&D). Later in this section, more details are provided on the construction-related applications of nanotechnology.

8.1 Overview of the construction industry

From the OECD definition[298], the construction sector includes the building of houses, apartments, factories, offices and schools, but also roads, bridges, ports, railroads, sewers and tunnels, amongst many other things. In addition to building, the sector maintains and repairs those structures and produces the basic materials that are used to make them, such as concrete.

The construction sector is a cost-driven and traditional sector[299]. It is very labour-intensive[300] with most sub-sectors in the construction industry being focused on construction activities instead of the underlying materials in which nanotechnology has been applied. For the purpose of this report, nine groups of manufacturing sub-sectors are taken into account as having nanotechnology applications in materials that can be applied in the construction sector (as shown in the table below). However, it is essential to realise that these sub-sectors also provide products for other sectors such as the transport sector.

Table 8-1: Overview of NACE categories for manufacturing sub-sectors of construction

	Code	*Label*
1	C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
2	C203	Manufacture of paints, varnishes and similar coatings, printing ink and mastics
3	C2052	Manufacture of glues
4	C231	Manufacture of glass and glass products
5	C232	Manufacture of refractory products
6	C233	Manufacture of clay building materials
7	C234	Manufacture of other porcelain and ceramic products
8	C235	Manufacture of cement, lime and plaster
9	C236	Manufacture of articles of concrete, cement and plaster

Source: Eurostat

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294 Turnover is defined in these statistics as market sales of goods or services supplied to third parties (Source: Eurostat).

295 These monetary values are expressed in millions of Euros: http://ec.europa.eu/eurostat/cache/metadata/en/sbs_esms.htm

296 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).

297 Value added is the gross income from operating activities after adjusting for operating subsidies and indirect taxes. Value adjustments (such as depreciation) are not subtracted (Source: Eurostat).

298 http://www.oecd.org/regreform/sectors/41765075.pdf

299 http://www.nanowerk.com/nanotechnology/reports/reportpdf/report162.pdf

300 Trends and drivers of change in the European construction sector: Mapping report: http://webcache.googleusercontent.com/search?q=cache:Eb_ssxzC-BIJ:www.certificazione.unimore.it/site/home/documento124000637.html+&cd=1&hl=en&ct=clnk&gl=nl

8.1.1 Number of EU construction manufacturing enterprises

The construction sector is strategically important for Europe, delivering building and infrastructure which are crucial for all other sectors in the economy[301]. The total construction sector of the EU28 was made up of 3.4 million firms in 2014 (see table below), firms mainly active in construction activities (like construction of roads and railways) and not in the development of underlying materials.

Table 8-2: Number of companies in the construction sector

Number of companies (EU28)	2011	2012	2013	2014
Total construction sector	3,266,728	3,280,371	3,269,946	3,361,046

Source: Eurostat

From the manufacturing sub-sectors that are relevant for the construction sector, most firms are active in the sub-sector *"Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials"*. This is about 74% of the manufacturing sub-sectors that are relevant for construction (see table below). The subcategory *"Manufacture of paints, varnishes and similar coatings, printing ink and mastics"*, in which nanotechnology is most often applied in the construction sector, is 2% of these sub-sectors. The smallest sub-sector in terms of the number of enterprises is *"Manufacture of glues"* with 533 firms in 2013.

Table 8-3: Number of companies in the manufacturing sub-sectors relevant for construction

No. of companies (EU 28 countries)	2011	2012	2013	2014
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	185,000	177,753	171,766	171,371
Manufacture of paints, varnishes and similar coatings, printing ink and mastics	4,000	4,100	4,000	4,035
Manufacture of glues	598	532	533	:
Manufacture of glass and glass products	16,000	15,711	15,500	15,359
Manufacture of refractory products	851	860	843	800
Manufacture of clay building materials	4,000	3,627	3,240	3,278
Manufacture of other porcelain and ceramic products	13,695	13,288	13,134	13,406
Manufacture of cement, lime and plaster	1,130	1,100	1,020	1,000
Manufacture of articles of concrete, cement and plaster	24,820	23,500	22,130	21,602

8.1.2 Turnover, production and value-added in EU construction

The European construction sector is composed of around 99% of Small and Medium Enterprises (SMEs)[302]. Overall for 2011-2014, the construction sector has had turnover of about EUR 1.5 billion, production value of EUR 1.5 billion and value added of EUR 0.5 billion per year as shown in the table below.

[301] http://bwcv.es/assets/2011/2/15/ObservatoryNANO_Economic_assessment_construction_final_report-1.pdf
[302] http://www.ueapme.com/spip.php?rubrique17

Table 8-4: Turnover, production value and value added in the construction sector(EU28)

	2011	2012	2013	2014
Turnover (MEUR)	1,566,177	1,545,459	1,493,477	1,546,051
Production value (MEUR)	1,549,935	1,528,954	1,485,741	1,541,033
Value added (MEUR)	501,287	492,897	487,022	:

Source: Eurostat

The manufacturing sub-sector "*Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials*" has the largest turnover (about 37% of the selected sub-sectors in 2014), production value turnover (37% in 2014) and value added (33% in 2013) compared to the other manufacturing sub-sectors relevant for construction, as shown in the table below. Although these numbers show some decrease between 2011 and 2012, turnover, production value and value added show an increase afterwards. This indicates a recovery of the economic situation in these sectors.

Table 8-5: Turnover, production value and value added by sub-sector for construction

Turnover (MEUR)	2011	2012	2013	2014
Wood, products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	124,000.00	120,131.10	118,849.80	123,253.70
Paints, varnishes and similar coatings, printing ink and mastics	40,930.70	40,816.60	40,920.50	40,670.70
Glues	5,876.20	5,764.20	5,627.20	:
Glass and glass products	47,000.00	45,000.00	44,000.00	43,946.30
Refractory products	5,948.50	5,898.90	5,530.10	5,959.90
Clay building materials	18,889.20	17,073.40	16,800.00	17,222.20
Other porcelain and ceramic products	9,366.20	8,822.30	8,831.60	9,276.90
Cement, lime and plaster	21,558.70	19,982.00	19,232.20	19,085.50
Articles of concrete, cement and plaster	76,317.50	69,809.70	65,228.80	66,474.10

Production value (MEUR)	2011	2012	2013	2014
Wood, products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	:	113,843	112,067	116,736
Paints, varnishes and similar coatings, printing ink and mastics	37,287	36,616	37,090	37,714
Glues	5,216	4,990	4,807	:
Glass and glass products	:	:	40,000	42,062
Refractory products	5,607	5,393	5,040	5,319
Clay building materials	17,972	16,221	16,000	16,313
Other porcelain and ceramic products	8,191	7,796	7,670	8,075

Production value (MEUR)	2011	2012	2013	2014
Cement, lime and plaster	21,635	20,574	19,172	19,217
Articles of concrete, cement and plaster	71,606	65,305	61,258	62,657

Value added (MEUR)	2011	2012	2013	2014
Wood, products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	31,700.00	29,956.30	29,584.80	:
Paints, varnishes and similar coatings, printing ink and mastics	10,449.90	10,501.20	10,938.50	:
Glues	1,453.20	1,366.70	1,413.80	:
Glass and glass products	16,000.00	15,000.00	14,000.00	:
Refractory products	1,739.80	1,640.10	1,587.00	:
Clay building materials	6,414.80	5,623.50	5,400.00	:
Other porcelain and ceramic products	3,556.70	3,314.00	3,322.90	:
Cement, lime and plaster	7,642.20	6,639.40	6,051.60	:
Articles of concrete, cement and plaster	19,269.30	17,519.90	16,948.60	:

Source: Eurostat

8.1.3 Employment in EU construction

Although the relative share of construction in Europe's economic activity has declined over the past years (before 2011), construction is still of significant importance for the European economy. The construction sector provided 12.4 million jobs in 2014 and contributed to about 10% of the EU's GDP in 2016[303, 304].

Table 8-6: Number of employees in the construction sector, millions (EU28)

Number of employees, millions (EU28)	2011	2012	2013	2014
Total construction sector	13.1	12.7	12.2	12.4

Source: Eurostat

The manufacturing sub-sectors relevant for construction provide 2 million jobs in 2014. 47% of the people employed in these sub-sectors were active in the sub-sector "*Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials"* and 7% in the sub-sector "*Manufacture of paints, varnishes and similar coatings, printing ink and mastics".* The number of employees in these sub-sectors decreased by 8% in the period 2011-2013 as shown in the table below.

303 http://ec.europa.eu/growth/sectors/construction/index_en.htm
304 http://ec.europa.eu/growth/sectors/construction/index_en.htm

Table 8-7: Number of employees in construction sub-sectors in which nanotechnology can be applied

Employees, millions (EU28)	2011	2012	2013	2014
Wood, products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	10,400.00	10,005	9,671	9,932
Paints, varnishes and similar coatings, printing ink and mastics	1,564.00	1,538	1,518	1,522
Glues	195	177	182	:
Glass and glass products	3,196.00	3,100	2,997	3,003
Refractory products	317	314	297	295
Clay building materials	1,230.00	1,150	1,087	1,06,402
Other porcelain and ceramic products	1,091.00	1,071	1,053	1,07,107
Cement, lime and plaster	703	673	651	623
Articles of concrete, cement and plaster	4,119.00	3,862	3,633	3,589

Source: Eurostat

8.1.4 EU Business R&D expenditures in the construction sector

According to the "2014 EU Industrial R&D Investment Scoreboard"[305], the construction and materials sector belongs to sectors with a low research and development (R&D) intensity. The EU Industrial R&D Investment Scoreboard of the European Commission listed the top 1000 EU-companies with their R&D expenditure by sector. The construction and material sector spend EUR 1.7 billion on R&D in 2014, 38 firms being responsible for the expenditure. This is about 0.5% of total R&D expenditures of the top 1000 companies in the EU[306]. Most of these firms are from Germany, Belgium, France and Spain. The highest expenditures are from firms in France, Spain, Sweden and Germany.

8.1.5 Innovative EU construction enterprises

As mentioned earlier in the report, innovation in the construction sector is limited by the need to ensure that buildings and infrastructure will last a long time and retain its performance during that time. Materials and processes that have stood the test of time are generally more attractive to the building trade than untested ones and companies are reluctant to be the first to adopt a new technology. Therefore, the construction industry is not noted for being very innovative or R&D oriented. The sector is mainly dominated by SMEs[307] engaged in construction activities.

R&D activities using nanotechnology developments are therefore mainly undertaken by large multi-national manufacturers such as BASF, AKZO-NOBEL, DuPont, Heidelberg and ItalCementi or at specialised research institutes (either university-based or private research institutes)[308, 309] that are active in the manufacturing sub-sectors mentioned in the previous sections. This suggests that the majority of construction SMEs play little or no role in pioneering nano activities within the construction sector. Exceptions are SME spin-offs or start-ups that have a contract that allows them

305 http://iri.jrc.ec.europa.eu/scoreboard14.html
306 http://iri.jrc.ec.europa.eu/scoreboard15.html
307 European Builders Confederation annual report 14-15
https://webcache.googleusercontent.com/search?q=cache:-U3qslLzlD8J:https://www.etui.org/content/download/3555/40007/file/Nano%25E2%2580%2590products%2Bin%2Bthe%2BEuropean%2BConstruction%2BIndustry.pdf+&cd=1&hl=en&ct=clnk&gl=nl
309 https://www.irjet.net/archives/V3/i1/IRJET-V3I151.pdf

to use the research facilities of their "mother" company or laboratory, SMEs that were set-up as university spin-offs focused on specific nano-niche markets like for example the production and design-on-demand of specific nanomaterials.

It is mainly in the field of paint and coatings that SMEs are starting to play a role and fabricate their own nano products[310]. However, the paint and coatings sub-sector (called "*Manufacture of paints, varnishes and similar coatings, printing ink and mastics"* in the previous sections) is one of the smaller sub-sectors in terms of number of enterprises (2% of the firms active in the manufacturing sub-sectors relevant for construction), turnover (13% of the total turnover of the manufacturing sub-sectors relevant for construction), production value (12% of the total production value of the manufacturing sub-sectors relevant for construction), and employment (7% of the total persons employed in the manufacturing sub-sectors relevant for construction).

8.2 Nanotechnology in the construction industry

There are applications of nanotechnology in various areas of the construction industry, including coatings, insulation materials, fire protection and cement-based products[311]. However, the penetration of these products on the market is limited, resulting in a very low amount of wider economic data on turnover, value added etc. In this section, the available information on firms applying nanotechnology in the construction sector will be discussed. First, some information will be provided on the constraints which make the construction industry slower to adopt nanotechnology than some other industries.

8.2.1 Constraints on the use of nanotechnology in the construction industry

FIEC (the European Construction Industry Federation) and the EFBWW (the European Federation of Building and Wood Workers) investigated the role of nanotechnology in the European construction market[312] and showed the potential for nanotechnology to bring many technical and economic advantages to the construction sector in the future. For example, nano-based solutions to improve energy efficiency are expected to play a more important role in the construction sector in the coming years[313]. However, only a limited number of nano products make it to the market for construction products simply because the techniques and materials are too expensive to produce products that can compete with the existing products. Some large players in the field mention: "*in this respect, the construction industry falls about 10 years behind industry at large, because of the costs involved and because of the technical and safety standards required for the materials used*". Although this research is from 2009, experts confirmed during interviews that these research findings are still valid and more recent research cited this report.

Different reasons are given for the limited use of nano applications in the construction sector[7,8] including that:

- ***Nano applications often do not reach the construction market due to the high costs involved[314]:*** Nano-materials and products are still more expensive than non-nano alternatives because of the technology required for manufacturing. For consumer products, the additional costs are not a big issue for market acceptance. However, this is not the case for the construction sector. Already at the R&D phase, initiatives to apply nanotechnology in construction are stopped when it is foreseen that the nano product to be produced will never reach competitive pricing. Construction products often have large volumes, and small price differences at the kilogramme level become enormous at that scale. For instance, industrial flooring nano-coatings could be offered at a maximum price difference of no more than about 1 euro per kg. This makes manufacturers of construction materials reluctant to develop nano products (especially when the

https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_23_2014_assessment_of_impacts_of_a_european_register_of_products_containing_nanomaterials-schwirn.pdf

[311] https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_23_2014_assessment_of_impacts_of_a_european_register_of_products_containing_nanomaterials-schwirn.pdf

[312] Van Broekhuizen F. & van Broekhuizen P., (2009), Nano products in the European production Industry State of the Art 2009, initiative financially supported by the European Commission in the framework of programmes and actions in the social and employment sectors.

[313] https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_23_2014_assessment_of_impacts_of_a_european_register_of_products_containing_nanomaterials-schwirn.pdf

[314] https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_23_2014_assessment_of_impacts_of_a_european_register_of_products_containing_nanomaterials-schwirn.pdf

performance of existing non-nano products is believed to be sufficient) and those nano products that are developed remain niche products that are only applied upon request. This is especially the case for the larger volume products like concrete or mortar and for construction coatings. However, developments are being seen in the areas of, for example, insulation materials and architectural and glass coatings. These niche markets have improved energy performance as their goal. The current focus of society is also on the improvement of energy management in the context of climate change and the reduction of greenhouse gasses, which stimulates the application of nanotechnology in the construction sector.

- ***Technical performance needs to be proven to meet the technical standards:*** Especially for new materials with new functionalities, this involves testing. When the laboratory results show positive results pilot projects are required to prove and test the behaviour under real life conditions. The uncertainty about substitution by other technologies does slow down the market introduction of nanotechnology in the construction sector. For concrete this is a major issue. For self-cleaning window coatings, this issue is much smaller since the safety standards are much lower.
- ***Awareness among stakeholders in the European construction sector about nano application is limited:*** Construction involves product manufacturers and suppliers, construction workers and their employers, project developers and architects. Their knowledge of nanotechnology, and its potential in construction, is generally quite limited, leaving only a small number of key players to develop the market.

The next section reports on products, markets and companies for nanotechnology and construction.

9 PRODUCTS AND MARKETS FOR CONSTRUCTION THROUGH NANOTECHNOLOGY

9.1 Introduction

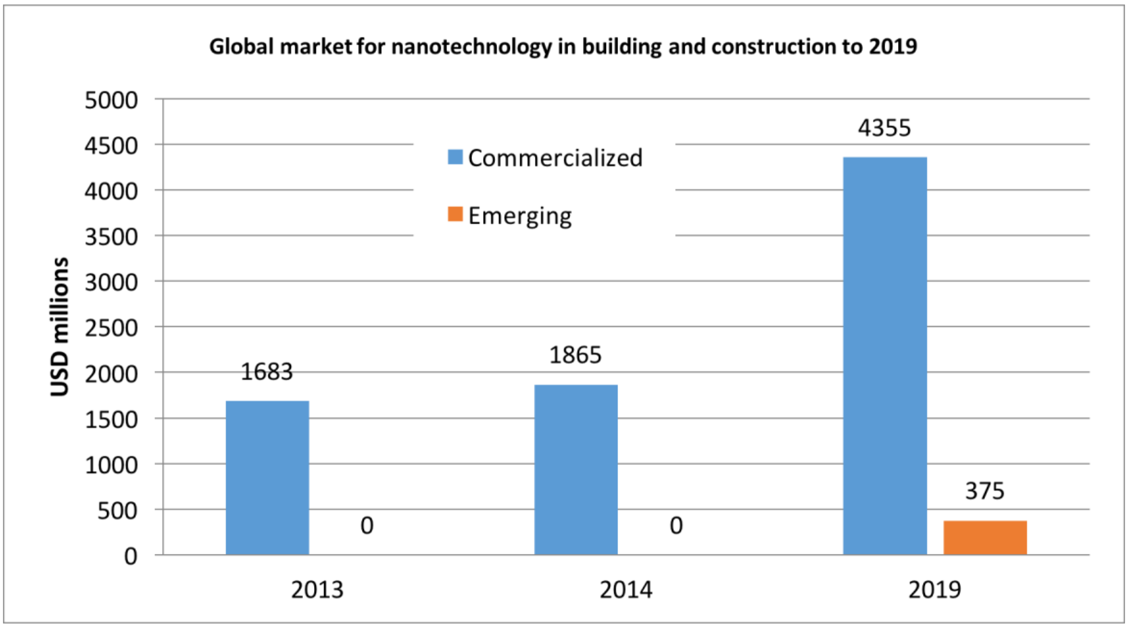
The commercial applications of nanotechnology in the field of building and construction include coatings, lighting, and other products such as building insulation and concrete.

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 construction, their product will often not appear as specific to construction. Here, efforts have been made to identify only products that are building and construction-specific, thereby increasing the relevance (but reducing the number) of products.

Global markets and forecasts for construction products using nanotechnology are considered below.

9.2 Global markets and forecasts for construction products using nanotechnology

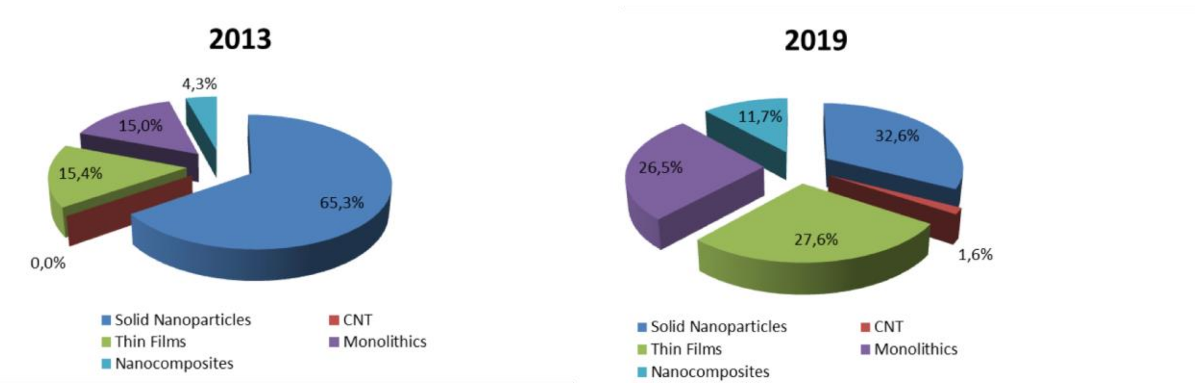
Global sales for nanotechnology products in the construction sector were estimated to be USD 1.8 billion in 2013 and are forecast to be USD 4.7 billion in 2019. The figure below shows the forecast growth in commercialised products (USD 4.35 billion in 2019) and the expected growth in emerging products (USD 375 million in 2019). It is seen that much of the growth is expected to be driven by products that have already been commercialised.



Source: BCC Research, 2014

Figure 9-1: Global market outlook for nanotechnology in construction to 2019

Nanotechnology can be used in construction in the form of particles, films and coatings, composites, etc. A comparison of global sales estimates by type of nanomaterial shows that solid nanoparticles accounted for the largest share in 2013, with a decrease to almost half its size forecast to 2019. In contrast to that decrease, global sales estimates of both nano-scale thin films and nano-structured monolithics are expected to almost double their share by 2019 (c. 15% to c. 27%). Sales of nanocomposites are projected to almost triple in relative share (4.3% to 11.7%). Carbon nanotubes are currently forecast to play only a marginal role in terms of shares of sales.



Source: BCC Research, 2014

Figure 9-2: Global sales estimates for nanotechnology and construction by material type, 2013 and 2019

The section that follows explores these markets in greater detail, beginning in each case with the technology and products (including company examples in the form of snapshots and case studies) and concluding with market estimates and forecasts. In addition, information is presented on likely future products and markets where appropriate. First there is an overview of the products.

9.3 Commercialised products for construction through nanotechnology

9.3.1 Overview

To date, 95 building and construction-related products using nanotechnology have been identified as being commercially available on the market. About one quarter of those are in the area of lighting (OLEDs 16% and LEDs 11%), and one fifth in the area of coatings (photocatalytic coatings 11% and anti-stick coatings 9%). Paints, coatings and adhesives account for 17% of the products while insulation products have a share of 16% as shown in the figure below.

The figure shows an approximate breakdown of the types of products, albeit that some categories overlap and a decision has been taken as to which category to put them in. The main message is that nanotechnology occurs most in components but also strongly in materials.

9.3.2 Products for construction through nanotechnology, by application market

The products identified as being relevant to nanotechnology and construction are divided as follows:

- Coatings;
- Lighting;
- Energy recovery systems for buildings;
- Insulation for buildings;
- Nanocomposites: hydrophobic/oleophobic;
- Conductive fibre;
- Wire and cable sheathing; and
- Concrete and cement.

In each case, details are given of the technology and its purpose as well as market estimates and forecasts. Company case studies and company snapshots provide additional information. Existing applications and emerging applications are considered.

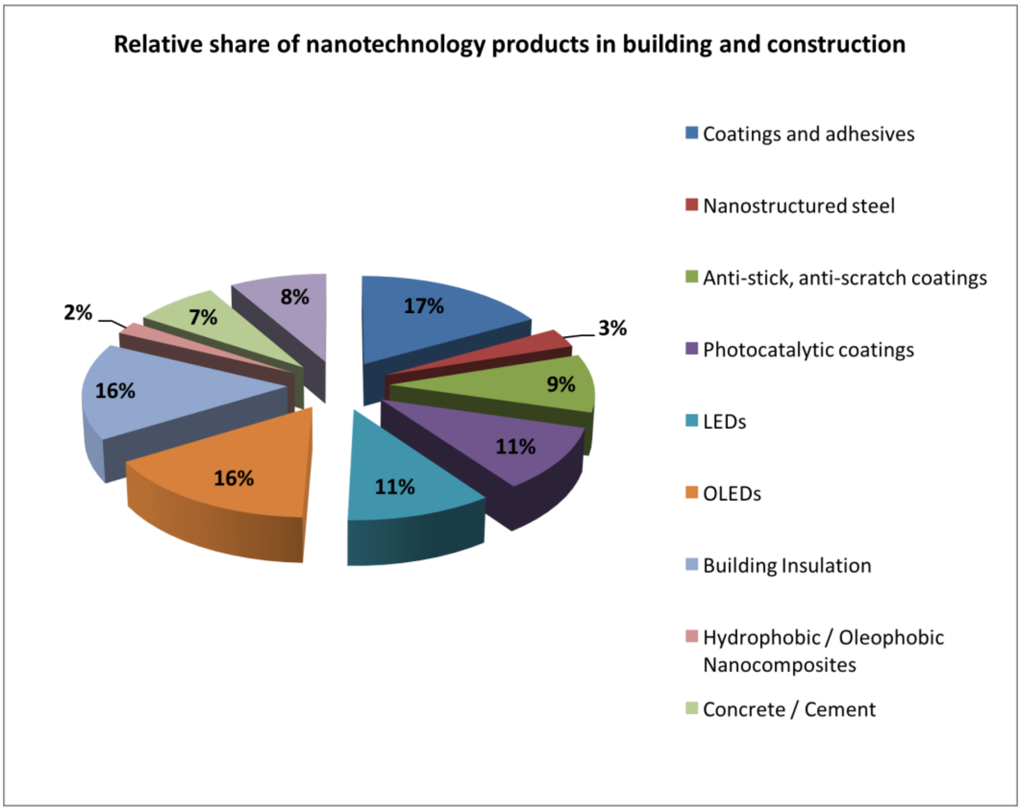


Figure 9-3: Nanotechnology in building and construction by product type

9.3.2.1 Coatings

A COATINGS AND ADHESIVES

TECHNOLOGY AND PRODUCTS

Of all nanotechnology products introduced into the construction industry, coatings and paints have probably up to now been the most successful in reaching the market to a significant extent[315]. Paint is a pigmented liquid chemical which is applied to a substrate (in case of construction to interior and exterior walls / roofs and pipes) to protect the surface and to give it a specific colour. Today, paint is also used for energy conservation e.g. by modifying the reflection of light or heat by a surface. Paint is also used on metal surfaces e.g. to impede corrosion. Paint is composed of pigments, adhesives, binder, solvent and other additives[316].

Aqueous polymer dispersions have widespread applications as exterior paints, coatings and adhesives, as well as in the finishing of paper, textiles and leather. They can be both decorative and protective against weathering, as binders in paint or plaster work and as coatings for concrete roofing tiles. If the dispersions are made soft and tacky, they can be used as pressure-sensitive adhesives for labels or adhesive tape. As binders for paper coatings, they provide brilliance to a wide variety of printed products. However, not all of the polymer particles used in these dispersions have truly nanoscale dimensions, ranging up to 800 nm in diameter. It has been estimated[317] that about 10% of the polymer particles measure less than 100 nm[318].

A research team at University College London has developed a nanoparticulate titanium dioxide for use in construction paints. The new paint imparts high performance, durability and self-cleaning properties. It is compatible with a many substrates including paper, glass and steel. It can be added with adhesives or simply coated and its self-cleaning properties remain even after wiping off with

[315] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, Amsterdam
[316] ObservatoryNano (2009), Economical Assessment / Construction sector, Final report, p.30
[317] BCC Research
[318] BBC Research (2014), Nanotechnology, a realistic market assessment, p.??

water and alcohol. The paint can be used on the exteriors of buildings or customised for use on automotive vehicles and clothes[319].

Some examples of paints include:

- Bioni Roof is an acrylic-based, highly resilient, patented roof coating developed in conjunction with the Fraunhofer Institute for Chemical Technology (ICT). With its Silver System Technology and siliceous light fillers, Bioni Roof is durably resistant against algae and moss growth. In addition, it is highly reflective making it suitable for existing roofing as a protective coating against environmental and climatic conditions[320].
- COL.9® is a nanobinder for paints from BASF that protects the paint against dirt and weather due to its ability to create a hydrophilic surface. Akzo Nobel has used COL.9® to develop Herbol® Symbiotec®, an exterior wall paint with dirt-repellent features. The paint prevents the build-up of dirt, bacteria, mould and algae on the surface and is also effective in maintaining the insulating properties of wall and other insulation systems through good moisture management[321].
- I-Cannano [322] (Garia, India) wood paints are made using nanotechnology. They are moisture repellent, UV resistant, microbe resistant, can be used as wood paints for a wide variety of exterior and interior surfaces and have a long shelf life I-CanNano products are established and in the last 10 years have been developed to serve a broad base of customers. The paint becomes embedded in the surface not just masking the wood. It does not weather out over time and is made from proprietary inorganic nano-particles incorporated in the paint matrix. Some of the innovative attributes include termite resistant, hygienic barrier, scratch resistant and anti-sticking and a customised fire resistance option.
- Akzo Nobel has designed an exterior paint for buildings, NorsjöOne, with self-cleaning properties, durability, mould resistance and dust resistance. NorsjöOne Supertech is environmentally certified and its self-cleaning properties come from a nano-silica material called silicic acid (colloidal silica; amorphous silica, SiO2). Silicon dioxide particles have not been shown to be harmful to the user and are established particles used in the construction industry[323].

Other important retailers for paints are PPG, Rohm & Haas, Jotun Group and Nippon.[324]

Company snapshot: Bioni CS GmbH

BIONI is a medium-sized company founded in 2001 in Oberhausen, Germany. It works closely with the Fraunhofer Institute for Chemical Technology (ICT) and is the technology leader in the field of multi-functional wall, façade and roof paints based on silver-system-technology. Based upon the latest scientific findings in nanotechnology and together with the researchers at Fraunhofer ICT, Bioni has developed a new nano-filler combination that, when used in both interior and façade paints, permanently prevents the formation of mould, bacteria and algae. These coating properties neither negatively affect the health of the residents nor pose a threat to the environment. The company has patented their product in the following countries: USA, Canada, Russian Federation, and the EU (pending).

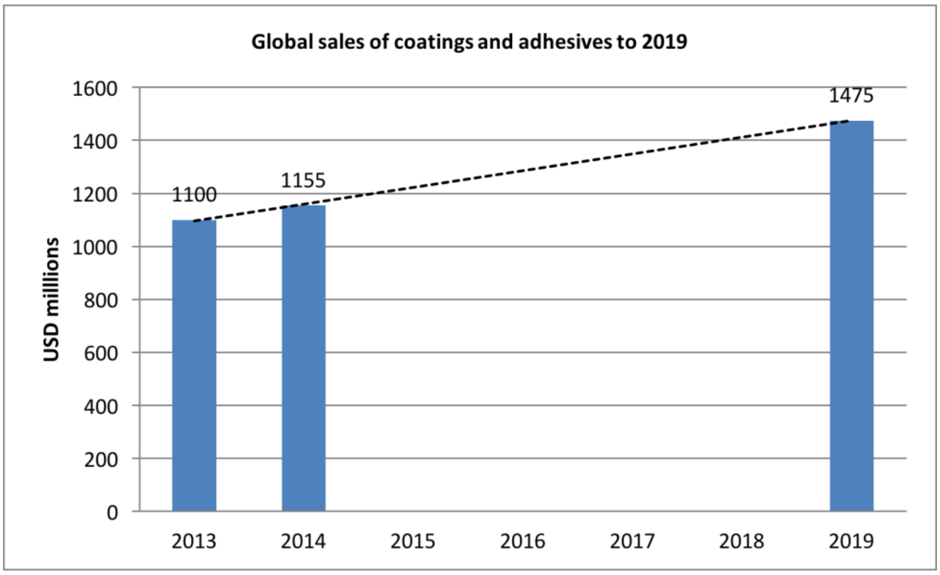
http://www.bioni.de/en/

MARKET DATA AND FORECASTS [325]

Global consumption of polymer nanoparticles used to produce paints and other coatings was around 55,000 tons, with an estimated value of USD 1.1 billion in 2013, based on a 10% proportion of the particles being nano in size, the cost of materials being about half of the value of the product and

[319] http://www.nanowerk.com/nanotechnology-news/newsid=39293.php
[320] http://www.bioni.de/en/277.html
[321] ObservatoryNano (2009), Economical Assessment / Construction sector, Final report, p.32
[322] http://www.icannanopaints.com/nanoWoodPaints.html
[323] http://advantage-environment.com/buildings/self-cleaning-paint-for-the-nordic-climate/
[324] ObservatoryNano (2009), Economical Assessment / Construction sector, Final report, p.30
[325] BCC Research (2014), Nanotechnology: A Realistic Market Assessment

the worldwide market for aqueous polymer dispersions being worth an estimated USD 22 billion in 2013.



Source: BCC Research 2014

Figure 9-4: Global market for coatings and adhesives to 2019

The overall global coatings market is projected to grow at about 5% per year through 2015. Applying a similar percentage to related sales of polymer nanoparticles yields the projections in the figure above.

Company snapshot: Nanophos

Nanophos was founded in 2005 in Greece, focused on making solutions for problems such as moisture, mould and thermal insulation. It provides chemical products that repel water, provide thermal insulation and protect surfaces such as tiles, walls, metals and cement, adding new properties and boosting energy efficiency in buildings and construction projects. In 2014, NanoPhos shifted its focus to marine coatings and exported products to more than 25 countries in Europe, Middle East, Asia and America. It developed materials to solve issues such as fouling, sea water corrosion, incident heat radiation and accumulation of salt deposits.

Antifouling coatings with no metal oxide biocides, thermal insulating paints and self-cleaning protection are only some of the product enhancements nanotechnology can offer. The Nanophos marine product portfolio includes 25 products focusing on maintenance, cleaning, hull protection, antifouling and fuel saving. The managing director of the company has co-authored more than 20 scientific articles that have been cited over 500 times. The company has approximately 16 full-time employees and generates an estimated USD 3 million (EUR 2,67 million) in annual revenue. The company works in association with the Hellenic Federation of Enterprises, the Hellenic Association of Chemical Industries, HEMEXPO Hellenic Marine Equipment Manufacturers and Exporters European Cool Roofs Council and Advanced Polymer Coatings.

http://nanophos-marine.com/eng/

B High-strength coatings (nanostructured steel)

Technology and products

The trade-off between steel strength and ductility is a significant issue for steel. Modern construction requires high strength materials, with safety and stress re-distribution requiring high ductility. The presence of very hard nanometre-sized particles in a steel matrix can lead to a combination of these properties, effectively matching high strength with exceptional formability. However, when the particles become too small, this effect can be reversed[326].

The range of possible properties available via nanostructuring may include steels with the hardness of alumina ceramics and the strength of carbon-based fibres. Other potential attributes may be superior corrosion resistance over nickel-based superalloys, higher strength-to-weight ratios than titanium alloys, and better weldability than cobalt-based materials[327].

There are several steel products that have been marketed using the word 'nano' but this mainly refers to a refinement of their material phases, i.e. reduction of the crystal size into the nano-scale. MMFX2 Steel by MMFX Steel Corp, Sandvik NanoFlex by Sandvik and Super Hard Steel (SHS) by The NanoSteel Company are examples of products in which the metal crystal size structure is reduced to below 75 nm resulting in a very strong steel (the last of the three having a Rockwell hardness of 66-69 HRc) [328].

In 2013, the UK National Institute for Materials Science introduced the first bulk nanostructured metal into commercial production. The nanostructure-controlled high-strength bainitic steel has a thickness of bainitic ferrite platelets that is controlled to be between 20 and 50 nm[329].

Company snapshot: : Sandvik Materials Technology AB - nanostructured steel

Sandvik Materials Technology AB, is based in Sandviken (Sweden), develops and manufactures products in stainless steel, special alloys, titanium and other high-performance materials. Its products are used in application areas including aerospace, automotive, chemical processing, industrial heating, medical devices, nuclear power generation, oil and gas, and renewable energy. In transport, Sandvik products are used in airbags, fuel and hydraulic lines, exhaust systems, compressor valves, brakes, and shock absorbers. Sandvik Nanoflex™ material has potential uses in the manufacture of engines and other moving mechanical parts.

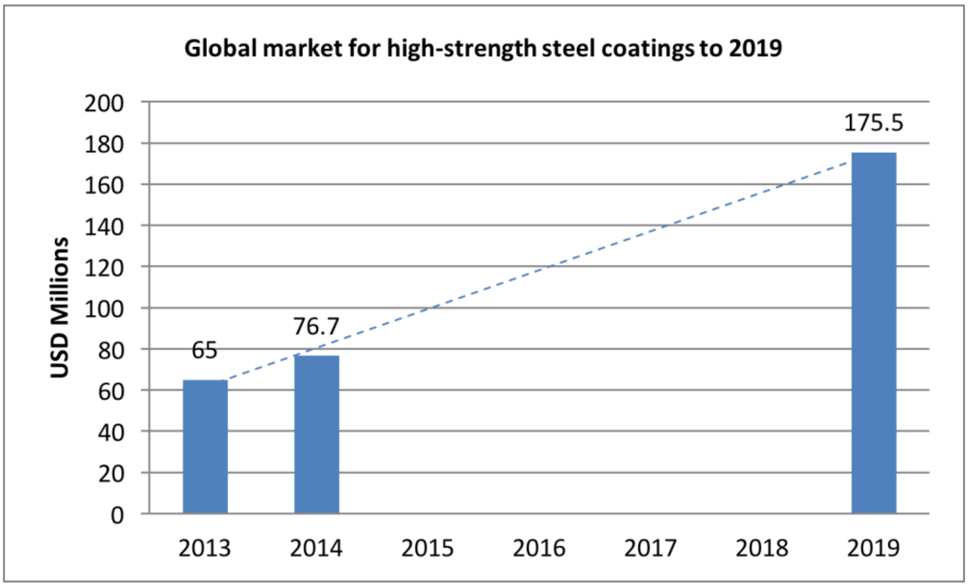
Sandvik has worldwide sales and services networks. In 2015, Sandvik Materials Technology AB had 6,500 employees and registered sales of 13.9 billion SEK (EUR 1.5 billion). The company operates as a subsidiary within the high-tech global engineering group Sandvik AB. In 2015, the Sandvik group as a whole had about 46,000 employees and sales of about 91 billion SEK (nearly EUR 10 billion) in more than 150 countries.

http://smt.sandvik.com/en/about-us/

[326] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.32
[327] BCC Research (2014), Nanotechnology, a realistic market assessment, p.64
[328] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.33
[329] National Institute for Materials Science: "World's first commercial nanostructured bulk metal." ScienceDaily, 10 November 2013.

Market data and forecasts

The market for nanostructured steel coatings was valued at USD 65 million in 2013 and is forecast to be USD 77 million in 2014 and USD 176 million in 2019.



Source: BCC Research, 2014

Figure 9-5: Global market for high-strength steel coatings to 2019

NanoSteel Inc. is currently the main vendor of nanostructured steel coatings, although there are a few other players such as Sandvik. NanoSteel does not publish separate sales data on its different product lines, but it is estimated to have sold at least USD 50 million worth of nanostructured steel coatings in 2013. The overall market for nanostructured steel coatings is expected to grow at a CAGR of at least 18% over the next five years.

C Anti-scratch/anti-stick coatings

Technology and products

High scratch resistant lacquers for wooden flooring systems (e.g. parquet floors) is an emerging market with several different types of coating systems. One is based on the addition of (amorphous) nano-SiO_2 to an acrylic binder material. During drying of the lacquer, the SiO_2 reacts chemically with the acrylic binder forming a highly branched and very strong network of silane polymers, the basis of the high scratch resistance[330]. Another high scratch resistant lacquer is based on the addition of nano sized Al_2O_3 particles (although the mechanism is not fully clear but seems related to an improvement of the elasticity of the coating matrix)[331].

In addition to these, various types of coatings are being developed to protect or treat wood surfaces. A principle aim is to preserve the initial (fresh) wood appearance as wood normally changes due to wear over time (e.g. from UV irradiation, moisture or temperature fluctuations)[332]. One way to slow the ageing process is by blocking the wood surface from UV light. UV protection of wood surfaces can be achieved by adding various metal oxides and organic chemicals that work by selectively filtering the UV radiation but leaving the visible light spectrum intact as much as possible (to maintain the natural wood appearance).

Cetelon has introduced a series of acrylate nanocomposite lacquers (under the trade name Cetosil) that contain up to 30 wt% of nano-sized silica. The use of special surface-grafted silica nanoparticles ensures the transparency and low viscosity of the coatings. The main application areas include

[330] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.41
[331] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.42
[332] Ibid

wooden floor finishes[333].

Percenta AG[334] (Glücksburg, Germany) has developed a superhydrophobic nanomaterial-based concrete coating solution with good dust and dirt resistance. When treated with this coating, the shelf life of the concrete is expected to increase and less maintenance is needed. The Nano Concrete & Flooring Coating incorporates a multi-functional impregnator for all porous surfaces, such as cement, concrete or house façades, and any type of floor.

Company snapshot: NANO-X GmbH - anti-scratch coatings

NANO-X GmbH develops and produces customised materials with multi-functional properties. Founded in 1999 and based in Germany, it has more than 100 publications (scientific, trade and press articles), over 45 patent families and more than 40 products. Its products and services range from innovation consultancy to production and support for customers in the application of the coating solutions. Many of its novel coating materials have been transferred from being niche and customised developments for clients to materials in production for the mass market. Application areas include binders and additives, as well as ready-to-use coating materials for corrosion protection, protection against oxide scale formation, anti-fingerprint, easy-to-clean, photocatalysis (Catalytic-CleanEffect®), anti-fog and scratch resistance, many of which are used in transport applications. The company focus is mainly on industrial customers and in providing or enabling special surface properties for a variety of materials and objects.

http://www.nano-x.com/start-english/

Company snapshot: Nanovations

Nanovations Pty Ltd is a manufacturer of innovative product solutions and is targeting problems that can appear on surfaces and materials used in construction, automotive, marine and industrial markets. The company was founded by a group of entrepreneurs in early 2002 in New South Wales, Australia. Nanovations Pty Ltd is the only manufacturer of inorganic nano-scale glass coating technology in Australia and they also produce solutions like the abrasive glass cleaners and metal care and protection and Nano-hybrid solutions. The company has around 10-20 employees and annual revenue is estimated at around USD 1 million (EUR 0.89 million).

http://www.nanovations.com.au/

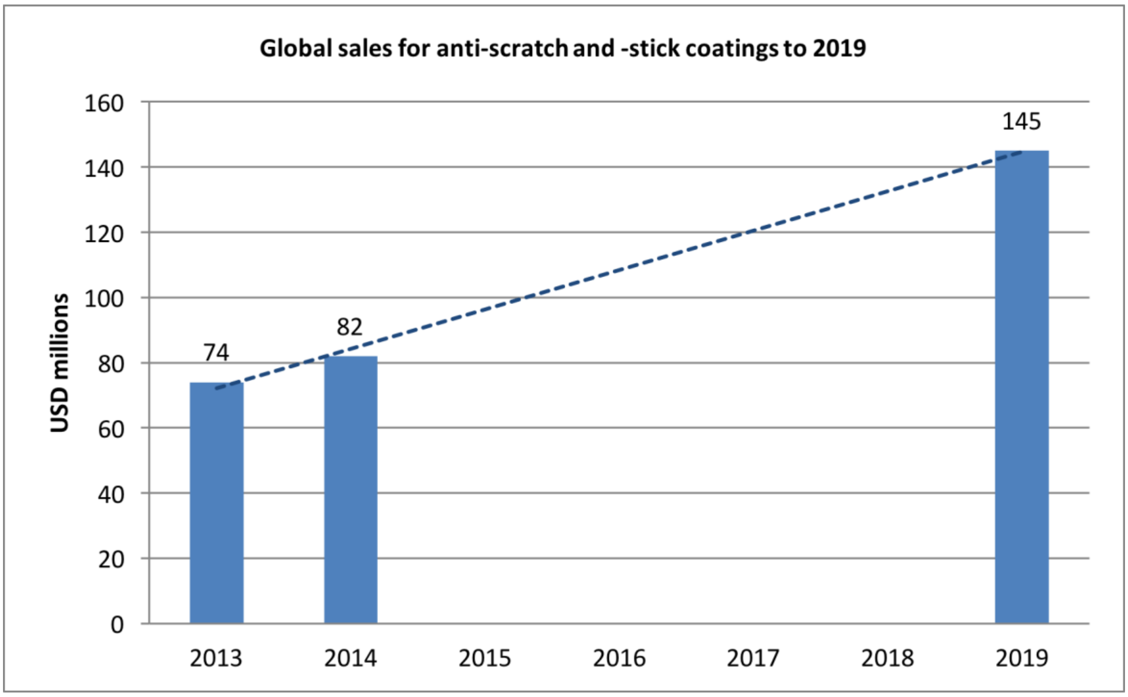
MARKET DATA AND FORECASTS [335]

Scratch-resistant nanostructured thin film coatings have found their most significant commercial usage to date in scratch-resistant coatings for plastic ophthalmic lenses and abrasion-resistant floor coatings. Other commercial applications, such as automotive clearcoat, are still at an early stage of commercialisation.

The total market for nanostructured anti-scratch coatings has been estimated to be 980 tonnes with a value of USD 74 million in 2013, a figure expected to grow to USD 82 million in 2014 and USD 145 million in 2019 (a CAGR of 12.1% between 2014 and 2019). In 2013 to 2014, the anti-scratch coating market was divided mainly between ophthalmic coatings and floor finishes. The market for polyurethane/alumina nanocomposite floor finishes in 2013 has been estimated to be USD 48 million. Most of the balance (USD 19 million in 2013) consisted of ophthalmic coatings.

Both ophthalmic coatings and floor finishes are relatively mature market segments that are expected to grow at CAGRs of 8.2% and 8.1%, respectively, from 2014 through 2019. The market for other types of anti-scratch coatings (especially auto clearcoat) is expected to grow much faster (i.e., at a CAGR of 32.7%) between 2014 and 2019.

[333] Cetelon Nanolacke: CETOSIL Acrylate - Nanocomposite Coatings, product description
[334] www.percenta-nanoproducts.com
[335] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.153



Source: BCC Research, 2014

Figure 9-6: Global market for thin film materials in optical recording media

D Photocatalytic coatings

Technology and products

The surfaces of building facades are under the constant corrosive influence of weathering, traffic exhaust fumes and micro-organisms. Nanotechnology offers ways to counteract these unwanted effects e.g. via self-cleaning coatings. Depending on the specific coating matrix, these can be used on various substrates ranging from natural stone and concrete to ceramics, composite material, metal, plastics or wood[336].

Self-cleaning coatings that actively degrade organic pollutants or micro-organisms (such as fungi, algae or bacteria) work due to the addition of small amounts of zinc oxide (ZnO) or titanium dioxide particles (TiO_2) that act via a light induced (photocatalytic) mechanism. The photocatalytic activity of ZnO or TiO_2 per gramme of substance increases significantly as their particle size gets smaller and their reactive surface area increases[337]. In addition to a photocatalytic effect, TiO_2 gives rise to a hydrophobic, water-repellent coated surface on which water easily slides, washing dirt away[338].

Case study: Pilkington Group

Pilkington Group Limited (UK) has been part of Nippon Sheet Glass (NSG, Japan) since 2006. NSG uses the Pilkington brand name. The company has a significant presence in Europe, both in terms of manufacturing facilities and sales. NSG has around 27,000 permanent employees of whom 12,000 are in Europe (UK, Germany, Finland, Italy, Poland Russia and Spain). Around 40% of the Group's sales are in Europe, 26% in Japan and 16% in North America, with the remaining 18% being mainly in South America, China and South East Asia. The company operates in three main sectors:

- *Architectural supplies glass for buildings and solar energy applications;*
- *Automotive supplies for original equipment manufacturers (OEMs), aftermarket*

336 van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.36
337 Ibid
338 van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.37

replacement and specialised transport glazing markets;

- *Technical glass products, including very thin glass for displays, lenses and light guides for printers, and glass fibres, used in battery separators and engine timing belts.*

Pilkington Group Limited was originated in 1826 as St. Helens Crown Glass Company, founded by John William Bell with capital from three of the most influential local families, the Pilkingtons among them. In 1894 it became a private company owned by the Pilkington family. The 1950s were of most significance to Pilkington because of the invention of the float glass process, formation of a ribbon of glass by floating the melted raw materials at high temperature over a bath of molten tin. Pilkington reported the float glass process in 1959 but further development work was necessary before the process could be fully exploited commercially. Pilkington decided on a policy of licensing the process to existing major glass manufacturers. It encouraged its licensees to further develop the process by granting them free use of any improvements they might make, on condition these were also made available to Pilkington itself. The modern large scale float glass production process gave the firm a decisive competitive advantage. It was quickly spread globally and lead to Pilkington's overseas growth.

In 1970, 10 percent of the family's shares were issued to the public, in order to allow the company to continue growing. Growth, diversification, recessions and a hostile takeover bid by BTR characterised the 1980s. Major growth came through acquisition in Europe and in the United States. Through the 1980s, the balance of the group changed considerably. In 1980, about 70% of operating profits came from the UK and Europe. Ten years later, the figure had reduced to 50%. In 1980, 22,600 out of 35,000 worked in the UK. In 1990, there were 13,700 in the UK and nearly 47,000 overseas. By 1993, numbers had fallen to 41,600, only 8,200 of who were in the UK. In the 1990s, Pilkington refocused on flat and safety glass and worked on making the core business more efficient.

The late 1990s and early 2000s were characterised by the license of float glass processing technology to various companies (including the leading Japanese glassmaker, Nippon Sheet Glass Co Ltd. – NGS), the development of markets (opening of new plants, factories or centres all over the world, in collaboration with companies like Shell, BP or Saint-Gobain), organisational change aimed at rigorous cost reduction as well as by technological development and successful introduction of new products, such as the first dual action self-cleaning glass Pilkington ActivTM, which has been cited as an example of nanotechnology and meant a major innovation in the largest sector of the glass industry.

The key element of Pilkington Activ™ self-cleaning glass is a microscopically thin, transparent coating of titanium oxide. The environmental-friendly innovation is a result of a long process (starting from the early 1990s) of research and development into thin-film technologies by the company's Research & Development Centre in Lancashire. In the period 1990-1996, Pilkington led two FP projects (in FP2 and FP3, under the JOULE programme) entitled Solid state electrochromic variable transmission windows. The total cost of the second stage of this project was EUR 1.0 million. Pilkington Activ™ was launched in 2001 after extensive field and laboratory testing. Knowledge of the properties of the titanium oxide compound in relationship to glass has been widely available for as long as 20 years. However, it is the on-line application of the coating that has been patented by Pilkington technologists. In July 2001 Kevin Sanderson, the Pilkington research scientist who led the team which pioneered the development of this product, won the prestigious Worshipful Company of Glass Sellers Award of Excellence for that year. Early in 2002, Pilkington announced that the product was available in Austria, Benelux, Germany, Ireland and Switzerland. The same year it was one of just two "Best of Show" products featured in the popular US TV programme (Home & Garden). The product was also shown in the 2003 Glassex exhibition held at the National Exhibition Centre.

By June 2003, the world's first dual-action self-cleaning glass had been successfully rolled-out to consumers throughout Europe in the largest new product launch programme ever staged by Pilkington. The UK's leading independent consumer magazine Which? tested the product against a standard pane of glass over a period of two months, by exposing it to the elements and subjected to sprays of dirty water. The product was found to be noticeably cleaner than the standard pane. In September 2003, the UK window, door and conservatory giant, Everest Ltd. described Pilkington Activ™ as the most ingenious concept product to reach the UK in decades. In 2004, the product was selected as one of the finalists in the prestigious Mac Robert Awards. In September 2006 it was announced that the STG 2 million "Keep us World" national advertising and promotional campaign, which resulted in sales of the product multiplying ten-

fold in just a year, had been voted Promotional campaign of the Year 2006 in the G06 Awards. Pilkington participated in 2004-2007 in the Self-Cleaning Glass Project (FP6) led by Saint-Gobain. The EC contribution for this project amounted to EUR 2,293,000. Other varieties of Pilkington Activ offer additional features like solar control, thermal insulation and low-emissivity energy-saving glass.

Other new products launched by Pilkington in the early 2000s include: the electrochromic environmental glass for buildings - Pilkington E Control™, the Group's first blue solar control glass products - Pilkington Arctic Blue™ and Pilkington Arctic Blue Eclipse™, the first hard-coated glass to offer both solar control and thermal insulation in the same product - Pilkington Solar E™; 3R™ clean air process (which won a Queen's environmental award and the American ceramic Society's corporate environmental achievement award), new translucent float glass - Pilkington Satin™, high performance mirror that protects people as well as the environment - Pilkington Optimirror™ Protect.

At the organisational level and in 2001, after a third consecutive year of profit growth, it was announced that the Nippon Sheet Glass Co. Ltd (NSG) had completed the purchase of 130 million shares in Pilkington plc., bringing its total shareholding to 20.6% of the company's issued share capital. In June 2006, Nippon Sheet Glass Co., Ltd acquired Pilkington plc through NSG UK Enterprises Limited, a wholly-owned subsidiary.

All of the operations of the former Pilkington plc are now fully integrated into the NSG Group, one of the world's leading manufacturers of glass and glazing systems in Building Products, Automotive and Technical Glass. At the time of the acquisition, the decision was taken to brand the enlarged Group as 'NSG Group' and to use the 'Pilkington' brand for the Group's flat glass businesses (building products and automotive). The NSG Group's European Technical Centre (which helped to deliver product innovations such as Pilkington Activ™ and more recently the energy efficient coated glass such as Pilkington K Glass™ S) is still currently located at Lathom in Lancashire (UK).

http://www.pilkington.com/

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[339].

Researchers at the Universitario Río San Pedro in Brazil have developed a simple and low cost process to make a TiO_2–SiO_2 nanocomposite-based photocatalytic coating for outdoor applications and as a building material. The coating is reported to have long-term durability, self-cleaning and strengthening properties. To demonstrate the photocatalytic activity of the building materials, the team has also varied the loading and size of titanium dioxide nanoparticles to study the effect on the photocatalytic activity. The study concludes that, though the nanocomposites impart high mechanical durability and self-cleaning attributes to the coating and building material, when the amount of it is significantly increased there is a rapid reduction in photocatalytic activity[340].

Products for construction include:

- Hydrotect (now HT), developed by Agrob Buchtal, is mainly used on ceramic floor tiles. The surface of Hydrotect tiles contains a coating of titanium dioxide (TiO_2) that is baked onto the tiles at high temperatures, ensuring the bonding of the materials with the tile surface. When light hits the tiles, the titanium dioxide activates oxygen from the atmosphere and the organic dirt on the surfaces is broken down via photocatalysis. [341]
- Erlus Lotus, introduced in 2004 as the first self-cleaning clay roof in the world. The burned-in

339 http://phys.org/news/2008-11-photo-catalytic-coating-exteriors.html
340 http://www.sciencedirect.com/science/article/pii/S0926337313000416
341 ObservatoryNano (2009), Economic Assessment – Construction Sector, p.12

surface finish of the clay roof tile destroys dirt particles, grease deposits, soot, moss and algae with the aid of UV light[342].

- MAXIT Airfresh Plaster is a plaster that can be applied on ceilings and walls. Making use of nano-sized TiO_2 particles, it eliminates unwanted odours, air pollutants and organic volatile compounds via photocatalysis[343].
- Glass incorporating photocatalytic coatings are available on the market. Examples include Bioclean self-cleaning glass by Saint-Gobain Glass[344] and Pilkington Active self-cleaning glass from the British company Pilkington[345].

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[346].

Company snapshot: Toto Ltd.

Toyo Toki K.K. (which became known as Toto Ltd.) was founded in Japan in 1917 as a ceramic sanitary-ware laboratory. Toto Manufacturing produced Japan's first ceramic sanitary ware (now toilet basins, urinals, sinks, washbasins, etc.). It has expanded into producing other bathroom and toilet equipment as well modular kitchens, bathroom vanity units, Marbright artificial marble counters, bathroom ventilation, heating and drying systems, welfare equipment, etc. Currently Toto is starting to produce more eco-friendly materials (tiles, Hydrotect coating materials, etc.) and ceramics (precision ceramics & optical components), some of which use nanotechnology coatings. The annual turnover of the company is around ¥ 35,579 million (EUR 355,79 million) with holding 28,148 consolidate and 7,283 non-consolidate employees. They have filed more than 1,300 domestic and overseas patent and have been granted approximately 350 worldwide patents to date. Toto Ltd also holds around 60 publications under its name.

http://www.toto.com/index.htm

Company snapshot: Deutsche Steinzeug Cremer & Breuer AG

Deutsche Steinzeug Cremer & Breuer AG produces and sells ceramic covering materials in Germany and internationally. It offers architectural ceramics under the Agrob Buchtal brand name, which includes modular systems for wall and floor; water inflow and pool edge systems; slip-resistant solutions for swimming pools; robust ceramics for industry and trade; special tile systems for the design of stairs, skirtings, edges, etc.; and design elements for public areas, as well as guiding tiles for the blind, shower tub systems, static electricity conducting ceramics, or laser-absorbing surfaces for operating theatres. The company also provides mosaic tiles, as well as matching wall and floor tiles under the Jasba brand name. Deutsche Steinzeug Cremer & Breuer AG was founded in 1890 and is based in Alfter-Witterschlick, Germany. In 2002, the company introduced a self-cleaning nano-coating technology, called Hydrotech® (now HT), in its ceramic products.

In the fiscal year 2014, the Deutsche Steinzeug Cremer & Breuer AG had 1,213 employees and generated a turnover of almost EUR 175 million.

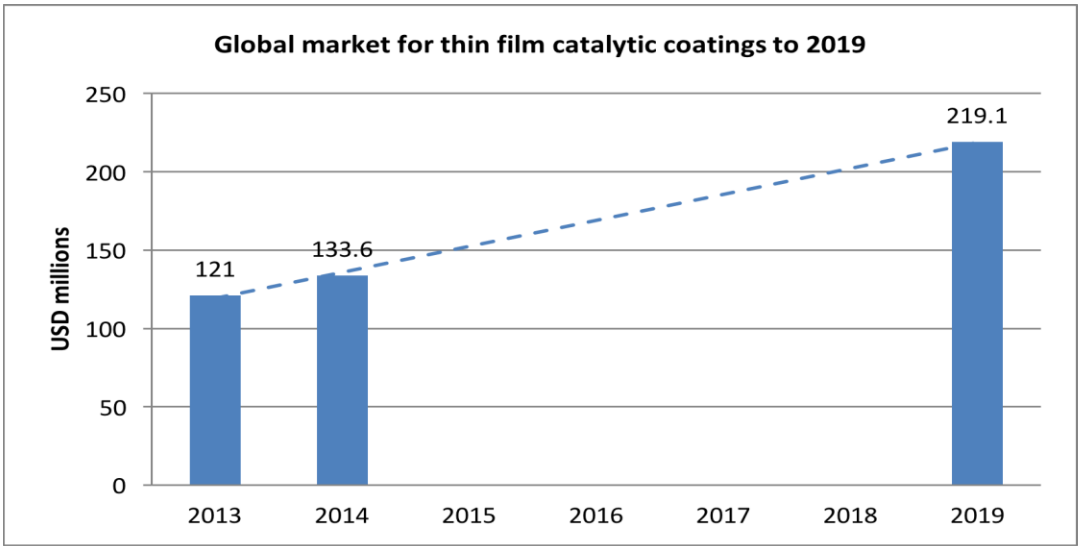
http://www.agrob-buchtal.at/service/presse/presse_und_news_details.html?nd_ref=2673

[342] http://www.erlus.com/ModelleSelbstreinigend/lotus/
[343] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.452.6825&rep=rep1&type=pdf
[344] http://uk.saint-gobain-glass.com/product/670/sgg-bioclean
[345] https://www.pilkington.com/en-gb/uk/householders/types-of-glass/self-cleaning-glass
[346] BCC Research (2014), Nanotechnology, a realistic market assessment, p.65

MARKET DATA AND FORECASTS [347]

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. The total consumption of nanoscale TiO^2 thin film materials in 2013 has been estimated 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

9.3.2.2 Lighting

A LIGHT EMITTING DIODES (LEDs)

TECHNOLOGY AND PRODUCTS

LEDs have substituted light bulbs already in an increasing number of lighting applications. Unlike conventional incandescent lamps which need to convert the electricity into thermal energy first and then to light, LED illumination is achieved when a semiconductor crystal is activated so that it directly produces visible light in a desired wavelength range[348]. Nevertheless, a low-cost, mass-market white-light diode with the potential to replace conventional incandescent bulbs and fluorescent tubes seems currently still out of reach for LED researchers and manufacturers.

One possible solution is the use nanophosphors (i.e. semiconducting nanoparticles that emit light under excitation) in white LEDs. If the phosphor particles are smaller than 20 nm in diameter, according to Mie theory, there will be in less scattering of light waves and thus greater optical and energy efficiency[349].

Phosphor Technology Ltd. (Hertfordshire, UK) has been a developer and manufacturer of phosphors for blue to white LED conversion for several years. It is also working on phosphors for CRTs[350], FEDs[351], plasma display panels, X-ray applications, IR and UV detection, scintillator applications and laser detectors[352]. Another British company that has been developing nanophosphor for LED

[347] BCC Research (2014), Nanotechnology, a realistic market assessment, p.157
[348] LED inside: Advantages and Weaknesses of LED Application, December.20, 2007
[349] Zachau M, Konrad A (2004), Nanomaterials for Lighting, Solid State Phenomena Vols. 99-100 (2004): 13
[350] Cathode ray tubes
[351] Field emission displays
[352] Mills A (2005), Phosphors development for LED lighting, III-Vs Review Volume 18, Issue 3, April 2005: 33

applications is Forge Europa (Ulverston, UK), which received national public funding of STG 1.27 million from 2004-2008 for its project on "Nanophosphors for Displays and Lighting" [353].

Another solution has been found by QD Vision (Watertown, MA, USA) developing a quantum dot film coating for the lens of LED lamps that is reported to give the light emitted a warmer, more yellow glow by using photoluminescence[354]. Quantum dots absorb one wavelength of light and emit another, the emission being determined by the materials and size of the quantum dot. Because the two can be controlled precisely and the emission itself is at most a few tens of nanometres wide, the resulting light can be tuned to achieve the best visual quality and efficiency[355]. QD Vision and Nexxus Lighting of Charlotte, N.C., announced in 2010 what they called the first commercially available QLED lightbulb with an industry-leading 60-lm/W white-light output[356].

Nanosys quantum-dot-enhancement film (QDEF), as the company calls its product, uses the dots to adjust the spectrum of LEDs so that it is closer to that of the white light the human eye is used to. It does this, as the product's name suggests, by passing the LED light through a transparent film with quantum dots which absorb and re-emit some of it[357]. The QDEF is composed of Nanosys proprietary quantum dot phosphors, which convert blue light from a standard GaN LED into different wavelengths based on their size. Blending together a mix of dot colours allows LCD manufacturers to accurately match their LED backlight to their LCD colour filters to achieve the best possible colour and efficiency performance. Nanosys has begun shipping QDEF material to OEMs such as ASUS (Taiwan) and VP Dynamics Labs (San Diego, USA) [358].

Company snapshot: Nanosys

Nanosys is a nanotechnology company that designs products based on "architected materials," or materials purpose-engineered for a given manufacturing process. This technology is currently being applied to multiple industries, including LED backlighting, LED general lighting, power (batteries and fuel cells), medical applications, and specialized nano-surface coatings. Founded in 2001, the company is headquartered in Silicon Valley, California where it operates the world's largest Quantum Dot nanomaterials fab with manufacturing capacity for over 25 tons of quantum dot materials per year. By 2011, the invested capital in the company was USD 130 million and the business had generated more than USD 75 million in revenues.

Their business model consists of two elements: sales of Quantum Dot Concentrate™ material and technology licensing of component designs to industrial supply chain partners. For instance, their Quantum Dot Enhancement Film (QDEF®) is a key component of ultra-high definition (UHD) televisions.

The company has one of the largest quantum dot patent portfolios with over 300 issued and pending patents worldwide that cover all processes from fundamentals of quantum dot construction to component and manufacturing designs. This portfolio has been created through collaborations between Nanosys and universities such as Massachusetts Institute of Technology (MIT), Lawrence Berkeley National Labs and Hebrew University, as well as industry collaborations with companies like Philips-Lumileds and Life Technologies. Among their partners for tablets and televisions are companies such as 3M, Samsung, Sharp and LG.

http://www.nanosysinc.com/#lcd-revolution

MARKET DATA AND FORECASTS

The first commercial LED products incorporating nanoparticles were Nexxus Lighting's quantum dot-coated LED ceiling lamp fixtures, which began arriving on the market in small quantities in 2010. High-brightness LEDs are a potential market for both quantum dots and rare earth nanophosphors.

[353] http://news.bbc.co.uk/2/hi/science/nature/3591192.stm
[354] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.40
[355] PHOTONICS Spectra: Quantum Dots Warm Up LED Lighting. October 2011.
[356] Ibid
[357] The Economist: Dotting the eyes - Quantum-dot displays, Jun 16th 2011
[358] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.40

The market for quantum dots used in LED applications could reach USD 34 million by 2019, matched by the demand for rare earth nanophosphors for LEDs, as shown in the table below[359].

Table 9-1: Global market for nanoparticles in LED production

	Global market (USD million)	
	2013	**2019**
Quantum dots	Negligible	34.0
Rare earth nanophosphor	Negligible	34.0
Total nanoparticles	Negligible	68.0

Source: BCC Research

Company snapshot: Zumtobel

The Zumtobel Group is an international lighting group and a leading player in the field of innovative lighting solutions and components. The Zumtobel Group is based in Dornbirn in the Vorarlberg region of Austria since 1950. With its three internationally established brands, Thorn, Tridonic and Zumtobel, and its two smaller brands, acdc and Reiss, the Group offers its customers around the world a comprehensive range of products and services. In the lighting business the Group with its Thorn, Zumtobel and acdc brands is the European market leader. The Reiss brand supplies OEMs with luminaires with a higher degree of protection. Through its lighting components brand, Tridonic, the Group plays a leading role worldwide in the manufacture of hardware and software for lighting systems (LED light sources and LED drivers, sensors and lighting management). The Group is listed on the Vienna Stock Exchange (ATX) and on the balance sheet date (April 30, 2016) employed a workforce of 6,761 employees. In the 2015/16 financial year, the Group posted revenues of EUR 1,356.5 million. The Zumtobel Group currently holds more than 4,000 patents.

http://www.zumtobel.com/com-en/company.html

B ORGANIC LIGHT-EMITTING DIODES (OLEDS)

TECHNOLOGY AND PRODUCTS

An OLED 'light bulb' is a thin film of material that emits light. OLED is the only technology that can create large "area" lighting panels (as opposed to point or line lighting enabled by LEDs and fluorescent bulbs). OLEDs can be used to make flexible and transparent panels, and can also be colour-tuneable. OLEDs emit soft diffused light, the closest light source to natural light with the exception of old incandescent lamps[360].

Applications in flexible signs and lighting are being developed[361]. Philips Lighting have made OLED lighting samples under the brand name "Lumiblade" available online since 2009[362] and Novaled AG (Germany) introduced a line of OLED desk lamps called "Victory" in September, 2011[363].

Osram AG (Munich, Germany), the lighting subsidiary of Siemens AG, took a step closer to true commercial production of OLED lighting in 2011 with the opening of a pilot-line manufacturing plant for organic light-emitting diodes (OLEDs). The facility in Regensburg West, which currently employs 220 people, required an investment of EUR 20 million[364]. At about the same time, Philips announced it was expanding its production capacity for Lumiblades as other companies began to enter the market. Also in 2011 Verbatim's VELVE line was introduced which is based on Mitsubishi Chemical Corporation's materials and production process to manufacture colour (RGB) tuneable OLED panels.

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[359] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.135
[360] http://www.oled-info.com/oled-light
[361] Michael Kanellos, "Start-up creates flexible sheets of light", CNet News.com, December 6, 2007
[362] http://oledworks.com/
[363] TMC NEWS: New OLED Luxury Luminaire Series Launched Under German Brand Name Liternity®, September 13, 2011
[364] Leds magazine: Osram opens OLED pilot-production facility in Germany

Mitsubishi Chemical Corporation announced in 2014 the development of an organic light-emitting diode (OLED) panel with a life of 30,000 hours, twice as much as conventional OLED panels. The new longer-life OLED module has a range of uses in offices, households and medical facilities. The new product will be manufactured by Pioneer OLED Lighting Devices, a Pioneer subsidiary, and sold by MC Pioneer OLED Lighting, a joint marketing venture of Mitsubishi Chemical and Pioneer[365].

Konica Minolta recently started mass producing flexible OLED lighting panels in what is probably the world's most advanced OLED fab - a roll-to-roll flexible OLED lighting fab that has a capacity to produce a million flexible and colour-tuneable OLED panels each month. The Japanese company recently announced that it shipped 15,000 flexible OLEDs to a Japanese tulip festival - by far the largest OLED installation to date[366].

Company snapshot: Philips

Koninklijke Philips N.V. (Royal Philips, commonly known as Philips) is a Dutch technology company headquartered in Amsterdam with primary divisions focused in the areas of electronics, healthcare and lighting. It was founded in Eindhoven in 1891 by Gerard Philips and his father Frederik. It is one of the largest electronics companies in the world. At the end of 2013 Philips had 111 manufacturing facilities, 59 R&D Facilities across 26 countries and sales and service operations in around 100 countries.

Philips is organised into three main divisions: Philips Consumer Lifestyle (formerly Philips Consumer Electronics and Philips Domestic Appliances and Personal Care), Philips Healthcare (formerly Philips Medical Systems) and Philips Lighting. Philips achieved total revenues of €22.579 billion in 2011. At the end of 2011 Philips had a total of 121,888 employees, of whom around 44% were employed in Philips Lighting, 31% in Philips Healthcare and 15% in Philips Consumer Lifestyle. Philips invested a total of €1.61 billion in research and development in 2011, equivalent to 7.1% of sales. The company currently holds around 54, patent rights, 39,000 trademarks, 70,000 design rights and 4,400 domain name registrations.

MARKET DATA AND FORECASTS

The market for OLED lighting was negligible in 2013 and 2014. Most of this early market was in niche applications such as high-end residential lamps and commercial showroom installations. In the longer term, though, potential markets for OLED lighting include architectural lighting and backlighting for displays and signage, switches, keypads, instrument panels and possibly automotive dashboards. The total market for OLED lighting could reach USD 765 million by 2019[367].

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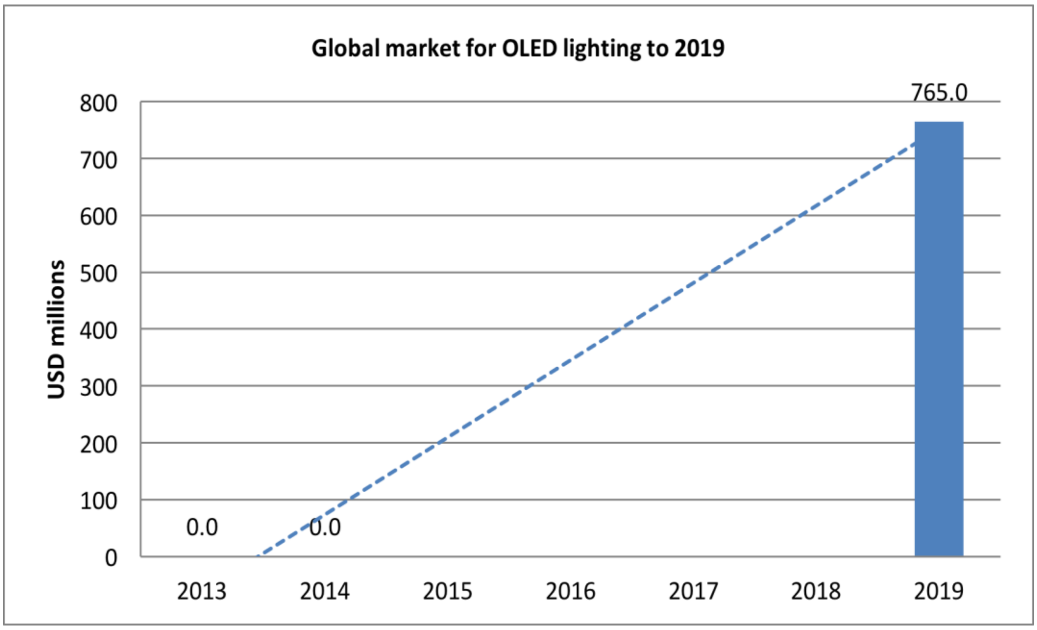
[365] Xinhua News Agency: Japanese company doubles diode panel's life span, Oct. 13, 2014
[366] http://www.oled-info.com/oled-light
[367] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.161



Source: BCC Research

Figure 9-8: Global market for OLED lighting to 2019

Backlighting applications are likely to represent the main market for OLED lighting between 2014 and 2019, with an initial emphasis on backlights for cell phone and PDA displays, later expanding into medium and large flat-panel displays. The main competitor for OLED backlights comes from LEDs, which started replacing cold cathode fluorescent lighting (CCFL) backlights around 2004. It has been estimated that the global market for LED backlights was worth USD 3.2 billion in 2013 and could reach USD 8 billion by 2019. It is difficult to forecast the potential market for OLED backlights, which have not yet reached the market in significant quantities. However, based on the market history of LED backlights, it is estimated that the market for OLED backlights could reach USD 1 billion by 2019, with the OLED thin film materials themselves accounting for about 50% of the total cost of the backlights, or USD 500 million[368].

Table 9-2: Global market for nanoparticles in OLED production (USD million)

	Global market (USD million)	
Type	**2013**	**2019**
Backlighting	Negligible	500.0
Architectural lighting	Negligible	265.0

Source: BCC Research

OLED lights generally cast a diffuse light, which makes them more of a competitor for fluorescent tube lights than for directional lights such as incandescent lights or LEDs. The global fluorescent lighting market is expected to reach at least USD 26.5 billion by 2019 with the OLED thin film materials themselves representing about USD 265 million of a market[369].

9.3.2.3 Energy recovery systems for buildings

Technology and products

Energy recovery ventilation (ERV) is the energy recovery process of exchanging the energy contained in the air of a normally-exhausted building or space and using it to treat (precondition) the incoming outdoor ventilation air in residential and commercial HVAC systems. During the warmer

[368] Ibid
[369] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.161

seasons, the system pre-cools and dehumidifies while humidifying and pre-heating in the cooler seasons[370].

Dais Analytic Corp. (Odessa, Fla.) manufactures and markets the ConsERV system, which preconditions incoming air by passing it through a proprietary nanostructured polymer filter. According to the company, the ConsERV system is twice as effective as alternative technologies in managing latent heat. Dais uses the same nanostructured polymer filter in its NanoAir system, which is still under development. NanoAir could replace traditional heaters as well as air conditioners while simultaneously delivering better air quality and significantly higher efficiency. NanoAir is targeted at all types of commercial and residential buildings, data centres, medical facilities, homes, cars, trains, buses, retail display coolers, refrigerated trucks and others[371].

Viessmann (Allendorf, Germany) has developed a gas-driven zeolite heating device to increase energy conversion efficiency and emission reduction for the heating of houses using a combination of a zeolite-water adsorption heat pump and a gas condensing boiler. The goal of the adsorption heat pump is the supply of useful heat at a higher temperature level by adding low-temperature heat to the work process. Due to the additional supply of ambient heat to the process, efficiencies of up to 135% relative to the heating value can be achieved, outperforming conventional condensing boilers with a maximum efficiency of 111%. This corresponds to a reduction in CO_2-emission of 20% compared to the state-of-the-art in gas heating of detached and semi-detached houses[372].

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.

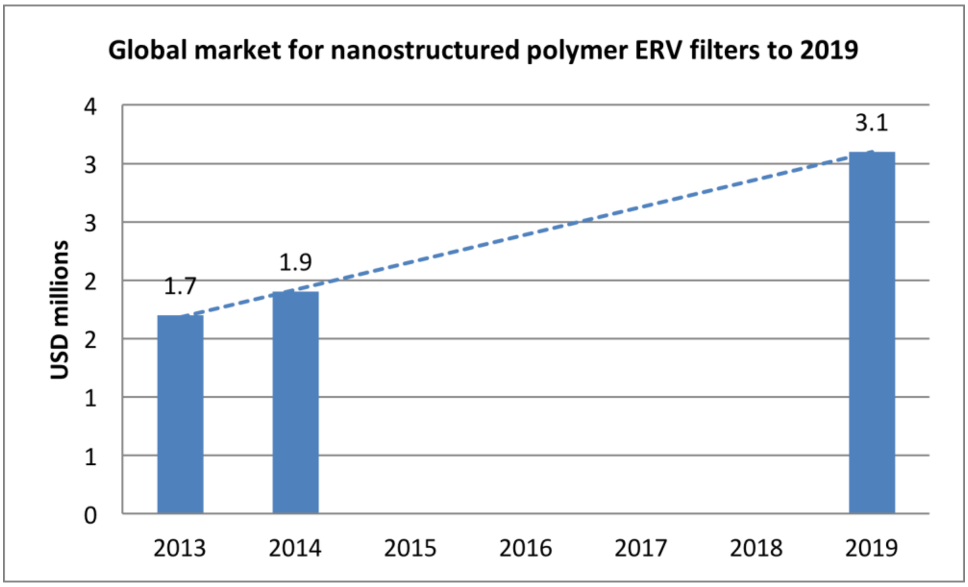
The first commercial product of the company was the energy recovery ventilator ConsERV™. Nowadays Dais Analytic Corp. includes a number of products in their portfolio such as NanoAir™ HVAC products for heating, ventilation, and air conditioning, NanoClear™ clean water systems for water treatment and 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

In 2013, Dais Analytic Corp. earned about USD 1.7 million from sales of its ConsERV energy recovery ventilation system, which is built around a nanostructured polymer filter. Sales of ConsERV have grown at a CAGR of more than 10% since 2008. At this rate, sales should approach USD 3.1 million by 2019[373].

[370] Dieckmann, John. "Improving Humidity Control with Energy Recovery Ventilation" ASHRAE Journal. 50, no. 8, (2008)
[371] BCC Research (2014), Nanotechnology, a realistic market assessment, p.77
[372] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.60
[373] BCC Research (2014), p.169



Source: BCC Research, 2014

Figure 9-9: Global market for nanostructured polymer ERV filters to 2019

9.3.2.4 Insulation for building

Technology and Products

Aerogels are a diverse class of porous, solid materials that exhibit an array of extreme materials properties. Most notably aerogels are known for their extreme low densities (which range from 0.0011 to c. 0.5 g cm^{-3}). In fact, the lowest density solid materials that have ever been produced are all aerogels, including a silica aerogel that as produced was only three times heavier than air, and could be made lighter than air by evacuating the air out of its pores. However, aerogels usually have densities of 0.020 g cm^{-3} or higher (about 15 times heavier than air). Typically aerogels are 95-99% air (or other gas) in volume, with the lowest-density aerogel ever produced being 99.98% air in volume[374]. Essentially an aerogel is the dry, low-density, porous, solid framework of a gel (the part of a gel that gives the gel its solid-like cohesiveness) isolated from the gel's liquid component (the part that makes up most of the volume of the gel). Aerogels are open-porous (that is, the gas in the aerogel is not trapped inside solid pockets) and have pores in the range of <1 to 100 nanometres (billionths of a meter) in diameter and usually <20 nm[375].

Aerogels have been prepared from many materials, including alumina, tungsten oxide, ferric oxide, tin oxide, nickel tartrate, cellulose, cellulose nitrate, gelatin, agar, egg albumen and rubber. However, most aerogels are formed from silica. Aerogels reportedly have the highest thermal insulation value of any solid material[376].

Aspen Aerogels, Inc.,[377] (Northborough, MA, USA) is an energy technology company that designs, develops and manufactures aerogel insulation products used primarily in energy infrastructure facilities. These include Pyrogel XT/XT-E that reduces the risk of corrosion under insulation in high temperature operating systems; Pyrogel XTF, which provides strong protection against fire; Cryogel Z for use in sub-ambient and cryogenic applications in the energy infrastructure market; and Spaceloft Subsea used in pipe-in-pipe applications in offshore oil production. The company also provides Spaceloft that is used in the building and construction market; and Cryogel X201, which is used in cold system designs, including refrigerated appliances, cold storage equipment, and aerospace systems where space is at a premium.

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[374] http://www.aerogel.org/
[375] Ibid
[376] BCC Research (2014), Nanotechnology, a realistic market assessment, p.76
[377] www.aerogel.com

Quartzene® by Svenska Aerogel AB[378] (Gävle, Sweden) is a silica aerogel which has excellent insulation properties and can resist temperatures up to 650°C due to the material's porosity. Even when exposed to high temperatures, the material will never burn. Quartzene® is a fine and porous silica-based powder. To handle the powder and use its insulation capacity, it has to be made into a more manageable form, such as a board or a blanket, using a binding agent.

Fixit 222 Aerogel High-Performance Insulating Plaster by Fixit AG[379] (Holderbank, Switzerland) is another example of a silica aerogel that is specially designed for the retrofitting of old building stock that is very common in Central Europe.

Aerogels Australia[380] (Perth, Australia) has developed Spaceloft, an aerogel-based insulating material that is flexible and nanoporous and has a very high R-value[381]. It is highly flexible with high compression resistance, and hydrophobicity, is easy to handle and is highly durable[382]. Being a nanoporous aerogel insulation blanket, its purpose is to reduce energy loss without taking up much space. It is thin and lightweight, for a range of residential and commercial building applications. It is operational temperatures between -40°C and 200°C.

Alison Aerogels[383] (Guangdong, China) has developed a unique series of nanoporous panels for thermal insulation with a large variety of customised thickness and temperature. It is hydrophobic, has good insulation properties, and is easy to handle and environmentally safe. With a new nanotechnology, Alison Aerogel Panel GY06 Series combines the nano-sized silica aerogel with fibres which makes it a leading product in its range in Asia.

A team from the Norwegian University of Science and Technology has developed a unique hollow nanosphere for thermal insulation, the end-goal being energy efficient buildings. The nanospheres are hollow, and hence lightweight, thermal insulation. The researchers report that hollow silica nanospheres with a typical wall thickness of 10-15 nm and a pore diameter of about 150 nm gave low thermal conductivity (about 0.02 W/(mK)). When compared against these, traditional silica had thermal conductivity of 1.4 W/(mK) significantly higher. Customising the wall thickness and pore diameter reduced the thermal conductivity for the nano structured silica[384].

A team at Stockholm University in Sweden has developed thermally insulated nano vacuum panels to improve the energy efficiency of buildings. The materials are developed to challenge the conventional fossil-fuel-derived insulation materials which have high thermal conductivity and do not suit the requirements of current commercial buildings. Traditional vacuum insulating panels are prone to perforation. The researchers used cellulose nanofibres, graphene oxide and sepiolite nanorods to test the insulating properties of these materials in comparison to expanded polystyrene and other non-eco-friendly insulators. The nano-materials have proven to be highly fire-retardant and are much better in terms of insulating properties than polymer-based insulating materials. In addition, being nanomaterials, they are lightweight and have low thermal conductivity[385].

Company snapshot: Cabot

Cabot Corporation (NYSE: CBT), established in 1882, is a leading global specialty chemicals and performance materials company headquartered in Boston, Massachusetts, USA. Its products are for energy efficiency and process technology and include rubber and specialty carbons, caesium formate brines, activated carbon, aerogel, fine caesium chemicals, fumed metal oxides, graphenes, inkjet colorants, master-batches and conductive compounds. It also sells aerogel additives, which have more than twice the insulating performance of still air.

Aerogel has an open structure that allows vapour to readily diffuse through its matrix.

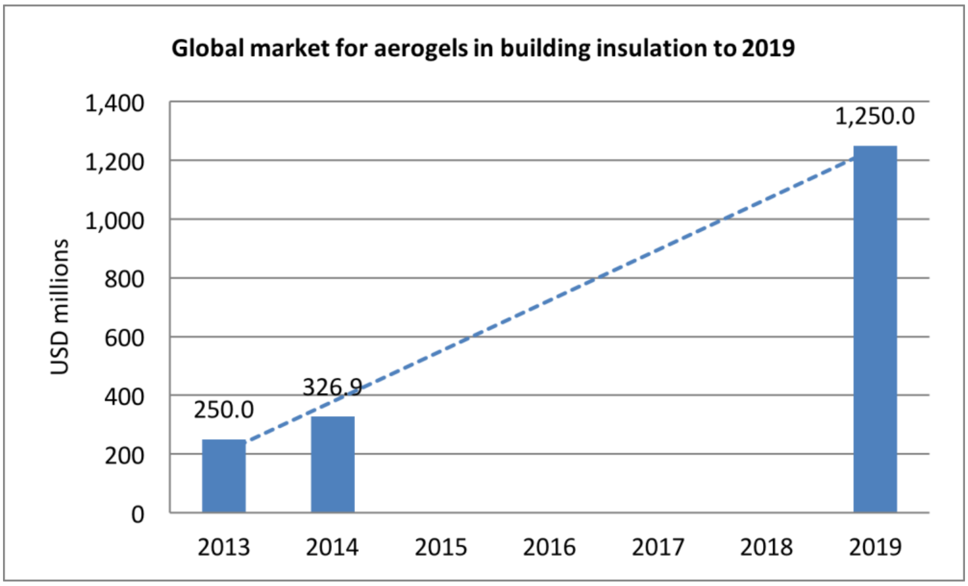
[378] www.aerogel.se/
[379] www.fixit.ch
[380] http://www.aerogel.com.au/
[381] The R-value depends on a solid material's resistance to conductive heat transfer.
[382] http://www.architectureanddesign.com.au/suppliers/aerogels-australia/ultra-thin-spaceloft-insulation-blankets-available
[383] http://www.ydalison.com/en/product/215.html
[384] https://www.researchgate.net/publication/258286511_Nano_insulation_materials_for_energy_efficient_buildings_a_case_study_on_hollow_silica_nanospheres
[385] http://www.nature.com/nnano/journal/v10/n3/abs/nnano.2014.248.html#author-information

Incorporating it into existing or new insulation materials can displace air and replace it with the superior performance of aerogel which enable insulation boards, blankets, plasters, coatings and composites to achieve previously unattainable thermal performance, increased space capacity, flexibility and higher moisture capacity. The company has 4,600 employs worldwide (in 2015) and according to its 2015 annual review the company had generated strong cash flow from operations of USD 499 million (EUR 444 million). It has around 126 patent families and around 120 publications.

http://www.cabotcorp.com/

MARKET DATA AND FORECASTS [386]

The global consumption of aerogel insulation materials has been estimated at USD 250 million in 2013. Over the next five years, the largest source of growth in the aerogel market is expected to be the commercialisation of aerogel building insulation. The global market for building insulation is currently estimated at about USD 20 billion. By 2017, it is projected to approach USD 29 billion. At present, aerogel insulation has about a 1.25% share of this market. Comparing with cellulose insulation, aerogels could take 10 years after introduction to capture a 15% share of the U.S. market. It seems unlikely that aerogel sales would go from USD 250 million in 2013 to USD 4.3 billion (i.e. 15% of the projected world market for building insulation), a nearly 20-fold increase, in just six years. However, a fivefold increase, to some USD 1.2 billion, might be achievable[387].



Source: BCC Research

Figure 9-10: Global market for aerogels in building insulation to 2019

Case study: Svenska Aerogel AB

Svenska Aerogel AB[388] is a Swedish SME that was founded in 2000 as a spin-off from the University of Gävle and the Royal Institute of Technology in Stockholm by two researchers from these institutions. In the first decade of its history, the company focussed on research and development and, in 2010, Svenska Aerogel AB made a breakthrough and started producing different grades of nanoporous silica-based aerogel material, Quartzene®.

[386] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, pp.177-178
[387] BCC Research (2014), Nanotechnology, a realistic market assessment, p.167
[388] http://www.aerogel.se/

Quartzene® is an input material that is then incorporated in different products by downstream users before it reaches the consumer. Three different versions of this aerogel have been developed to be used in insulation panels, paints and coatings or for filtration.

Svenska Aerogel AB received funding from Swedish soft loans, and Swedish and EU grants as well as private equity funding. Fundraising campaigns took place in 2009, 2010, 2012, 2014 and another campaign is planned for 2016. Since 2010, the company has relied equally on grants, soft loans and private equity funding (one third each).

Svenska Aerogel has received grants from VINNOVA, the Swedish innovation agency. In 2013, the programme granted SEK 500,000 for research and in 2014, the Forska & Väx programme of VINNOVA gave the company SEK 2.787 million to upscale its production. In 2013, Tillväxtverket (the Swedish Agency for Economic and Regional Growth) channelled to Svenska Aerogel another SEK 250 000 for product development.

Svenska Aerogel AB also joined two FP7 projects in 2013 under the theme Energy efficient buildings, nanosciences, nanotechnologies, materials and new production (EeB NMP). SESBE (smart elements for sustainable building envelopes) and H-House (healthier life with eco-innovative components for housing constructions) brought a total of EUR 836,000 to Svenska Aerogel AB as well as a chance to build a strong European network in consortiums. For the company, such projects are considered very important for it considers it 'very difficult or even impossible to rely solely on venture capital and soft loans'. At the moment, no patents have been filed as an output from these projects but it is not excluded for the future. Participating into such projects has also generated business leads with some potential customers. These two projects will end in 2017.

Svenska Aerogel AB is submitting proposals for further projects to other funding frameworks such as LIFE+ and the Horizon2020 SME Instrument.

Internationally, Svenska Aerogel AB cultivates links with the United States where a US-based investor serves as a lead funding generator, and with Asia.

Two patent families were filed by Svenska Aerogel AB in 2005 and 2014 in different countries including Sweden, the US, Canada, China and the European Union. These were funded internally and Svenska Aerogel AB still holds these patents, which are at the core of the business.

The company now works on customer-based research and development projects which are reaching the end of their term. For this reason, Svenska Aerogel AB expects to drastically increase its sales in the upcoming 6 months.

Svenska Aerogel AB grew from two to eleven staff members in 2015, and expects to hire up to four more staff members in the coming year. In 2016, the company will invest in production and plans to hire four or five new staff members.

Quartzene® does not consist of nanoscale particles. The product is in the micron range and it is the pores of this material that are nanometric. For this reason, Svenska Aerogel AB is not concerned by the uncertainties of the growing regulation around nanomaterials. The company nevertheless keeps an eye on the ongoing developments and enforces strict control measures to ensure both the safety of its workers and the quality of its product.

9.3.2.5 Nanocomposites: hydrophobic/oleophobic

Hydrophobic surfaces have established themselves as candidates for various engineering applications, including self-cleaning, anti-bio-fouling, anti-icing, anti-corrosion, drag reduction at micro- and macro-scales and textiles. Superhydrophobicity provides a pathway toward protecting sensitive properties of the surfaces, which can be easily affected by environmental factors such as rain, dirt, etc.[389].

[389] Asthana et al. (2014), Multifunctional Superhydrophobic Polymer/Carbon Nanocomposites: Graphene, Carbon Nanotubes, or Carbon Black? ACS Appl. Mater. Interfaces

Nanogate GmbH (Saarbrücken, Germany) has developed and markets a variety of products based on its proprietary hydrophobic/oleophobic nanocomposites. Little information is available on the composition of these nanocomposites. According to some published reports, the nanocomposite technology of Nanogate is based on a self-organising nanocomposite material that is created by breaking down a composite material consisting mainly of alcohol and sand into nanoparticles. Some of the resulting nanoparticles are adhesive and move naturally toward the substrate surface to which they adhere, whereas other anti-adhesive nanoparticles move toward the air, where they help to prevent dirt and grease from attaching themselves to the protective film. Nanoparticles with binding qualities keep the outside and inside layers of film together, creating a surface that is both hydrophobic and oleophobic[390].

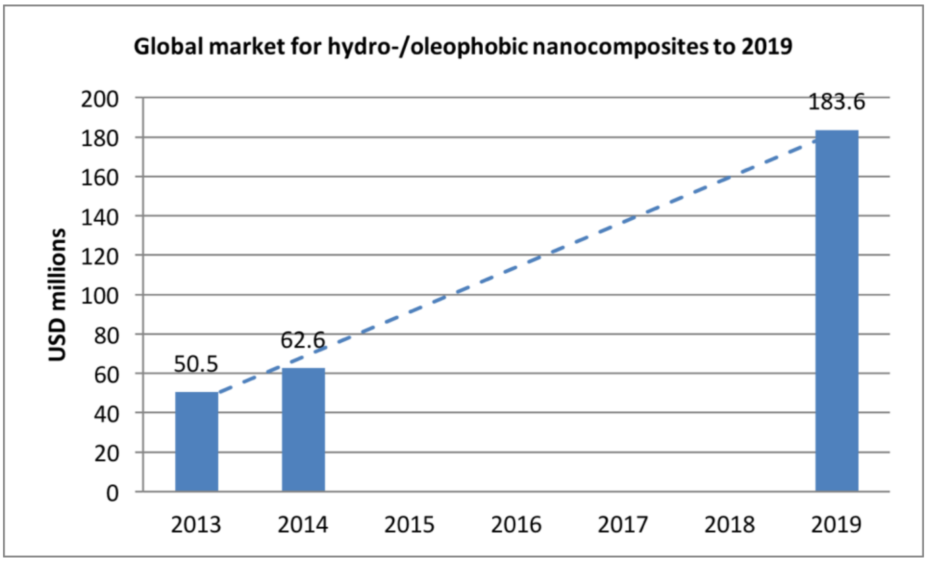
Wondergliss, is a coating developed by Duravit together with Nanogate AG. This coating has been used on sanitary ware ceramics e.g. at washbasins, toilets, bidets and urinals. WonderGliss deprives dirt of a suitable surface to attack - dirt and lime are unable to establish and hold on the smooth surface. Residues run off with the water droplets[391].

Villeroy Boch has a series of easy cleaning, hydro- and oleophobic products under the name of Ceramicplus. Ceramicplus provides an easy to clean and dirt repellent surface. This feature is obtained through a special finishing treatment[392].

MARKET DATA AND FORECASTS

Nanogate AG, the main supplier of hydrophobic/oleophobic nanocomposites, had sales of USD 50.5 million in 2013. In terms of volume, Nanogate sold 673 metric tons of its nanocomposite products at an average price of USD 75,000 per ton.

Nanogate's sales increased at a CAGR of 24% between 2014 and 2019. At this rate, consumption of hydrophobic/oleophobic nanocomposites is expected to reach USD 62.6 million in 2014 and USD 183.6 million by 2019. The cost-per-ton of the nanocomposites is projected to remain relatively constant at around USD 75,000 in real terms.



Source: BCC Research

Figure 9-11: Global market for hydrophobic/oleophobic nanocomposites to 2019

[390] BCC Research (2015), Global Markets for Nanocomposites, Nanoparticles, Nanoclays, and Nanotubes, p.66
[391] Duravit – Wondergliss Products User Manual
[392] https://pro.villeroy-boch.com/en/gb/bathroom-and-wellness/architects- planners/innovations/innovationen-detailseiten/ceramicplus.html

Case study: Nanogate AG

Nanogate was founded in 1999 as a spin-off from the Leibniz Institute for New Materials (INM) in Saarbrücken and changed in 2006 to an AG (a public limited company). The Nanogate Group consists of the parent company Nanogate AG, Quierschied-Göttelborn, and the consolidated portfolio companies Nanogate Industrial Solutions GmbH (NIS), Quierschied-Göttelborn, GfO Gesellschaft für Oberflächentechnik AG, Schwäbisch Gmünd, Nanogate Textile & Care Systems GmbH (NTCS), Quierschied-Göttelborn, and Plastic-Design GmbH, Bad Salzuflen. The shares in Eurogard B.V., Geldrop, the Netherlands, and Nanogate Glazing Systems B.V., Geldrop, the Netherlands, are pooled in the intermediate holding company Nanogate Nederland B.V., Geldrop, the Netherlands. In July 2014, the Nanogate Group acquired all of the shares in surface specialist, Vogler, which now trades under the name Vogler GmbH, Lüdenscheid. At the end of 2015, Nanogate AG transferred all of the shares in Vogler GmbH to Nanogate Industrial Solutions GmbH. Following the end of the reporting period, the Group also acquired a 75 % stake in plastics specialist Walter Goletz GmbH.

Nanogate is a leading international integrated systems provider for high-performance surfaces. The Group enables the programming and integration of additional properties – such as non-stick, scratchproof and anti-corrosive – into materials and surfaces. Nanogate opens up the diverse possibilities of multifunctional surfaces based on new materials for companies in a wide range of industries.

Nanogate concentrates on the sectors of automotive/mechanical engineering, buildings/interiors, sport/leisure and functional textiles as well as on the strategic growth areas of innovative plastics (e.g. glazing) and energy efficiency. The Group focuses primarily on optically high-quality plastic and metal coatings for all surface types (two and three-dimensional components). Its value drivers are the opening up of new, international markets, the development of new applications for the strategic growth areas of innovative plastics (e.g. glazing) and energy efficiency, as well as external growth. In the medium term, Nanogate also intends to achieve a considerable revenue share from environmentally friendly systems. Nanogate has first-class references (Airbus, Audi, August Brötje, BMW, BSH Bosch und Siemens Hausgeräte, Daimler, FILA, Jaguar, Junkers, Porsche, Volkswagen). Several hundred projects have already gone into mass production. The company also has strategic partnerships with many international corporations.

As of 31st December 2015, Nanogate Group had 586 employees. Nanogate increased sales in the 2015 financial year by about 30 % to over EUR 90 million (previous year: EUR 68.6 million). Overall performance exceeded EUR 94 million (previous year: EUR 71.1 million). In the expansion of its volume of business, the Group benefited from strong demand for systems in its strategic application areas of advanced metals and advanced polymers, as well as from consolidation effects and strong end-of-year business. The operating result (consolidated EBITDA) improved by around 35 % to over EUR 10 million (previous year: EUR7.4 million). Consolidated EBIT totalled more than EUR 2.8 million (previous year: EUR 2.5 million).

Nanogate will continue its expansion strategy in the 2016 financial year, focusing on extending its range of applications. Production relating to the new technology platform for the multifunctional metallisation of surfaces, primarily of plastics, should therefore begin in the course of the year. The Group is investing in the high single-digit million range in setting up production facilities and in its centre of excellence for high-quality metal applications, which was opened in 2015.

Nanogate is again optimistic about the current 2016 financial year. On the basis of existing projects as well as the majority acquisition of plastics specialist Goletz, the Group expects to see a substantial increase in sales to more than EUR 105 million. The Group would therefore exceed its medium-term sales target of EUR 100 million initially announced in 2014, reaching an important milestone in its Phase5 growth strategy, having generated sales of EUR 53 million in 2013. Despite the continued expenses associated with the expansion strategy as well as the one-off transaction and integration costs, the Group also expects the operating result (EBITDA) to increase significantly in 2016 and exceed the EUR 12 million mark. Substantial funds will continue to flow into the ongoing investment programme and international expansion. In view of the growth strategy, consolidated net income will continue to be shaped by depreciation and amortisation as well as financing costs.

Nanogate expanded its expertise and applications portfolio again in 2015. The Group's R&D ratio therefore came to 10 % in the reporting year (2014: 11 %). The company will continue this course in the current financial year. As a result, significant funds are currently flowing into the strategic growth areas of advanced metals and advanced polymers. With the expanded range, the Group is exploiting the opportunities offered by the growing demand for multifunctional high-performance surfaces. In doing so, the company is primarily concentrating on the further development of existing technologies and on customer projects. The Group is currently focusing on the set-up and market launch of the new N-Metals® Chrome technology platform, which is scheduled to commence operations in the course of 2016.

For reasons of efficiency, Nanogate collaborates on fundamental and applied research with recognised research institutes, such as the Leibniz Institute for New Materials (INM) in Saarbrücken, the plastics technology department of the Kaiserslautern University of Applied Sciences, the Öko-Institut Freiburg and the Kunststoff-Institut Lüdenscheid. Nanogate has furthermore successfully participated in projects within the EU's Sixth and Seventh Framework Programmes (FP6 and FP7).

To secure its competitive edge and to protect its ongoing innovation partnerships, Nanogate regularly reviews its patent portfolio, considering costs and future benefits, and pursues a market-oriented patent strategy. As at the end of 2014, the Group was in possession of 81 patents. Nevertheless, for reasons of cost, the company allows patents that are no longer required to expire. From the Group's perspective, internal expertise, especially in procedures and processes, is becoming increasingly more important than individual property rights.

9.3.2.6 Conductive Fibre

TECHNOLOGY AND PRODUCTS

Thread spun from polyvinyl alcohol (PVOH) in which single-wall nanotubes have been dispersed is a candidate to meet at least some of the growing demand for conductive fibre in smart and interactive textiles applications such as built-in furniture controls[393].

MARKET DATA AND FORECASTS[394]

It has been forecast that the global market for conductive fibre will grow from approximately USD 60 million in 2013 to more than USD 3 billion in 2019. If they are commercialised, carbon nanotube fibres could compete for this market with non-nanoconductive fibre such as coated yarns and fibres made from pure (i.e., noncomposite) nanotubes. PVOH/SWNT composites could capture 10% of the market for conductive fibres, worth at least USD 300 million, by 2019, while CNT based fibres could reach USD 75 million.

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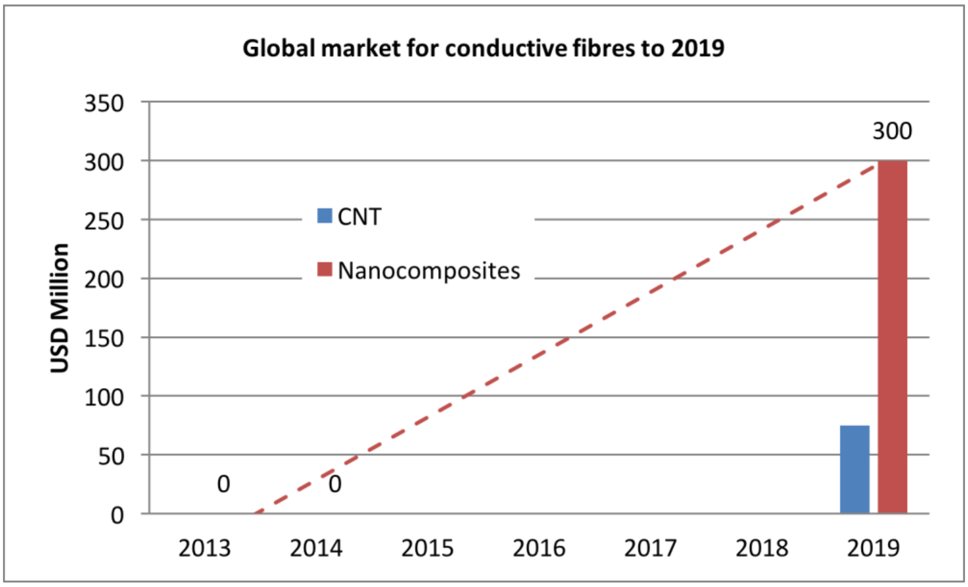
[393] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.144
[394] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.186



Source: BCC Research, 2014

Figure 9-12: Global market for conductive fibres to 2019

9.3.2.7 Wire and cable sheathing

TECHNOLOGY AND PRODUCTS

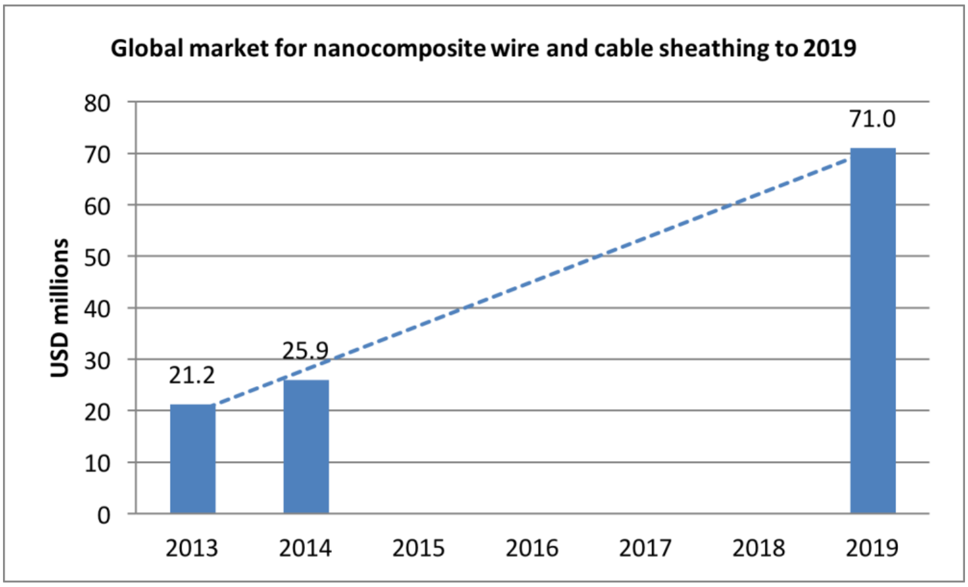
One of the best-known commercial applications of clay nanocomposites is EVA/montmorillonite wire and cable sheathing materials. In addition, Nanocor has developed a PP/montmorillonite concentrate for use in heavy-duty electrical enclosures that must meet various fire ratings[395].

MARKET DATA AND FORECASTS[396]

Consumption of EVA/clay nanocomposite material for wire and cable sheathing and other fire-retardant applications has been estimated at USD 21.2 million in 2013, 0.37% of the USD 5.7 billion global flame-retardant market.

According to industry sources, the global market for flame retardants is expected to grow at a CAGR of 9% over the next five years, reaching USD 9.6 billion by 2019. EVA/clay nanocomposites could increase their share of this market significantly, due to an environmentally motivated switch away from halogenated fire retardants. To illustrate the market potential of EVA/montmorillonite fire retardants, if they succeed in doubling their market share from 0.37% in 2013 to just 0.74% in 2019, sales could reach USD 71 million by 2019.

[395] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.84
[396] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.177



Source: BCC Research

Figure 9-13: Global market for nanocomposite wire and cable sheathing to 2019

9.3.2.8 Concrete and Cement

TECHNOLOGY AND PRODUCTS

Cement is the basic material of concrete, an indispensable and traditional building material since the Stone Age. Cement is made by crushing and grinding calcium carbonate (limestone) and other materials containing silicon, aluminium and iron oxides. The blended material is heated at extremely high temperatures (1400-1500°C) in a kiln where the compounds react. Products leave the kiln in the form of a nodular material which is called clinker. Later on, clinker is cooled and ground with small portions of gypsum, fly ash, aggregates and other additives to produce cement. To be used for construction applications cement is combined with sand, gravel and water to form concrete[397]. Concrete is a very versatile material which can be adapted to meet different needs like durability, enhanced ductility, improved thermal and acoustic insulation. It is made from natural raw materials with impurities and variability in the materials size ranging from nanometres to centimetres. Concrete is reinforced with metal bars, glass fibres, etc. to increase its strength[398].

Nanoparticles and materials offer interesting possibilities for the optimisation of cement-based materials. This involves the optimisation of strength and durability e.g. by increasing its resistance to microbial growth and crack progression. As the strength of concrete is based on its nanometre-size crystal structure, the use of nanoparticles as an additive, combined with new insights into crystal structure mechanics, has provided many new ideas for the improvement of cement based products[399]. The use of nanoparticles in cementaceous and concrete materials concentrates on TiO_2 and silica fume. Both additives are used in small quantities or in a two-layer system and only when specifically required for performance reasons because of the costs involved. Examples of products on a basis of silica fume that are currently at the market include Chronolia™, Agilia™ and Ductal™ by Lafarge and EMACO®Nanocrete by BASF[400]. Some products are described below:

- Chronolia™ is a quick-setting ready-mix concrete made possible by nanotechnology and the understanding of crystalline growth. Agilia™ was the world's first self-compacting, self-levelling concrete, while Ductal™ is one of the first commercial concrete where steel bars are not used.

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[397] ObservatoryNano (2009), Economical Assessment / Construction sector, Final report, p.15
[398] Ibid
[399] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.32
[400] http://nano.elcosh.org/index.php?module=NanoProduct&id=4&title=Ductal%E2%84%A2

It exhibits high mechanical strength, durability and self-healing properties [401].

- EMACO®Nanocrete by BASF (Ludwigshafen, Germany) is a concrete-repair concrete with exceptional properties, improved bond strength, improved densities and impermeability, reduced shrinkage, improved tensile strengths and reduced cracking tendency. It also provides improved compatibility with concrete over previous products[402].
- TX Active® by Italcementi and Heidelberg Cement can reduce organic and inorganic pollutants that are present in the air by photocatalysis. Its formulation is the result of ten years of research, tests and applications by CTG, Group Technical Centre, a company in the Italcementi Group, to reach the final formulation[403]. Italcementi offers two products with the TX label: TX Arca and TX Aria. TX Arca cement is specifically designed for the construction of prestigious architectural works. The decomposition of micro-organisms responsible for dirtying façades, the growth of which is promoted by the accumulation of fats, particulate matter and rain, ensures that surfaces remain clean. TX Aria is a binder for paints, mortars and smoothing materials, plasters & renders, concrete for photoactive building elements, capable of resisting the adhesion of unwanted substances produced by human activities (industry, transport and residential heating systems)[404].
- Vicon Ecosystems[405] (USA) has developed a nano-based eco-cement. Vicon is among the first cement companies in the USA to apply nanotechnology in their products. The advanced concrete cement is produced using proprietary nanomaterials that impart high performance and environmental benefits. The proprietary formulations for the nanocement ensures its sustainability as well as other attributes such as enhanced durability, lower cost, and even lower weight. The cement is made by encapsulation technologies of nanomaterials and even negates low level radon.

Case study: Italcementi

Italcementi is an Italian multinational company which produces cement, ready-mix concrete and construction aggregates. In 2015, it was the world's sixth-largest cement producer and the third in Europe after the French-Swiss LafargeHolcim and the German HeidelbergCement[406]. It has a staff of more than 20,000 employees, 42 cement plants and an annual production capacity of 60 million tons. In 2015, the Group reported consolidated revenues of EUR 4.3 billion. 400 employees from its workforce are engaged in technical support and research activities under the Groups Technical Centre CTG Spa (Centro Tecnico di Gruppo)[407].

Italcementi was founded in 1864 and has been listed on the Italian Stock Exchange since 1925[408]. Until the early 1990s, Italcementi was the market leader in the cement market in Italy, concentrating on the domestic market where both competition and demand for product innovation were relatively weak. Italcementi's research activities were confined to the company's in-house technical support centre, improving internal production processes and product reliability for general construction uses. Rare attempts to launch innovative products failed to generate meaningful customer interest.

Italcementi sensed the need to alter its approach to innovation with the advent of globalisation and in particular with changes in EU legislation in 1991 that lowered the entry barriers to national markets. Their first step was to integrate the expertise from leaders in other markets

[401] Concretes for the 21st Century, Lafarge www.lafarge.com/lafarge/CONTENT_SHEET/20070612/06122007-press_themabookextensia_
chronolia-uk.pdf
[402] www.emaco-nanocrete.com
[403] http://www.italcementigroup.com/ENG/Research+and+Innovation/Innovative+Products/TX+Active/
[404] Ibid
[405] http://www.viconecosystems.com/
[406] The top 100 global cement companies and global per capita ... 2015. 20 Apr. 2016 (http://www.globalcement.com/magazine/articles/964-preview-the-top-100-global-cement-companies-and-global-per-capita-capacity-trends)
[407] Italcementi Group profile, 31 Dec. 2014 (http://www.italcementigroup.com/NR/rdonlyres/0F6719F2-B57D-490C-A607-ADB130015C09/0/ItalcementiGroupprofile_311215.pdf)
[408] The Open Innovation Model. International Chamber of Commerce (http://www.iccwbo.org/Data/Documents/Intellectual-property/THE-OPEN-INNOVATION-MODEL/)

with the acquisition in 1992 of the French enterprise Ciments Français and then adopting new strategies to maintain competitiveness through innovation[409]*. For this purpose, the company created new innovation facilities, including a distinct R&D unit, a network of academic researchers, an Intellectual Property (IP) function and a scientific committee composed of academic professors.*

It is in 1995 that Italcementi further develops its strategy to distinguish the company through innovation, launching a major project named the "TX project" to enhance its innovative potential. The TX project was based on the idea of mixing traditional cement with photo-catalytic nanoparticles able to capture and neutralize polluting gases from the external environment. To obtain the necessary chemical knowledge for this project, the company engaged in an open innovation process by establishing formal relationships with a number of leading Italian research institutions. This meant that research projects multiplied and the company had to adapt its ICT systems to more effectively manage cross-functional teams across different countries. As a result, Italcementi strengthened the in-house IP function and began filing for patents. The first patent was filed in 1996 with the following title "Hydraulic binder and cement compositions containing photocatalyst particles". Nowadays, Italcementi together with the French enterprise Saint-Gobain Glass are among the top owner of patents in photocatalytic applications. In total, (not only nanotechnology related patents) the Group has filed 92 patents since 1992[410]*.1998 was the year in which the first meaningful application of photocatalytic concrete was carried out: the church "Dives in Misericordia" in Rome designed by the architect Richard Meier and made by white precast photocatalytic concrete panels in order to preserve the aesthetics of the building*[411]*.*

In 2002 Italcementi took part in a collaborative project named PICADA (EUR 1.9 million) and funded by the EU FP5[412]*. PICADA aimed at developing and assessing coverings for de-pollution based on photocatalysis. The photocatalytic performances of the products developed were tested first at laboratory scale and then in different real situations. It is in 2005 that Italcementilaunches TX Millennium, its first version of photocatalytic cement. Later on, Italcementi launched two product lines based on TX Active (TX Aria with depolluting effect and TX Arca with self-cleaning effect), the active principle with photocatalytic properties developed by the company. The TX Project, which led to the development of the TX Active principle, required an investment of EUR 10 million. Half of this budget (EUR 5 million) came from the EU within the framework of on-going research and innovation programs.*

Following the success of TX Project Italcementi further embraced an open innovation paradigm when it opened a new research centre named "i.lab" in the Kilometro Rosso Science Park near Bergamo[413]*. This centre aims at exploiting cross-fertilization in the presence of research labs of firms from different industry sectors (mechatronics, ICTs, biotechnology, energy and environment, etc.). The centre hosts about 170 people between engineers, technicians and researchers from the R&D and Laboratories of the Group's Technical Centre CTG and also from Italcementi's Innovation Direction, all engaged in investigating and developing innovative technological, functional and aesthetic solutions for new construction materials. An annual budget of 13 million euro is allocated to R&I activities, about 0.5% of the Group's turnover. The Groups' innovation rate (ratio of revenues generated by innovation projects to total sales) is equal to 4 and is increasing to achieve a target rate of 5 in the medium to long term*[414]*.*

The Group's research activity is structured as a synergistic network of international scientific partnerships involving research centres, universities and enterprises from the building materials and construction industry. At present, the network is comprised of 10 external

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[409] Ibid

[410] NANOfutures project: A cross-ETP Coordination Initiative on Nanotechnology (http://www.nanofutures.eu/sites/default/files/Successful_cases_on_nanotechnology_0.pdf)

[411] "Dives in Misericordia", the church of the Third Millennium http://www.italcementigroup.com/NR/rdonlyres/38BC84DA-6F1C-476B-A827-22E67B61AEC1/0/DivesinMisericordia_UK.pdf

[412] PICADA Project: http://www.picada-project.com

[413] I.Lab The heart of innovation: http://www.italcementigroup.com/NR/rdonlyres/096FC255-89F7-46BC-B1B7-511EEC9861B1/0/Booklet_UK.pdf

[414] Italcementi Group: Research and Innovation (http://www.italcementigroup.com/ENG/Research+and+Innovation)

centres, 30 enterprises and 26 universities in Italy, Europe and in other non-European countries.

Since 2006, Italcementi increased considerably the involvement of customers in its innovation activities, creating new organizational units that allow the company to evaluate the commercial potential of innovation products, to receive rapid feedback on their practical use, and to co-develop ad hoc solutions if necessary[415]. The company also began designing long-term IP strategies, making them an integral part of its business development plans.

Market data and forecasts [416]

No market data are available for nano-enabled concrete and cement products.

The next section looks at the wider environment for nanotechnology and construction – regulation and standards, environmental health and safety issues, communication and public attitudes.

[415] The Open Innovation Model. International Chamber of Commerce (http://www.iccwbo.org/Data/Documents/Intellectual-property/THE-OPEN-INNOVATION-MODEL/)
[416] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.132

10 THE WIDER ENVIRONMENT FOR NANOTECHNOLOGY AND CONSTRUCTION

10.1 Regulation and standards for nanotechnology

The use of nanotechnology in construction has implications for three main areas of regulation: construction products; occupational health and safety aspects of construction work; and compliance with environmental performance legislation for new construction.

10.1.1 European regulations for nanotechnology

In Europe, construction products are covered by the Construction Products Regulation (CPR) 305/2011. This legislation establishes the European rules for marketing construction product. It contains provisions on the CE marking of construction products, and sets up a system of notified bodies as well as a system of harmonised technical specifications for construction products.

CPR defines a construction product as follows:

Article 2(1): A 'construction product' means any product or kit which is produced and placed on the market for incorporation in a permanent manner in construction works or parts thereof and the performance of which has an effect on the performance of the construction works with respect to the basic requirements for construction works.

This regulation evaluates the environmental impact of construction products but does not specifically cover nanomaterials. Nanomaterials used in construction must also comply with the overarching regulatory framework in place for chemical substances: *Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)*, and CPR specifically refers to REACH. However, recital 25 of the CPR states that '*the specific need for information on the content of hazardous substances in construction products should be further investigated with a view to completing the range of substances covered so as to ensure a high level of protection of the health and safety of workers using construction products'.*

With the *first Regulatory Review on Nanomaterials SEC (2008) 2036* and the *Second Regulatory Review on Nanomaterials SWD (2012) 288 final*, the European Commission has given REACH a central role in regulating nanomaterials. *"There are no provisions in REACH referring explicitly to nanomaterials. However, nanomaterials are covered by the 'substance' definition in REACH",* states the 2008 EC Communication. A third Regulatory Review is planned in 2016.

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. However, the rules of ECHA (the European Chemicals Agency) prevent the modification of the regulation two years prior to the next round of registration, which is set for 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
- Guidance on read-across for nanoforms.

One of the milestones of the European regulatory framework is the *European Commission Recommendation on the Definition of a Nanomaterial.* This non-binding document has been used by other pieces of regulation that needed to define the term 'nanomaterial'.

The definition is the following:

"2. '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 with a planned conclusion date of December 2014. An outcome of this review could be a revision of the definition. The process of review of this definition is still ongoing.

Construction workers are also covered by occupational health and safety legislation. Under the European Framework Directive on Safety and Health at Work (Directive 89/391 EEC), employers are required to assess and manage the risks of nanomaterials for their workers. While nanomaterials are not expressly covered by the directive, the European Agency for Safety and Health at Work (EU-OSHA), dedicates a part of its work to nanomaterials.

In 2013, the Agency published *E-Fact 74 Nanomaterials in Maintenance Work: Occupational Risks and Prevention.* A fact sheet on the use of nanomaterials in maintenance work which according to which it 'could be the main activity for construction workers'. The fact sheet notes the lack of information on nanomaterials accessible to workers on Safety Data Sheets, depending directly on REACH and CLP.

Finally, the building industry must comply with the Energy Performance of Buildings Directive –EPBD (2010/31/EU) and the Energy Efficiency Directive (2012/27/EU). With this directive, the European Union set a target for all new buildings to be nearly zero-energy by the end of 2020. EU Member States are required to set minimum energy performance requirements as well as independent control systems. In order to attain these objectives, the European Regional Development Fund (ERDF) and the European Investment Bank (EIB) support the investment in energy-efficient materials, which may include nanotechnology innovations.

An overview of regulations for nanotechnology use in Europe is given below, followed by information about nanoregistries.

Table 10-1: Overview of regulations for nanotechnology use in Europe

Status	Name of the document	Country /Region	Scope	Nano-specific
Implemented	Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (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

Nanomaterial registries

While the European Union has been developing a regulatory framework for nanomaterials under REACH, some European Member States have sought to find additional ways to 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 European Union has opened the discussion on a 'harmonised database of nanomaterials'. This was followed by a 2012 letter to the European Commission calling for a European Reporting Scheme and signed by ten European Member States, plus Croatia. The European institutions are still weighing up the pros and cons of such a reporting scheme. Nevertheless, some European Member States have been proceeding.

In addition, as part of the electoral promises of the 2007 French Presidential Elections, the 'Grenelle de l'Environnement', a large environmental debate was organised in France and resulted in two major environmental acts, the *Grenelle Acts (Lois Grenelle I & II),* that 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[417] 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 2015 report of r-nano[418] identified 122 declarations referring to the use code su19, Building and Construction work. This represents 0.81% of the total registrations that year.

The Belgian FPS (Public Health, Food Chain Safety and Environment) has also 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.

In June 2014, 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. 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.

Other EU Member States and associated countries have been considering options for a registration scheme for nanomaterials. Norway is considering such a register under its Pollution Control Authority (SFT). Since 2013, the Norwegian Product Register has required information for chemicals containing 'a substance in nano form' with a 'tickbox' system. 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 to establish 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 leading the way and encouraging 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 RPA and BiPro. Three reports were published to help the EC to 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

[417] 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

[418] Ministère de l'Environnment de l'Energie et de la Mer. 2015, *Bilan 2015 des déclarations des substances importées, fabriquées ou distribuées en France en 2014*. Available at ; http://www.developpement-durable.gouv.fr/IMG/pdf/Rapport_public_R-nano_2015.pdf

nanomaterials and their use in Europe.

10.1.2 Nanotechnology regulation in the rest of the world

No country has currently developed specific legislation to cover the use of nanomaterials in construction.

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 record-keeping 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 Autumn 2016.

The 2013 American Occupational Safety and Health Administration fact sheet on *Working Safely with Nanomaterials* states that nanomaterials fall under OSHA Construction Standards.

In Canada, Health Canada and Environment Canada have been looking at similar approaches. Canada requires manufacturers and importers to register information on a selection of 206 substances at the nanoscale under the *Canadian Environmental Protection Act (CEPA 1999*).

10.1.3 Standardisation and nanotechnology

The International Organisation for Standardisation (ISO) technical committee on nanotechnologies, ISO/TC 229 Nanotechnologies, has not directly addressed construction in its work.

However, at ISO level, a number of technical committees cover areas linked to construction. The main committees are: ISO/TC 59 Buildings and civil engineering works, ISO/TC 195 Building construction machinery and equipment, and ISO/TC 205 Building environment design. Standards covering construction developed in these and other technical committees are gathered under the International Classification for Standards (ICS) code 91: Construction materials and building. At the moment, however, these do not provide for the use of nanotechnologies in these products.

In Europe, the European Committee for Standardisation (CEN) committee on nanotechnology (CEN/TC 352) is currently working on a technical report dealing with the construction sector. Tentatively entitled: '*Manufactured nanomaterials (MNMs) in the construction industry. Guidelines for occupational risk management'* this project is being developed under Working Group 3: Health, safety and environmental aspects. It originates from the SCAFFOLD[419] project of the European Union Seventh Framework Programme for Research (FP7), which aimed to develop 'innovative strategies, methods and tools for occupational risks management of manufactured nanomaterials in the construction industry'. The project produced a toolkit for risk management and is looking to translate its findings into a standardised guidance document.

Over 80 technical committees are dealing with construction at CEN[420]. However, these have not yet produced standards dealing with the use of nanotechnology in construction.

[419] SCAFFOLD ; http://scaffold.eu-vri.eu/
[420] See CEN website: https://www.cen.eu/work/areas/construction/products/Pages/default.aspx

10.2 Environment, health and safety and nanotechnology

Exposure to nanomaterials in the construction sector may be quite diverse. Seven categories of categories of construction materials were identified within the NanoData project. All combinations of nanoparticles and sectors were evaluated. The basis for the evaluation was "Stoffenmanager Nano" application[421, 422, 423], a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to hazardous nanoparticles for a broad range of worker scenarios.

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[424]. 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[425]. However, nanoparticles as such are very unlikely to penetrate the skin[426] and consequently nano-specific systemic toxicity via the dermal route is improbable. Therefore, when evaluating risks from nanotechnology for the respiratory route, the most important aspects of occupational and consumer safety are covered.

10.2.1 Hazard assessment of nanoparticles

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). The table below presents an overview of nanoparticles (selected for their use in the construction sector) and their hazard bands, either taken from le Feber et al. (2014)[427] or van Duuren et al. (2012)[428] or derived in this project.

[421] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles. TNO2014 R11884.

[422] 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.

[423] 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.

[424] 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.

[425] Ibid

[426] 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

[427] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles. TNO2014 R11884.

[428] 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.

Table 10-2: Hazard bands for the specified nanoparticles

Nanoparticles	Hazard band	Source
Carbon nanotubes	E	This report
Carbon nanofibres	D	This report
Copper	D	This report
Graphene	E	This report
Graphite nanoparticles	E	This report
Iron oxide	D	This report
Molybdenum	C	van Duuren et al. (2012)
Silicon carbide	C	This report
Silicon dioxide (silica), crystalline	E	van Duuren et al. (2012)
Silicon dioxide (silica), synthetic amorphous	C	le Feber et al. (2014)
Titanium dioxide	D	le Feber et al. (2014)
Tungsten oxide	E	van Duuren et al. (2012)
Vanadium pentoxide	E	van Duuren et al. (2012)
Zinc oxide	B	le Feber et al. (2014)

Details of the hazard bands derived for each material are given below.

CARBON NANOTUBES (CNTS), SINGLE- (SWCNTS) AND MULTI-WALLED (MWCNTS)

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.

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). 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. In addition, 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, although MWCNTs 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.

Based on the data summarised above, there are indications that carbon nanotubes are mutagenic and carcinogenic while some can be classified as persistent fibres. Therefore, they are consigned to the highest hazard band, E.

CARBON NANOFIBRES (CNFS)

CNFs are related to CNTs[429, 430]. The former consist of stacked graphite platelets, while the latter consist of graphite platelets rolled up in cylinders. Due to their graphitic structure, CNFs are highly insoluble, and thus highly bio persistent, and are not expected to be broken down when inhaled[431].

[429] Fubini, B., Fenoglio, I., Tomatis, M., Turci, F., 2011. Effect of chemical composition and state of the surface on the toxic response to high aspect ratio nanomaterials. Nanomedicine (Lond). 6, 899–920. doi:10.2217/nnm.11.80

[430] NIOSH, 2013. Current Intelligence Bulletin 65. Occupational exposure to carbon nanotubes and nanofibres. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Washington DC, USA.

[431] Fubini, B., Fenoglio, I., Tomatis, M., Turci, F., 2011. Effect of chemical composition and state of the surface on the toxic response to high aspect ratio nanomaterials. Nanomedicine (Lond). 6, 899–920. doi:10.2217/nnm.11.80

The *in vitro* toxic properties of CNFs have been summarised[432] in comparison with carbon black, an extremely fluffy fine powder with a large surface area composed of elemental carbon (IARC, 2010), and CNTs. The most important observations are mentioned below.

Several studies show that the cytotoxicity of CNFs is very low. The sequence of increasing potency for carbon black, CNTs and CNFs is: carbon black < CNFs < CNTs.

Carbon nanofibres also have a low inflammatory potential. While CNTs induced a dose-dependent increase in DNA damage at all dose and treatment times, CNFs induced DNA strand breaks and chromosomal damage in human bronchial epithelial only after a long time of treatment with no dose dependence. However, CNFs containing iron impurities (<1.4% wt) showed a genotoxicity comparable with asbestos and stronger than SWCNTs[433]. Exposure to CNFs can cause respiratory effects similar to those observed for CNTs. CNFs are a less potent inflammatory agent than MWCNTs and of comparable potency as carbon black.

Concluding, CNFs appear to be of comparable toxicity with carbon black and are less toxic than MWCNTs. Since MWCNTs are attributed to hazard band E and carbon black to hazard band D in Stoffenmanager Nano (Van Duuren-Stuurman et al., 2012), carbon nanofibres are placed in hazard band D.

COPPER

No *in vivo* inhalation toxicity studies adequate for toxicological risk assessment of metallic copper nanoparticles were identified in public literature. As metallic copper is insoluble in water, classification of the bulk material could be used to derive a hazard band for metallic copper nanoparticles. Bulk copper is not classified for human toxicological endpoints, which would mean it should be attributed hazard band C (Van Duuren-Stuurman et al., 2012). However, the ECHA registration dossier explicitly mentions the classification is only applicable to copper powders, with particle size > 10µm and <1 mm. Furthermore, like e.g. silver nanoparticles, copper nanoparticles are antimicrobials whose effectiveness increases with decreasing size[434, 435] suggesting that nanocopper, like nanosilver, is more toxic than its bulk counterpart. Comparative *in vitro* evaluation of cytotoxicity showed nanocopper to even be slightly more cytotoxic than nanosilver[436]. Nanosilver has been attributed hazard band D[437] and based on the comparison mentioned above, nanocopper is attributed the same hazard band.

GRAPHENE

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)[438].

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

[432] Ibid

[433] Fubini, B., Fenoglio, I., Tomatis, M., Turci, F., 2011. Effect of chemical composition and state of the surface on the toxic response to high aspect ratio nanomaterials. Nanomedicine (Lond). 6, 899–920. doi:10.2217/nnm.11.80

[434] Nuñez-Anita, R.E., Acosta-Torres, L.S., Vilar-Pineda, J., Martínez-Espinosa, J.C., de la Fuente-Hernández, J., Castaño, V.M., 2014. Toxicology of antimicrobial nanoparticles for prosthetic devices. Int. J. Nanomedicine 9, 3999–4006. doi:10.2147/IJN.S63064

[435] Schrand, A.M., Rahman, M.F., Hussain, S.M., Schlager, J.J., Smith, D.A., Syed, A.F., 2010. Metal-based nanoparticles and their toxicity assessment. Wiley Interdiscip. Rev. Nanomed. Nanobiotechnol. 2, 544–68. doi:10.1002/wnan.103

[436] Lanone, S., Rogerieux, F., Geys, J., Dupont, A., Maillot-Marechal, E., Boczkowski, J., Lacroix, G., Hoet, P., 2009. Comparative toxicity of 24 manufactured nanoparticles in human alveolar epithelial and macrophage cell lines. Part. Fibre Toxicol. 6.

[437] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles

[438] 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.

retention, and relatively long circulation time in the blood[439].

Currently, limited information about the *in vitro* and *in vivo* toxicity of graphene is available[440]. 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[441].

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[442]. Single intravenous (i.v.) injection of graphene oxide into mice accumulated in the lung resulting in pulmonary oedema and granuloma formation[443]. Furthermore, surface functionalised graphene (PEGylated) appears to be far less toxic: no toxic effects after single i.v. injection[444]. 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[445].

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* experiments), dose, time of exposure, and synthesis methods[446]. Generalisations are therefore hard to make, but graphene nanostructures are not fibre-shaped and theoretically may be assumed to be safer than carbon nanotubes[447].

Based on the scarce available evidence, and in spite of its theoretical advantage in relation to carbon nanotubes, it cannot be excluded that some forms of graphene will be as potent a toxicant as carbon nanotubes. Therefore, graphene is assigned to hazard band E.

GRAPHITE NANOPARTICLES

Graphite is one of only three naturally-occurring allotropes of carbon (the others being amorphous carbon and diamond) and has a honeycomb lattice structure. For some researchers, nanographite

[439] 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.

[440] 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.

[441] Nezakati, T., Cousins, B.G., Seifalian, A.M., 2014. Toxicology of chemically modified graphene-based materials for medical application. Arch. Toxicol. 88, 1987–2012

[442] 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.

[443] 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

[444] 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.

[445] 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.

[446] 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.

[447] 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.

is synonymous with graphene[448], while others[449] make a distinction between graphene and graphite nanoplatelets, without being specific on how the one is distinguished from the other, both possessing the hexagonal graphite structure at the molecular level. As long as the distinction between nanographite and graphene is not clear, it is considered to be one of the many forms of graphene and evaluated in that category (see section above).

IRON OXIDE

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm)[450]. 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.

MOLYBDENUM

No relevant toxicity studies on nano-molybdenum were identified in public literature. It is insoluble in water and therefore, applying the methodology of van Duuren et al. (2012)[451], the hazard characteristics of the parent material are used. Molybdenum is classified by a considerable number of CLP-notifiers as a suspected reprotoxicant (category 2) (affecting reproduction) as confirmed by the WHO[452]. Based on the self-classification of (bulk) molybdenum as a reprotoxicant, nanomolybdenum should be placed in hazard band E according to the criteria of Stoffenmanager Nano[453].

SILICON CARBIDE (SIC)

SiC occurs in several forms: (spherical) particles, fibres, and whiskers. SiC particles are manufactured (mostly for use as industrial abrasive) mainly by the Acheson process, with SiC fibres being unwanted by-products. SiC fibres are generally poly-crystalline and of variable length and diameter. They may include fibres that are indistinguishable from whiskers. SiC whiskers are intentionally produced by different processes as durable industrial substitutes for asbestos; they are physically homogeneous and monocrystalline, and their dimensions are similar to asbestos amphiboles[454].

SiC nanoparticles were not genotoxic in an *in vitro* Comet assay nor were they cytotoxic[455]. However, SiC nanoparticles did cause oxidative stress reactions in vitro as well as inflammatory responses[456, 457]. Long and short CNTs were also investigated as well as different nanoTiO$_2$ compounds[458,]. SiC

[448] Figarol, A., Pourchez, J., Boudard, D., Forest, V., Akono, C., Tulliani, J.-M., Lecompte, J.-P., Cottier, M., Bernache-Assollant, D., Grosseau, P., 2015. In vitro toxicity of carbon nanotubes, nano-graphite and carbon black, similar impacts of acid functionalisation. Toxicol. In Vitro 30, 476–85. doi:10.1016/j.tiv.2015.09.014

[449] Ma-Hock, L., Strauss, V., Treumann, S., Küttler, K., Wohlleben, W., Hofmann, T., Gröters, S., Wiench, K., van Ravenzwaay, B., Landsiedel, R., 2013. Comparative inhalation toxicity of multi-wall carbon nanotubes, graphene, graphite nanoplatelets and low surface carbon black. Part. Fibre Toxicol. 10.

[450] 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

[451] Ibid

[452] WHO, 2011. Molybdenum in Drinking-water, Background document for development of WHO Guidelines for Drinking-Water Quality. Geneva, Switzerland.

[453] 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.

[454] Grosse, Y., Loomis, D., Guyton, K.Z., Lauby-Secretan, B., El Ghissassi, F., Bouvard, V., Benbrahim-Tallaa, L., Guha, N., Scoccianti, C., Mattock, H., Straif, K., 2014. Carcinogenicity of fluoro-edenite, silicon carbide fibres and whiskers, and carbon nanotubes. Lancet. Oncol. 15, 1427–1428.

[455] Barillet, S., Simon-Deckers, A., Herlin-Boime, N., Mayne-L'Hermite, M., Reynaud, C., Cassio, D., Gouget, B., Carrière, M., 2009. Toxicological consequences of TiO2, SiC nanoparticles and multi-walled carbon nanotubes exposure in several mammalian cell types: an in vitro study. J. Nanoparticle Res. 12, 61–73. doi:10.1007/s11051-009-9694-y

[456] Ibid

[457] Pourchez, J., Forest, V., Boumahdi, N., Boudard, D., Tomatis, M., Fubini, B., Herlin-Boime, N., Leconte, Y., Guilhot, B., Cottier, M., Grosseau, P., 2012. In vitro cellular responses to silicon carbide nanoparticles: impact of physico-chemical features on pro-inflammatory and pro-oxidative effects. J. Nanoparticle Res. 14, 1143. doi:10.1007/s11051-012-1143-7

[458] Barillet, S., Simon-Deckers, A., Herlin-Boime, N., Mayne-L'Hermite, M., Reynaud, C., Cassio, D., Gouget, B., Carrière, M., 2009. Toxicological consequences of TiO2, SiC nanoparticles and multi-walled carbon nanotubes

nanoparticles were less potent than all the other particles on a per weight basis. The degree to which SiC nanoparticles caused these toxic reactions depended on surface area, crystallite size, nature of crystallite phase, and iron content[459].

The carcinogenicity of SiC fibres was investigated in two studies on workers who were exposed to fibrous and non-fibrous SiC, quartz, and cristobalite while involved in the production of SiC nanoparticles via the Acheson process. Based on these studies, occupational exposures associated with the Acheson process were classified IARC as carcinogenic to humans (Group 1) on the basis of sufficient evidence in humans that they cause lung cancer[460]. Since the correlation between exposures to SiC fibres and cristobalite made it difficult to disentangle their independent effects, IARC concluded that fibrous SiC is possibly carcinogenic to humans (Group 2B)[461]. No data on humans exposed to SiC whiskers were available. In experimental animals, there was sufficient evidence for the carcinogenicity of SiC whiskers for IARC to classify SiC whiskers as probably carcinogenic to humans (Group 2A), on the basis that the physical properties of the whiskers resemble those of asbestos and erionite fibres, which are known carcinogens. In addition, the results of available mechanistic studies were consistent with proposed mechanisms of fibre carcinogenicity[462], although carcinogenicity of SiC nanoparticles was not explicitly discussed.

Since SiC fibres and whiskers are persistent fibres and are suspected carcinogens, they should attributed hazard band E, according to Stoffenmanager Nano[463]. SiC nanoparticles are not genotoxic, be it based on scant evidence, but exhibit characteristics (ROS formation, inflammatory responses) similar to e.g. titanium dioxide nanoparticles. In an update on some metal oxide nanoparticles hazard band C was attributed to titanium dioxide nanoparticles[464], consequently the same hazard band is attributed to SiC nanoparticles.

SILICON DIOXIDE NANOPARTICLES, CRYSTALLINE

Classified by Stoffenmanager Nano in hazard band E[465].

SILICON DIOXIDE NANOPARTICLES, SYNTHETIC AMORPHOUS

In an update on some oxide nanoparticles hazard band B was attributed to synthetic amorphous silicon dioxide nanoparticles[466]

TITANIUM DIOXIDE

In an update on some metal oxide nanoparticles, hazard band C was attributed to titanium dioxide nanoparticles[467].

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exposure in several mammalian cell types: an in vitro study. J. Nanoparticle Res. 12, 61–73. doi:10.1007/s11051-009-9694-y

[459] Pourchez, J., Forest, V., Boumahdi, N., Boudard, D., Tomatis, M., Fubini, B., Herlin-Boime, N., Leconte, Y., Guilhot, B., Cottier, M., Grosseau, P., 2012. In vitro cellular responses to silicon carbide nanoparticles: impact of physico-chemical features on pro-inflammatory and pro-oxidative effects. J. Nanoparticle Res. 14, 1143. doi:10.1007/s11051-012-1143-7

[460] Grosse, Y., Loomis, D., Guyton, K.Z., Lauby-Secretan, B., El Ghissassi, F., Bouvard, V., Benbrahim-Tallaa, L., Guha, N., Scoccianti, C., Mattock, H., Straif, K., 2014. Carcinogenicity of fluoro-edenite, silicon carbide fibres and whiskers, and carbon nanotubes. Lancet. Oncol. 15, 1427–1428.

[461] Ibid

[462] Ibid

[463] 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

[464] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles.

[465] 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.

[466] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles. TNO2014 R11884.

[467] Ibid

TUNGSTEN OXIDE

Nano tungsten oxide is insoluble in water[468]. No toxicity studies on it were identified in public literature. Due to this lack of data, it needs to be hazard banded based on the hazardous properties of its bulk parent compound[469]. There is no official EU classification for tungsten oxide and most registrants have not (self)classified tungsten oxide, while some have classified it as possibly carcinogenic. In the registration dossier published by ECHA, no data supporting one or the other conclusion has been submitted. ATSDR[470] has published a toxicity profile for tungsten as well as an update of the earlier profile[471]. Its sodium salt (sodium tungstate) is not mutagenic in the Ames test nor did it cause chromosome aberration *in vitro,* but it did prove to be mutagenic in the Chinese hamster lung V79 cell HGPRT forward mutation assay[472]. Sodium tungsten dehydrate was negative in *in vivo* micronucleus tests in rats and mice, but positive in in vivo Comet assays in mice[473]. Alloys with cobalt and tungsten carbide are carcinogenic when implanted in mice. It is unclear whether cobalt or tungsten is the causative agent. A drinking water carcinogenicity study with sodium tungstate dehydrate has been performed by the NTP[474] but so far the results have not been published[475]. Epidemiological studies did not show an association between tungsten exposure (as measured by urinary tungsten levels) and carcinogenicity, however the power of the studies was too low to draw definitive conclusions[476]. Concluding, there are indications tungsten oxide may be a mutagenic carcinogen and therefore tungsten oxide nanoparticles should be attributed hazard band E according to the criteria of Stoffenmanager Nano[477].

VANADIUM PENTOXIDE (DI-VANADIUM PENTOXIDE)

No toxicity studies on nano-vanadium pentoxide were found in public literature. It is soluble in water and can therefore be hazard banded based on the hazardous properties of its bulk parent compound[478]. Vanadium pentoxide is classified in the EU as reprotoxic and mutagenic and should therefore be assigned to the highest hazard band, E.

ZINC OXIDE NANOPARTICLES

In an update on some metal oxide nanoparticles, hazard band B was attributed to zinc oxide nanoparticles[479].

10.2.2 Exposure assessment

10.2.2.1 Cement/lime concrete and mortars and other derivatives

Concrete is widely used in the world. An ordinary concrete is a mixture of cement, sand, gravel and water. Additives are used for special properties, e.g. to increase strength, hardness or corrosion

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[468] ATSDR, 2005. Toxicological profile for Tungsten. Agency for Toxic Substances and Disease Registry, Atlanta, USA.

[469] 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

[470] ATSDR, 2005. Toxicological profile for Tungsten. Agency for Toxic Substances and Disease Registry, Atlanta, USA.

[471] ATSDR, 2015. Addendum to the Toxicological Profile for Tungsten. Agency for Toxic Substances and Disease Registry, Atlanta, USA.

[472] ATSDR, 2005. Toxicological profile for Tungsten. Agency for Toxic Substances and Disease Registry, Atlanta, USA.

[473] ATSDR, 2015. Addendum to the Toxicological Profile for Tungsten. Agency for Toxic Substances and Disease Registry, Atlanta, USA.

[474] Ibid

[475] NTP site last checked on March 7, 2016

[476] ATSDR, 2015. Addendum to the Toxicological Profile for Tungsten. Agency for Toxic Substances and Disease Registry, Atlanta, USA.

[477] 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

[478] Ibid

[479] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles.

resistance. Among these additives, silica fumes are very important materials. By adding microsilica, high performance concrete is produced, but by using nanosilica ultra-high performance concrete is formed, which is used increasingly. In addition, nanotitania particles have been added to concrete for self-cleaning properties at the surface.

Furthermore, CNTs and CNFs are being incorporated in concrete, as both of them can fill the pore spaces in concrete more effectively than more conventional fillers like sand. CNFs are considered to be superior to CNTs for this because their stacked structure has exposed edges, increasing surface area and thus improving bonding characteristics.

In “Stoffenmanager Nano” sets of exposure scenarios are assigned to exposure bands labelled 1 to 4 (1=low exposure, 4= highest exposure). As explained in the introduction, only respiratory exposure is considered here.

The likelihood of exposure to nanoparticles while handling cement, concretes etc. is highly dependent upon the type of process and the type of equipment involved in the process. Nevertheless, the usage (building phase e.g. mixing, dumping, transferring) of powder materials results in the highest exposure potential (4). If the nanomaterial is included in a liquid mixture (the cement/concrete, building phase) the exposure potential is highly reduced (2). If the nanomaterial is in a matrix (use phase, hardened cement/mortal) the exposure potential is low (1). During abrasive activities (demolition phase) on the cement/concrete the worker can be exposed to nanomaterials but the exposure potential is still relatively low (2). The most common applications are considered below.

10.2.2.2 Steel: nano-modified steel and nano-additions to steel

In addition to carbon and iron, some compounds like copper, vanadium oxide and molybdenum may be added to steel as nanoparticles. The likelihood of exposure to nanoparticles during the handling of nano-additions in powder form results in the highest exposure potential (building phase, 4). If the nanomaterial is in the steel the exposure potential is low (use phase, 1). Abrasion of an object which includes nanomaterial may result in exposure to steel aerosols which include nanomaterials, resulting in a relative low exposure potential (demolition phase, 2).

10.2.2.3 Glass: self-cleaning, energy-saving windows

Nanomaterials (titanium dioxide) are used in glass for self-cleaning properties and to reduce the sunlight and heat entering a building. When the nanomaterial is in the glass, the exposure potential is low (use phase, 1). Handling powder titanium dioxide to produce the glass results in the highest exposure potential (building phase, 4).

10.2.2.4 Heat insulation materials

The use of nanomaterials (e.g. nanoscale silica, graphite or silicon carbide) here includes aerogels and vacuum insulation panels for heat insulation. In the occupational setting, powder nanomaterials may be handled, resulting in the highest exposure potential (building phase, 4). If the nanomaterial is in the matrix of the insulation material the exposure potential is low (use phase, 1).

10.2.2.5 Coatings and paints

Paints or coatings are frequently used in construction to protect the surface from harmful weathering effects (e.g. in the case of wood, for durability, water resistance, fungi resistance). They can also make surfaces more attractive. Paints are composed of base; vehicle or binder; solvent or thinner; drier and colouring pigments. In addition, several nanomaterials (e.g. TiO_2, ZnO, SiO_2) are applied as coatings for self-cleaning properties, better water resistance etc. Naturally, silica dioxide can be present as amorphous or crystalline nanoparticles, but in most applications the amorphous form is used[480]. In the building phase, the exposure potential is relatively low (2) since the nanomaterial is dispersed in the coating, except when the coating is sprayed on a surface, when the exposure potential is high (4). When the coating is on the surface, the exposure potential is again low (use phase, 1).

[480] Kaiser, J.-P., Zuin, S., Wick, P., 2013. Is nanotechnology revolutionizing the paint and lacquer industry? A critical opinion. Sci. Total Environ. 442, 282–9. doi:10.1016/j.scitotenv.2012.10.009

10.2.3 Risk assessment

The hazard and exposure bands discussed above 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 or to establish the risk involved with more precision. It should be emphasised that, because of the general scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Roughly four phases can be discerned in the life cycle of construction materials: production, building, use and demolition. If in a phase different degrees of exposure may occur, the highest exposure scenario is taken into account in the risk assessment (worst case scenario).

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 construction sector are listed the table below.

Table 10-4: Priority bands for the construction sector

		Exposure band		
		Building phase	**Use phase**	**Demolition phase**
Nanoparticle	**Hazard band**	4	1	2
CNTs/CNFs	E	1	1	1
Copper	D	1	2	2
Graphene / nanographite	E	1	1	1
Iron oxide	D	1	2	2
Molybdenum	E	1	1	1
Silicon carbide, fibres & whiskers	E	1	1	1
Silicon carbide, spherical particles	C	1	3	2
Silicon dioxide (silica), crystalline	E	1	1	1
Silicon dioxide (silica), synthetic amorphous	B	1	3	3
Titanium dioxide (titania, rutile, anatase)	C	1	3	2
Tungsten oxide	E	1	1	1
Vanadium pentoxide	E	1	1	1
Zinc oxide	B	1	3	3

Due to the high expected exposure, all nanomaterials reach the highest risk priority during the building phase.

In the use phase, amorphous silicon dioxide, titanium dioxide, spherical SiC and zinc oxide nanoparticles have a low risk priority while carbon nanotubes, molybdenum, nanographite, silicon carbide fibres and whiskers, crystalline silicon dioxide, tungsten oxide and vanadium pentoxide have the highest risk priority and the remainder of the nanomaterials have an intermediate risk priority. It should be noted that in the use phase all nanomaterials are contained in a solid matrix, meaning exposure will be negligible and thus health risks will be low.

In the demolition phase, risk management/evaluation of building materials containing carbon nanotubes, molybdenum, nanographite, silicon carbide fibres and whiskers, crystalline silicon dioxide, tungsten oxide and vanadium pentoxide should receive the highest priority, while amorphous silicon dioxide and zinc oxide have a low risk priority. The building materials containing the remainder of the listed nanomaterials should receive intermediate priority during the demolition phase.

This section on human health and safety is presented in full in the Annex: *Human Health and Safety.*

The next section looks at communication on nanotechnology and construction.

10.3 Communication, public attitudes and societal issues

This section looks at nanotechnology and construction in printed and online media and then reviews some surveys of the public.

10.3.1 Printed and online media

A search on the web of terms related to nanotechnology and keywords related to construction is summarised in the table below. News sites were searched using the Google News search tool. 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 construction topics

Selected construction keywords	Web, thousands	News, thousands	News / Web, %
Asphalt	427	2.8	0.66%
Construction	8,780	19.6	0.22%
Cement	971	7.5	0.77%
Concrete	888	12.2	1.37%
Glazing	230	0.4	0.17%
Masonry	280	0.2	0.07%

A second search, using Google Scholar[481], 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.

Table 10-6: Frequency on Google Scholar of nanotechnology construction topics

Selected construction keywords	Scholar, thousands	Scholar/Web %
Asphalt	10.9	2.6%
Construction	1,100	12.5%
Cement	1,020	105.1%
Concrete	2,130	239.9%
Glazing	6	2.61%
Masonry	3.9	1.39%

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 construction topic.

More than 200 scientific journals regularly publish articles on nanotechnology[482]. 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

[481] 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.)

[482] http://www.nanowerk.com/nanotechnology/nanotechnology_periodicals.php

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 2010-15[483]	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

No journals specialising in construction related aspects of nanotechnology were found.

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	68,785
Nanotechnology World Association	33,612
Nanotechnology Now	10,012
Nanowerk Media/News/Publishing	9,552
The International Nano Science Community	6,539
Nature nanotechnology	2,562

This information may be useful in targeting any information for the public in future over and above the EC's own web pages.

10.3.2 Surveys of the public

More rigorous measures of public awareness, attitudes and communication can be seen through surveys. Although not representative for 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[484]. 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

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[483] h-5 index is the largest number h such that h articles published in 2010-2015 have at least h citations each.
[484] www.nanopinion.eu

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) curriculum.

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[485]. 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[486]. 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)[487], as well as a survey among young people conducted within the framework of the NANOYOU project (NANOYOU, 2010)[488] and a recent survey in the USA (Shipman, 2010)[489]. 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)[490].

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 good or perceived individual benefit" (Böl, 2010; Fleischer et al., 2012)[491,492]. Construction is not specifically included in the assessment (the closest being 'surface treatment') but may fall into this category in the future.

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485 www.nanodiode.eu

486 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)

487 Zimmer, R., Hertel, R., Böl, G.F., 2009, "Public perceptions about nanotechnology: Representative survey and basic morphological-psychological study", Bundesinstitut für Risikobewertung (BfR)

488 Nanoyou, 2010 http://cordis.europa.eu/publication/rcn/15319_fr.html

489 Shipman, M., 2010, "Hiding risks can hurt public support for nanotechnology", News Services of the North Carolina State University

490 http://www.oecd.org/sti/biotech/49961768.pdf

491 Böl, G.F., Epp A., Hertel, R., 2010, "Perception of nanotechnology in internet-based discussions", Bundesinstitut für Risikobewertung (BfR)

492 Fleischer, T., Jahnel J., Seitz S.B., 2012, "NanoSafety – Risk governance of manufactured nanoparticles", European Commission

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)
Cosmetics (excl. sunscreens)	59 : 41	51 : 49
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)
Sunscreen products	10 : 90	78 : 22
Dietary supplements	0 : 100	not asked

11 CONCLUDING SUMMARY

Nanomaterials can be found in many ordinary construction materials and products such as cement, mortar and concrete, paints, coatings, insulation materials and glass. The properties that they offer include self-cleaning and non-wetting, photocatalytic cleaning, weight reduction, energy efficiency, safety, longevity, fire resistance and thermal stability. Currently, nanotechnology is largely applied only to niche markets in the construction industry and market penetration is limited.

Policy supports in Europe include the EU RTD Framework Programmes projects, ERA-NETs[493], European Technology Platforms and Networks of Excellence. Member States support nanotechnology within broad science and technology initiatives but usually do not single out construction specifically.

The largest proportion of funding for nanotechnology and construction in the EU Framework Programmes was under the NMP theme of the Co-operation Programme in both FP6 (88%) and FP7 (80%). Participants from Germany, Spain, the United Kingdom and Italy received more than half of total nanotechnology and construction funding throughout FP6 and FP7. Unlike other sectors and nanotechnology overall, where research under the FPs is led (in terms of funding) by higher education organisations, research organisations receive almost a third of the funding closely followed by SMEs.

The strongest publishing countries for nanotechnology and construction in 2014 were the China and the US, followed by Spain, France, the United Kingdom and Korea. Of the EU28, the strongest in publications in 2014, after Spain, France and the United Kingdom, were Germany, Italy and Portugal.

The top EU and EFTA countries for patents (applications and granted) are Germany, the Netherlands, France, the United Kingdom and Italy. Of the top ten, only the United Kingdom is in also the top ten for publications on nanotechnology and construction and that Spain is missing despite its strong performance in both FP projects and publications.

In terms of individual organisations in the EU28, the countries of Germany (Fraunhofer Gesellschaft) and Spain (Tecnalia and Acciona Infraestructuras S.A.) are strongly represented in projects, while in patents, France (CEA[494], CNRS[495]) and Germany (Fraunhofer Gesellschaft, Leibniz Materials Institute) are the strongest. Evonik Degussa and Merck are the strongest European companies for patent applications and Evonik Degussa (DE), Wacker Chemie (DE), Rhodia Chemie (FR) and ASML (NL) have patents granted, albeit low numbers of patents.

The global market for products in nanotechnology and construction is expected to grow from USD 1.8 billion in 2013 to USD 4.7 billion in 2019. Most of the growth is expected to come from products that already exist in some form. 95 building and construction-related products using nanotechnology have been identified as being commercially available on the market. About one quarter of those are in the area of lighting (LEDs and OLEDs) and one fifth in the area of coatings (photocatalytic and anti-stick). Paints, coatings and adhesives account for 17% of products and insulation products 16%.

[493] Also ERA-NET plus
[494] Commissariat à l'énergie atomique et aux énergies alternatives
[495] Centre national de la recherche scientifique

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[496] (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'.

[496] 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.

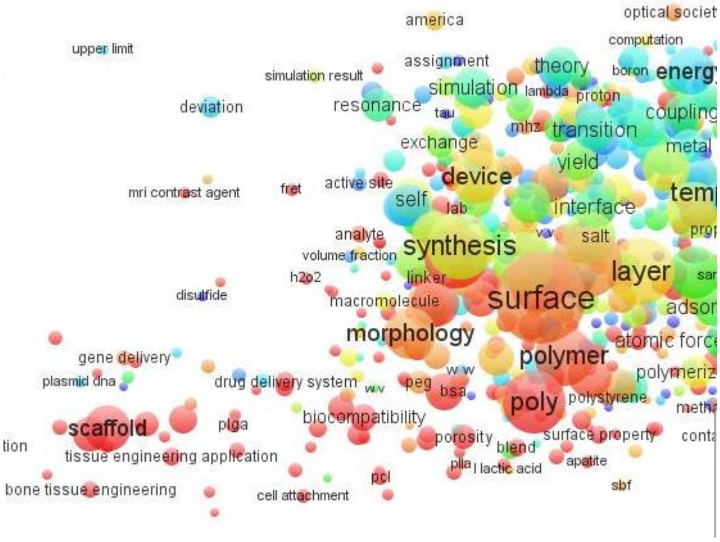

Figure A: Partial VOSViewer map for nanotechnology and health

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[497]	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[498]	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.

[497] In FP6 these were called Priorities and in FP7 Work Programmes.
[498] 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'[499] in the title or abstract of the project. 3,544 projects were selected in this way[500], 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.

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%

499 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".

500 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).

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[501], 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.

[501] 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)[502].

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.

[502] 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+[503].

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**[504]	United Kingdom
EL[505]	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[506].

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

[503] Data was also analysed from countries outside of the EU28 namely Iceland (IS), Israel (IL), Norway (NO), Switzerland (CH) and Turkey (TR).
[504] GB is also used
[505] GR is also used
[506] 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[507]. 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[508] 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[509] as well as existing market reports[510]. 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[511], Nanowerk[512],

[507] 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.

[508] http://www.iso.org/iso/country_codes

[509] E.g. Nanomedicine: Nanotechnology, Biology, and Medicine 9 (2013) 1–14, Hessen Nanotech (2008) Applications of Nanotechnologies in the Energy Sector.

[510] See BCC Research www.bbcresearch.com

[511] http://www.azonano.com/

[512] http://www.nanowerk.com/

the consumer products inventory of the Project on Emerging Nanotechnologies[513], the product database of understandingnano.com[514], the Nanoinformationsportal of the Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH[515], the Danish Inventory of Nanoproducts[516] and the nanowatch.de database[517]. 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[518], 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[519], the Nano-Map of the German Federal Ministry of Research[520], the database on photonic companies compiled by EPIC, the members directory of SEMI[521], and the Nano-Bio Manufacturing Consortium (USA)[522], 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,

[513] http://www.nanotechproject.org/cpi/
[514] http://www.understandingnano.com/nanotechnology-product-suppliers.html
[515] http://nanoinformation.at/produkte.html
[516] http://nanodb.dk/
[517] http://www.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank/
[518] http://www.ema.europa.eu/
[519] http://www.nanora.eu/
[520] http://www.werkstofftechnologien.de/en/
[521] http://www.semi.org/en/Membership/MemberDirectory/
[522] http://www.nbmc.org/members-only/

and public database. European Patent Office[523], PRODCOM[524] and patentlens[525] 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[526]. 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

[523] https://www.epo.org/searching.html
[524] http://ec.europa.eu/eurostat/web/prodcom
[525] https://www.lens.org/lens/search?n=10&q=nanotechnology&p=0
[526] 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: CONSTRUCTION KEYWORDS

Below is the list of keywords used in the extraction of data and the subsequent analyses. Asterisks are used to indicate that part of a word is missing.

aggregate concrete
architectural acoustic*
asphalt*
bitum*
building acoustic*
building construction
building enclosure*
building engineering
building envelop*
building envelope*
building fabric
building industry
building insulation
building material*
building refurbishment
building renovation
building retrofit
building sector
building technology
built infrastructure
cement composite*
cement concrete
cement hydration
cement mortar
cement paste*
cementitious composite*
cementitious material*
cementitious matrix
ceramic tile*
civil engineering
civil infrastructure*
clinker*
commercial building*
concrete composite
construction engineering
construction industry
construction material*
construction product*
construction project*
construction sector
construction site
construction technology
curtain wall
energy efficient building*
energy-efficient building*

existing building*
facade*
façade*
geopolymer*
glazing
green building*
gypsum
heating, ventilation and air conditioning
high performance concrete
high strength concrete
historical building*
HVAC
indoor climate
indoor environment*
indoor heating system*
insulated glass
insulating glass
insulation panel*
lightweight building*
lightweight concrete
limestone
low carbon building*
low energy building*
low-carbon building*
low-energy building*
manufactured building*
manufactured hous*
masonry
mineral admixture
modular building*
ordinary cement
passive building*
passive hous*
pavement
plywood
existing building*
Portland cement
portlandite
pozzol*
pre-engineered building*
prefabricated building*
pre-fabricated building*
prefabricated wall
public construction
refurbishment of building*

reinforced concrete
residential building*
retro-fitted building*
retro-fitted building*
retrofitting building*
road construction
road material*
roof tile*
roofing
self-compacting concrete
slag cement
sustainable building*
urban fabric
urban infrastructure*
vacuum insulated panel*
vacuum insulation panel*
VIP insulation*
VIP panel*
wall panel*
window glass*
wood composite*
zero energy building*
zero-energy building*

ANNEX 3: ABBREVIATIONS

Abbreviation	Definition
BEUC	Bureau Européen des Unions de Consommateurs
CAGR	Compound Annual Growth Rate
CBRAM	Conductive Bridge Random Access Memory
CBRNE	Chemical, Biological, Radiological, Nuclear and Explosive
CEN	European Standardisation Committee
CMC	Chemistry, Manufacturing and Controls
CMOS	Complementary Metal-oxide Semiconductor
CNT	Carbon Nanotubes
COD	Co-decision Procedure
DFG	Deutsche Forschungsgemeinschaft
d-MRI	Diffusion Magnetic Resonance Imaging
DRAM	Dynamic Random-Access Memory
EC	European Commission
EEB	European Environmental Bureau
EFSA	European Food Safety Authority
EGE	European Group on Ethics Roundtables
EoL	End of Life
EPA	Environmental Protection Agency
EPR	Enhanced Permeation and Retention
ESD	Electrostatic Discharge
ETUC	European Trade Union Confederation
EU	European Union
Eurofound	European Foundation for the Improvement of Living and Working Conditions
FDSOI	Fully-depleted Silicon on Insulator
FET	Field Effect Transistor
f-MRI	Functional Magnetic Resonance
FP7	Seventh European Framework Programme
GMR	Giant Magnetoresistance
GOI	Germanium-on-insulator
ICT	Information and Communication Technologies
IPC	International Patent Classification
IPR	Intellectual Property Rights
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
MAPP	Manual of Policies and Procedures
MEMS	Micro-electromechanical System
MNBS	Micro- and Nano-Bio Systems
MOSFET	Metal Oxide Semiconductor field-effect transistor
MR	Magnetic Resonance
MRAM	Magnetoresistive Random Access Memory
MRI	Magnetic resonance imaging
MRS (MRSI)	Magnetic Resonance Spectroscopy (imaging)

Abbreviation	Definition
MWCNT	Multi-walled Carbon Nanotubes
MX2	Metal Dichalcogenides
NACE	Nomenclature Statistique des Activites Economiques dans la Communauté Européenne
NEMS	Nano-Electromechanical System
NGO	Non-Governmental Organisation
NIR	Near Infrared
NIR-II	Near-Infrared-ii Imaging
NOC	Network on Chip
NOMS	Nano-Optomechanical System
NP	Nanoparticles
NST	Nanoscience and Nanotechnology
NT	Nanotechnology
OFET*	Organic Field Effect Transistor
OLED	Organic Light-Emitting Diode
OSHA	European Agency for Safety and Health at Work
OSH-professional	Occupational Safety and Health Professional
PATSTAT	European Patent Office Worldwide Patent Statistical Database
PMC	Programmable Metallisation Cell
ppm	Parts Per Million
QD	Quantum Dot
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RRAM	Resistive RAM
SME	Small or Medium Sized Enterprise
SNAP	Strategic Nanotechnology Action Plan
SOI	Silicon-On-Insulator
SRAM	Static Random Access Memory
STOA	Science and Technology Options Assessment
STT MRAM	Spin Transfer Torque Magneto-Resistive Random Access Memory
STT RAM	Spin Transfer Torque Random Access Memory
SWCNT	Single Walled Carbon Nanotubes
TMDC	Transition Metal Dichalcogenide
TT	Technology Transfer
US	United States
US EPA	US Environmental Protection Agency
US NIOSH	US National Institute for Occupational Safety and Health
USA	United States of America
UV/Vis/IR	Ultraviolet / Visible / Infra-red
VC	Venture Capital
WEEE	Waste Electrical and Electronic Equipment

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.
Liposomes	An artificially-prepared vesicle composed of a lipid bilayer
Nanobiosensors	Biosensor at nano-scale: measurement system for detection of an analyte that combines a biological component with a physiochemical detector
Nano-biotechnology	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 of non-toxic 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
Nano-coatings	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
Nano-indentation	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
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).

Word/phrase	Definition/explanation
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	Suit 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[527]), 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)[528] and the Federal Ministry for Transport, Innovation and Technology (BMVIT)[529]. The largest share of direct support for R&D is channelled through three funding agencies: The Austrian Science Fund (FWF)[530] that focuses on funding academic research; the Austrian Research Promotion Agency (FFG)[531] specialising in funding applied industrial research and the co-operation between the higher educational sector and industry; and the Austria Economic Service (AWS)[532] 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**"[533] 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 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 Transnational Projects).

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527 https://rio.jrc.ec.europa.eu/
528 http://www.en.bmwfw.gv.at/
529 https://www.bmvit.gv.at/en/
530 https://www.fwf.ac.at/en/
531 https://www.ffg.at/en
532 http://www.awsg.at/
533 https://www.bmlfuw.gv.at/dam/jcr:00058164-0320-4544-b6a4-320325dcfd86/Austrian%20Nanotechnology%20Action%20Plan.pdf

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[534], 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)[535] 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**[536]**,** 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[537]**, 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)[538]: 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.

Strategische onderzoekscentra[539] (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

[534] http://www.sozialministerium.at/cms/site/attachments/6/1/7/CH2120/CMS1371046721712/umsetzungsbericht_2012_en.pdf
[535] https://www.ffg.at/en
[536] http://www.bionanonet.at/about-bionanonet
[537] http://www.bionanonet.at/about-nanotoxicology?lang=english
[538] http://www.wirtschaft.steiermark.at/cms/beitrag/10430090/12858597
[539] http://www.ewi-vlaanderen.be/wat-doet-ewi/excellerend-onderzoek/strategische-onderzoekscentra

business worlds. Each of the institutes have their own specific focus.

- Imec[540] 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[541], 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[542], 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[543] 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 programmein order to support research projects in that field which led to the creation of **NanoWal**[544], 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[545]. It included four different sub-programmes in the areas of: nano-particles, nano-fibres and nano-composite materials; nano-biology and nano-medicine; nano-macro interface; and new phenomena and materials for nano-electronics, 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[546], 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.

Denmark

In Denmark, the Ministry of Higher Education and Science[547] has the main responsibility for research and innovation policy.

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540 http://www2.imec.be/be_en/home.html
541 http://www.vib.be/en/Pages/default.aspx
542 https://vito.be/en
543 https://www.iminds.be/en
544 www.nano.be/
545 http://www.csnmt.cz/getfile.php?type=file&IDfile=24
546 http://www.vyzkum.cz/FrontClanek.aspx?idsekce=1020
547 http://ufm.dk/en

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[548]). The last phase of the foresight programme was closely linked to the establishment of the Danish National Advanced Technology Foundation[549] 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[550]** 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[551].

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 Innovation Fund Denmark[552] (IFD), has been the responsible body since 2014.

[548] Danish Nano-science and Nano-technology for 2025, Foresight Brief No. 032
[549] http://www.tekno.dk/about-dbt-foundation/?lang=en
[550] http://ufm.dk/en/publications/2004/technology-foresight-on-danish-nanoscience-and-nanotechnology
[551] http://www.nano-vaccine.org/
[552] 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

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[553]. 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.

In 2011, the final report on FinNano was published, showing the results of the Programme[554]. 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

[553] http://www.tekes.fi/globalassets/julkaisut/research_and_technology.pdf
[554] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf

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*[555] in Grenoble (centred in Minatec);
- The *Laboratoire d'Analyses et d'Architectures des Systemes*[556] (LAAS) in Toulouse ;
- The *Laboratoire de Photonique et de Nanostructures*[557] (LPN) in Marcoussis ;
- *The Institut d'Électronique Fondamentale*[558] *(IEF) Orsay,* in Minerve; and
- The *L'Institut d'Electronique, de Microélectronique et de Nanotechnologie* [559] (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**[560]) 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**[561] (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 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

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[555] http://www-leti.cea.fr/en/
[556] https://www.laas.fr/public/
[557] http://www.lpn.cnrs.fr/fr/Commun/
[558] http://www.ief.u-psud.fr/
[559] http://exploit.iemn.univ-lille1.fr/
[560] http://www.agence-nationale-recherche.fr/suivi-bilan/historique-des-appels-a-projets/appel-detail1/programme-national-en-nanosciences-et-nanotechnologies-pnano-2005/
[561] http://www.gouvernement.fr/investissements-d-avenir-cgi

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**[562]" 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**[563] in 2006. This was done through the **Nano Initiative—Action Plan 2010**[564], 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**[565], 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 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

562 http://d-nb.info/97392179x/34
563 http://www.research-in-germany.org/en/research-landscape/r-and-d-policy-framework/high-tech-strategy.html
564 http://www.cleaner-production.de/fileadmin/assets/pdfs/Nano_initiative_action_plan_2010.pdf
565 http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf

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)[566]: 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; 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.

566 https://www.cluster-bayern.de/en/

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)[567]**. 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[568] 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. Members of the BioNano Laboratory are also members of the **Integrated Nanoscience Platform for Ireland (INSPIRE)[569],** 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

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567 http://www.crann.tcd.ie/

568 Forfás ceased to exist in 2015 and was, in part, subsumed under the Department of Jobs, Enterprise and Innovation.

569 http://www.crann.tcd.ie/Research/Academic-Partners/testt.aspx

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)[570]** 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[571]), Delft University of Technology (with the **Else Kooi Laboratory**[572], previously called Dimes research centre on nanoelectronics) and the University of Groningen (with **BioMaDe[573]** focused on bio-nanotechnology). The early 2000s, these formed the core of **NanoNed** - the Nanotechnology R&D initiative in the Netherlands[574]. 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[575]**. 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 research groups, centres, department and laboratories. On the national level, **NanoLab NL[576]** 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

570 http://ambercentre.ie/
571 https://www.utwente.nl/mesaplus/
572 http://ekl.tudelft.nl/EKL/Home.php
573 http://www.biomade.nl/
574 However, four other universities, and TNO, the Netherlands Organisation for Applied Scientific Research, are also represented.
575 http://www.rritrends.res-agora.eu/uploads/27/8079721-bijlage%281%29.pdf
576 http://www.nanolabnl.nl/

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**[577] 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**[578], 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**"[579]. 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 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 specialization area in Poland.

[577] http://www.nanonextnl.nl/
[578] http://topsectoren.nl/english
[579] www.bioin.or.kr/fileDown.do?seq=5186

PORTUGAL

In 2005, the Portuguese and Spanish Governments decided to jointly create the **International Nanotechnology Laboratory (INL)[580]** 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.

In 2005, the Government of Spain launched the strategic programme **INGENIO 2010[581]** 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

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580 http://inl.int/
581 http://www.ingenio2010.es/

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**[582] was implemented by the Ministry of Economy and Competitiveness. This policy measure was part of the National Plan for R+D+I 2008-2011[583] 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[584] and in the State Plan of Scientific and Technical Research and Innovation 2013-2016[585] (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)[586]: 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 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

[582] http://www.idi.mineco.gob.es
[583] Ibid
[584] http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_Strategy_Science_Technology.pdf
[585] http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_RDTI_Plan_2013-2016.pdf
[586] http://www.nanobasque.eu/aNBW/web/en/strategy/index.jsp

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[587]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[588] 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**[589] 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 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)[590]** 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

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587 https://www.gov.uk/government/organisations/innovate-uk
588 https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative
589 http://webarchive.nationalarchives.gov.uk/20130221185318/http://www.innovateuk.org/_assets/pdf/taylor%20report.pdf
590 https://connect.innovateuk.org/web/nanoktn

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 STG 82 million for UK industry, mainly focussed on SMEs, providing a good return investment on the initial input of STG 3 million. 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**[591] 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**[592]", 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**[593] 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**[594]. 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)**[595] 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 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**[596] 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

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[591] https://www.epsrc.ac.uk/newsevents/pubs/report-of-the-nanotechnology-strategy-group/
[592] https://www.epsrc.ac.uk/newsevents/pubs/nanotechnology-programme/
[593] http://www.nibec.ulster.ac.uk/uploads/documents/nanoscaletechnologiesstrategy.pdf
[594] http://www.steptoe.com/assets/htmldocuments/UK_Nanotechnologies%20Strategy_Small%20Technologies%20Great%20Opportunities_March%202010.pdf
[595] https://www.gov.uk/government/groups/nanotechnology-strategy-forum
[596] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015

identified as having a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.

ANNEX 6: PRODUCTS FOR NANOTECHNOLOGY AND CONSTRUCTION

This Annex is divided largely into the same categories as used in the main body of the report:

1. Coatings and adhesives (paints)
2. Nanostructured steel
3. Anti-stick, anti-scratch coatings
4. Photocatalytic coatings
5. Lighting (LEDs)
6. Lighting (OLEDs)
7. Building insulation
8. Nanocomposites – hydrophobic/ oleophobic
9. Concrete/ cement
10. Other

1 COATINGS AND ADHESIVES (PAINTS)

Product Name	Description	Producer
ADMANANO	ADMANANO is a patented silicaceous product which is developed in liquid phase to be mixed with organic and inorganic powder to impart fluidity, filling rate, sinterability, compressibility. It can be used with inorganic pigment, functional ceramics like $BaTiO_3$, etc.	Admatechs Company Ltd
UNIVERSAL COATING LACQUER 9200	It is a colourless coating that can be used as lacquer and offer good filling capacity and sanding properties. It is highly resistant to cleaners and alcohols and does not decolourise.	Alfred Clouth Lackfabrik GmbH & Co.KG
COL.9®	COL.9® is a nanobinder from BASF which is applied onto paints. It protects paints against dirt and weather. Herbol® Symbiotec® is an exterior wall paint developed by Akzo Nobel using COL.9®. This paint has dirt-repellent feature due to this nanobinder which creates a hydrophilic surface in its composition. It does not allow build-up of any dirt, bacteria, mould and algae on the surface. This product is also effective in maintaining insulating properties of wall and insulation systems through a good moisture management system.	BASF
Bioni Comfort	Bioni Comfort is a long-lasting, universal acrylic interior coating that contains siliceous light fillers and has multi-functional properties. Due to its special filler technology, Bioni Comfort is suitable for use in residential, office, educational, as well as in catering and hotel industry buildings.	BIONI CS GmbH
Bioni Hygienic	Bioni Hygienic, with its anti-microbial properties, is an interior paint especially for spaces where high hygiene is required.	
Bioni Nature	Bioni Nature is a nano-enhanced paint that has anti-bacterial and air purifying functionalities.	
Bioni Perform	Bioni Perform is an external paint with moisture regulating and anti-mould properties.	
Bioni Roof	Bioni Roof is a special multi-purpose paint / coating for roofs of clay, concrete, artificial slate tiles and corrugated iron. It is resistant to UV light, to harsh (cold/hot) weather conditions. It prevents growth of moss and also reduces the build-up of heat in the building.	

DuraBind™	DuraBind™ bioresin is a biobased solution of petro based binders. Use of formaldehydes can be reduced with the use of these biopolymers. It can also be used as a thermal resistance material.	EcoSynthetix Inc.
AEROSIL®	Evonik non-drip paint, a fumed silica-based product sold under the name of AEROSIL®. It is used to control rheological features and also to improve the corrosion resistance of paints.	Evonik
V-COLOR ®	V-COLOR concerns "coating materials", can sustain temperatures between 920°C and 1,250°C. It also offers the roof with a unique colour intensity and brilliance.	Viking Advanced Materials GmbH
VACOMP	This is a phosphate-based binding agent that can be used to manufacture composite components with high performance and good strength.	Viking Advanced Materials GmbH
Nano Ipek Matt	Nano Ipek Matt, Nanomatt and Nanotex are nano-enhanced paints from Yasar Paint Group (DYO) with self-cleaning, anti-scratch and anti-bacterial features. Nano Ipek Matt is for interior applications.	Yaşar Holding A.Ş.
Nanomatt	Nano Ipek Matt, Nanomatt and Nanotex are nano-enhanced paints from Yasar Paint Group (DYO) with self-cleaning, anti-scratch and anti-bacterial features. Nanomatt is for interior applications.	Yaşar Holding A.Ş.
Nanosön	Nanosön is flame-retardant water based paint from Yasar Paint Group.	Yaşar Holding A.Ş.
Nanotex	Nano Ipek Matt, Nanomatt and Nanotex are nano-enhanced paints from Yasar Paint Group (DYO) with self-cleaning, anti-scratch and anti-bacterial features. Nanotex is for exterior spaces.	Yaşar Holding A.Ş.

2 NANOSTRUCTURED STEEL

Product Name	Description	Producer
MMFX2 Steel	MMFX2 is an uncoated corrosion-resistant and high-strength reinforcing steel that cuts the costs of infrastructure by decreasing steel requirements and providing lower maintenance costs over the life of the bridge.	MMFX Steel Corp
Super Hard Steel (SHS)	NanoSteel's Super Hard Steel® (SHS®) alloys for applications as weld overlays and thermal spray coatings are the company's first generation of nano-structured, high-strength steel materials.	NanoSteel Company
Sandvic NanoFlex	Sandvik Nanoflex is an ultra-high-strength stainless steel material with a combined good corrosion resistance. By a simple heat treatment after cold deformation, extremely high tensile strength levels in combination with a good toughness are obtained. Because the heat treatment is made at a low temperature, dimensions are perfectly maintained. In the as-delivered condition, Sandvik Nanoflex displays excellent forming properties.	Sandvik

3 ANTI-STICK, ANTI-SCRATCH COATINGS

Product Name	Description	Producer
Wirewear Protective Coating	Wirewear is a coating with high abrasion resistant properties for ferrous and non-ferrous wires used for complex architectural and building applications. Besides this attribute others such as low friction, non-sticking, features can be achieved.	A&A COATINGS
nCOLOR®	Beneq provides different coatings and coating systems for glass industry under the registered names of nCOLOR®, nCLEAN® and nHALO®. They have anti-reflective coatings, energy control coatings, easy to clean coatings and anti-bacterial coatings.[38]	Beneq OY
nHALO®	Beneq provides different coatings and coating systems for glass industry under the registered names of nCOLOR®, nCLEAN® and nHALO®. They have anti-reflective coatings, energy control coatings, easy to clean coatings and anti-bacterial coatings.	Beneq OY
2000 Series Maintenance Coatings	This coating makes the surface hard, abrasion resistant, non-stick, slick surface that cleans easily with soap and water, reducing equipment down time and labour cost. The coating can be used on any types of construction equipment giving it high corrosion resistance.	Ecological Coatings, LLC
tutoPROM®	tutoPROM® is an (organo)-polysilazane based anti-graffiti coating developed for concrete by Clariant.	Merck KGaA
Nanoguard®	Nanoguard® is a technology developed by Behr Paints and gives paints enhanced functionalities e.g. improved adhesion, dirt repellence, moisture resistance and UV resistance. BEHR Basement & Masonry Waterproofing Paint and BEHR Premium Plus Ultra are some of the products that are using Nanoguard Technology.	NewPro
Nanoguard®StoneProtect	Nanoguard®StoneProtect is a coating from Nanogate AG which is applied to concrete parts of Europe's longest city tunnel Södra Lanken in Stockholm.	NewPro
Percenta Nano Window Sealant SR	Percenta Nano Window Sealant SR is an alcohol-based system, which protects outer glass and synthetic surfaces from tarnishing. The applied sealant develops a thin, invisible, hydrophilic film on the surface, which due to a photocatalytic process reacts with daylight / UV radiation. This reaction breaks down muck on the glass, with no need for detergent. It can be used for greenhouses, solar panels and conservatories. When water hits it, a hydrophilic effect is created, so water and dirt slide off, the so-called 'self-cleaning effect'.	Percenta Europe Ltd

RELIUS Roof Acryl Nano Tech®	Water-based, semi-gloss, self-cleaning, extremely weather resistant, cold and heat resistant roof coating the latest technology on the basis of unique nanostructured fluorine polyurethane acrylic polymer binder to recoating , restoration and long-term protection of purified roofing from concrete roof tiles, clay tiles, artificial slate, asbestos-free fibre cement and metal.	RELIUS Farbenwerke GmbH

4 PHOTOCATALYTIC COATINGS

Product Name	Description	Producer
Photocatalytic Nano TiO2	Self-healing titanium oxide-based glass coating, which has no byproducts affecting the environment. The material is sterile and is UV resistant.	42TEK
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), which 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, and the organic dirt on the surfaces is broken down due to the photocatalytic process.	AgroBuchtal
Fog Protect	DryWired® Fog Protect nanocoating technology enables transfer from different temperature environments without condensation issues. Fog Protect is ideal for application on work goggles, dive masks, car windows, mirrors, visors, ski goggles and many other transparent hard surfaces. Application can be done manually with a wipe or by liquid spray.	DryWired
ERLUS Lotus	ERLUS Lotus is the first self-cleaning clay roof in the world. The burned-in surface finish of Erlus clay roof tile destroys dirt particles, grease deposits, soot, moss and algae with the aid of UV light.	ERLUS
TA2219 coating	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
Pilkington Active	Self-cleaning glass	Pilkington
SunClean®	SunClean® is a long-lasting multi-functional self-cleaning glass from PPG Industries with a coating which includes nanoparticles of TiO2. In addition to its easy cleaning feature, it also reduces the transmittance of UV and increases the solar heat gain coefficient.	PPG Industries
BIOCLEAN	Self-cleaning glass	Saint-Gobain Glass
MAXIT Airfresh plaster	MAXIT Airfresh Plaster can be applied on ceilings and walls. Making use of nano-sized TiO_2 particles it includes in its formula and the so-called photocatalytic effect it eliminates unwanted odours, air pollutants and organic volatile compounds.	Saint-Gobain Weber GmbH
Top Glass NANO	Ready to use agent maintains glass surfaces, makes thin protective anti-static layer (titanium nano elements). Removes finger prints, grease stains, natural dirt and dust, recommended for: home, office	Tenzi Sp. z o.o.

	and car equipment. Does not leave streaks and has citrus aroma.	

5 Lighting LEDs

Product Name	Description	Producer
Crystalplex	Crystalplex produces patented industrial-scale sapphire quantum dots and proprietary down-converting diffuser technologies. It is a nano-illuminating technology for full-scale lighting.	Crystalplex
Nanowire light-emitting diodes (nLEDs)	Nanowire light-emitting diodes (nLEDs) are based on proprietary hetero-structured semiconductor nano-wire epitaxial growth and process technologies for which standard manufacturing equipment and materials can be utilised.	glō AB
RCLED & LED	Resonant cavity light emitting diode InGaAs/AlGaAs chips operating at 930nm, 960nm, 1170nm, 1240nm and 1270nm.	Innolume
Superluminescent Diodes (SLD, SLED)	A superluminescent light emitting diode is, similar to a laser diode, based on an electrically driven pn-junction that, when biased in forward direction, becomes optically active and generates amplified spontaneous emission over a wide range of wavelengths. The peak wavelength and the intensity of the SLD depend on the active material composition and on the injection current level. SLDs are designed to have high single pass amplification for the spontaneous emission generated along the waveguide but, unlike laser diodes, insufficient feedback to achieve lasing action. This is obtained through the joint action of a tilted waveguide and anti-reflection coated facets.	
LED phosphors	LED phosphors for white LEDs	Phosphor Technology Ltd.
Quantum Light™	Quantum dot based white LEDs	QD Vision

6 Lighting - OLEDs

Product Name	Description	Producer
CANVIS HRZ / HZM	OLED Pendant Mount Drape / Twist	Acuity Brands Lighting, Inc
CANVIS VRT / VTM	OLED Pendant/Wall Mount Screen / Pose	
KINDRED PM	OLED Pendant Mount	
KINDRED WM	OLED Wall Mount	
NOMI	OLED Straight and Curve Wall Sconces	
REVEL GCM	OLED Grid Ceiling Mount	
REVEL HCM	OLED Hard Ceiling Mount	
TRILIA	OLED Ceiling Mount TRI / STR Units	

ASON'S OLED	ASON'S OLED emits light with little colour change, independent of an angle.	ASON Technology Co.,Ltd.
OLEDs	Low power consumption OLED	Lumiotec
AMBER OLED	Large surface emission OLED	OLEDWorks GmbH
BRITE FL300	Very thin structure OLED panel	
BRITE FL300L	Smooth light OLED (can view the light source directly)	
Lumiblade	OLED lighting system	Philips Lighting
VELVE OLED	VELVE OLED lighting: color-tunabe and dimmable OLED lighting panels	Verbatim Americas, LLC.

7 Building insulation

Product Name	Description	Producer
Vitrification process	The AFP vitrification process is robust and is able to handle materials of high ionic character or with significant moisture content. Materials used in the process are fully oxidised and can be landfilled It finds applications in construction as abrasives, glass/mineral wool insulation, and ceramic tiles.	Advanced fibres and powders LLC
Airglass	Silica based aerogel	Airglass
Cryogel	Foam-like hydrophobic aerogels	Aspen Aerogels Inc.
Pyrogel		
Spaceloft		
Nanogel Thermal Wrap	Silica based aerogel	Cabot Corporation
BAYMER®	Baymer® is an insulating material for bonding foam that combines perfect insulation with state-of-the-art fire protection. Baymer® products are partially and fully formulated polyol blends combining all raw materials, auxiliaries and flame retardants which are necessary for a perfect polyurethane foam in the construction industry.	Covestro
Desmodur	The product is basically Diphenylmethane-Diisocyanate and Toluylene Diisocyanate. It has excellent insulation properties.	
Fixit 222 Aerogel High-Performance Insulating Plaster	Silica based aerogel	Fixit AG
NANOGEL	A new material, solid state; 90 to 99.8% of its composition is air. NANOGEL PROPERTIES: Low refractive index. Low density, 1000 times less dense than glass and 3 times denser than air. Excellent thermal insulator. High mechanical strength, supports more than 1000 times its own weight.	Graphendis

Aerogel	Silica based aerogel	MarkeTech International Inc.
HP-150 HT-170	VIP-based aerogels	NanoPore
Aerogel	Silica based aerogel	SEPAREX S.A.
Quartzene®	Silica based aerogel	Svenska Aerogel AB
CFOAM Carbon Foam	CFOAM can absorb 20-60% of a sound wave directed at it, depending on the frequency of the wave. The higher the thickness of insulation, the better is the sound absorption. The foam has also good insulation properties.	Touchstone Research Laboratory
Thermoskin	Silica based aerogel	Vinzenz Harrer GmbH

8 Hydrophobic / Oleophobic Nanocomposites

Product Name	Description	Producer
Wondergliss	Wondergliss, is a coating developed by Duravit together with Nanogate AG. This coating, which is commercially known as WonderGliss, has been used on sanitary ware ceramics e.g. at washbasins, toilets, bidets and urinals. WonderGliss deprives dirt of a suitable surface to attack - dirt and lime are unable to establish and hold on the smooth surface. Residues run off with the water droplets.	Duravit AG
ceramicplus	Villeroy Boch has a series of easy cleaning products under the name of ceramicplus. Ceramicplus provides an easy to clean and dirt repellent surface. This feature is obtained through a special finishing treatment.	Villeroy Boch

9 Concrete/ cement

Product Name	Description	Producer
Agilia™	Agilia™ by Lafarge, the world's first self-compacting, self-levelling concrete.	Agilia™
Chronolia™	Chronolia™ by Lafarge, quick-setting ready-mix concrete made possible by nanotechnology and the understanding of crystalline growth.	Chronolia™
Ductal™	Ductal™ by Lafarge is one of the first commercial concrete where steel bars are not used. It exhibits high mechanical strength, durability and self-healing properties.	Ductal™
MasterEmaco	MasterEmaco Nanocrete from BASF is a concrete-repair concrete with exceptional properties, improved bond strength, improved densities and impermeability, reduced shrinkage, improved tensile strengths and reduced cracking tendency. It also provides improved compatibility with concrete. This product has found applications in the renovation of office building in Brussels, in a	MasterEmaco

	wastewater plant in France, in the renovation of bridge structure in Spain, in a cooling tower, etc.	
PCI Nanosilent®	PCI Nanosilent® is a polymeric isolation mortar material developed by BASF. This material is a mixture of special polymers and rubber granules, which replaces mortar in concrete. In addition to giving flexibility to concrete, it also provides improved sound insulation. 15kg of Nanolight replace 25kg of flexible mortar.	PCI Nanosilent®
TiOCem®	TiOCem® is the commercial name of the cement with TX Active technology from Heidelberg Cement.	TiOCem®
TX Active™	TX Active™is a self-cleaning cement efficient in destroying atmospheric pollutants (collaboration of Heidelberg Cement and Italcementi). In Milan a commercial building's surface, 3000 m^2, is coated with TX Active™ cement from Italcementi. Iglesia Dives (Church) in Misericordia, IT, is a well-known building where TX Active cement was used. In addition to its self-cleaning property, TX Active® plays role in reducing pollution. Another example where TX Active was used for construction is the two white concrete gateway elements of the I-35W Bridge over the Mississippi River in Minneapolis, US.	TX Active™

10 OTHER

Product Name	Description	Producer
Transparent Ray Blocker Film	ANP produces IR blocking film and coating solutions. TRB Paste is UV-curable IR-shielding liquid containing ITO, ATO, and other ultra-fine compounds (solar control paste) with high vis ray transparency as well as high IR/UV blocking properties and is applied to window film in automobiles and buildings.	Advanced Nano Products
Carbon Nanotube-reinforced Epoxy (CNT Epoxy)	ANI's CNT-reinforced nanocomposite offers strong mechanical properties, which makes it a superior value added to the construction industry.	Applied Nanotech Inc.
Cereplast Sustainables®	Cereplast Sustainables® are biobased resins which are good replacement for petro plastics. The resins are suitable for durable applications primarily in automotive and construction. The company has developed a Bio-polyolefins® grades which can be used as construction materials.	Cereplast Inc.
ConsERV	ConsERV is the best fixed-plate ERV on the market worldwide, as validated by third-party rating agencies. The product raises the amount of indoor fresh air to meet ventilation building codes while saving up to 30% of energy costs, offering the potential to reduce the size of heating and cooling equipment by 1/3rd, while also reducing harmful CO_2 emissions by 1.95lbs per hour per ton of use avoided for the heating and cooling equipment.	DAIS analystics
Nansulate® HomeProtect	Nansulate® HomeProtect™ is a clear thermal insulation coating that lowers heating and cooling costs for families in all climates and seasons while also providing powerful protective benefits: Resistance to UV damage, moisture, and to mould	Industrial Nanotech Inc.

	and mildew growth. Simple do-it-yourself application that is low maintenance and as easy to apply as painting a wall.	
SPD-SmartGlass	Electronically tintable glass, which has the ability to change the tint of any window by aligning tiny particles electronically in a glass or plastic film. It has the ability to make buildings and homes comfortable, energy efficient. It can be used in windows, skylights, doors and partitions.	Innovative Glass Corporation
Pilkington Optilam	Pilkington Optilam is a high security glass, which remains in place even when broken. Different varieties of Optilam are produced for different applications i.e. noise control, solar control, UV screening, bullet and blast resistance or privacy. K-glass is a low-emissivity glass from Pilkington.	Pilkington
Solarban	Solarban is a low-E glass especially developed for hot climate regions by PPG Industries. The thin low-E coating blocks solar energy. It is said to let 64% less heat from the sun enter through window compared to an ordinary glass window.	PPG Industries
SunGate®	SunGate® is a low-E glass from PPG Industries aimed for the consumers in cold climate zones. SunGate transmits the sun's visible light and directs solar shortwave infrared energy into the home. It also reflects the heat energy (infrared wave) that comes from a building's heating system back to the building. Low-E coating present on SunGate glass is transparent and reduces the transmittance of UV light.	PPG Industries
COOL-LITE	COOL-LITE is a solar control glass produced by Saint Gobain Glass. It is manufactured by depositing a coating of metallic oxides by magnetically enhanced cathodic sputtering under vacuum conditions onto clear or body tinted glass.	Saint-Gobain Glass

ANNEX 7: HUMAN HEALTH AND SAFETY

INTRODUCTION

Exposure to nanomaterials in the construction sector may be quite diverse. Seven categories of categories of construction materials were identified within the NanoData project. All combinations of nanoparticles and sectors were evaluated. A risk-banding tool called Stoffenmanager Nano (Le Feber et al., 2014; Marquart et al., 2008; Van Duuren-Stuurman et al., 2012) was used to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios.

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.

HAZARD ASSESSMENT OF NANOPARTICLES NOT ASSESSED IN STOFFENMANAGER NANO

INTRODUCTION

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). Not for all nanomaterials of importance for the construction sector which are listed in the table, hazard banding has been performed within the context of Stoffenmanager Nano. For those nanoparticles toxicity data have been collected and hazard bands are derived according to the methodology described for "Stoffenmanager Nano" in van Duuren-Stuurman et al. (2012). In essence, it applies the toxicity classification rules of EU Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures. The method is summarised in the figure.

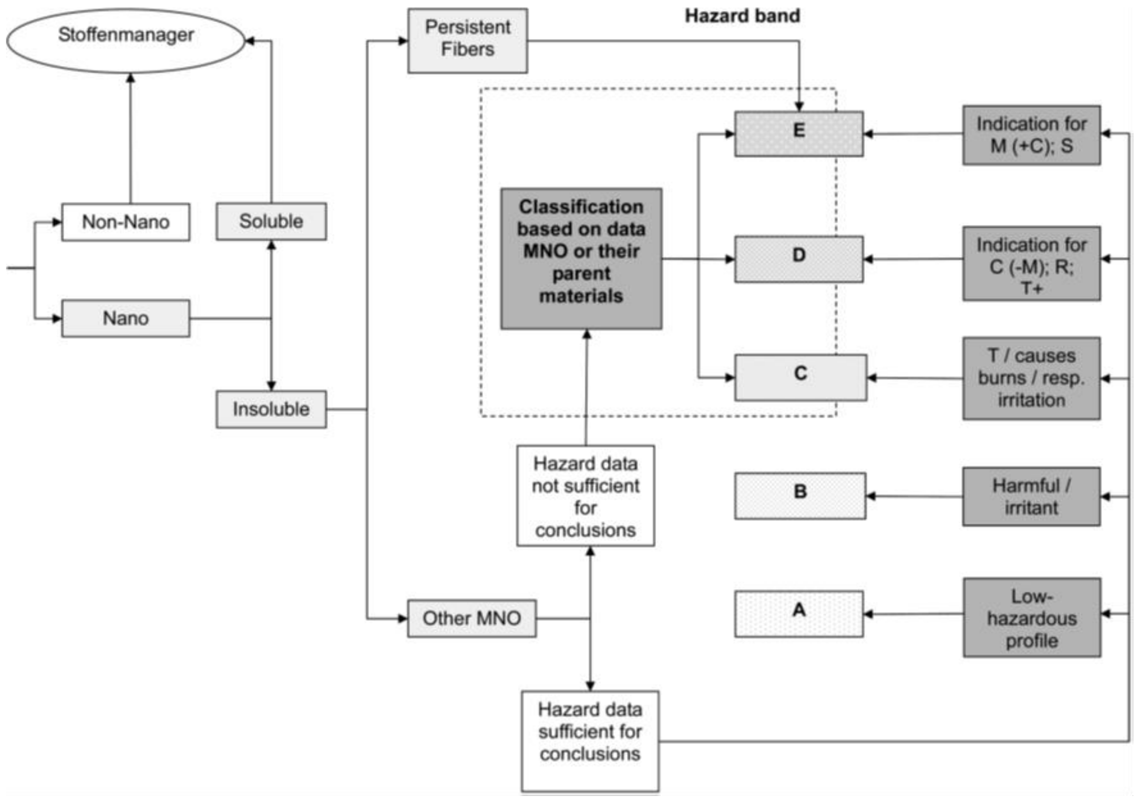

Figure 1: The stepwise approach of hazard banding of Stoffenmanager Nano (Van Duuren-Stuurman, et al. 2012)

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).

Carbon nanotubes (CNTs), single- and multi-walled

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. In addition, 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 (Palomaki 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.

Carbon nano-fibres (CNFs)

CNFs are related to CNTs (Fubini et al., 2011; NIOSH, 2013). The former consist of stacked graphite platelets, while the latter consist of graphite platelets rolled up in cylinders. Due to their graphitic structure, CNFs are highly insoluble, and thus highly biopersistent, and are not expected to be broken down when inhaled (Fubini et al., 2011). Fubini et al. (2011) have summarised the in vitro toxic properties of CNFs in comparison with carbon black, an extremely fluffy fine powder with a large surface area composed of elemental carbon (IARC, 2010), and CNTs. The most important observations are mentioned below.

Monocytic cells treated with CNFs entangled into aggregates of approximately 10 μm in diameter do not exhibit signs of incom¬plete uptake, unlike monocytic cells treated with straight and well-dispersed CNTs. Several studies show that the cytotoxicity of CNFs is very low. Different carbon nanoparticles in human lung-tumour cell lines all decrease the number of viable cells as a function of dose. The sequence of increasing potency in this test is carbon black < CNFs < CNTs. Carbon nanofibres have a low inflammatory potential. CNFs did not significantly stimulate inflammatory cyto¬kines, such as TNF-a in monocyte cells. Genotoxicity was assessed by the comet and the micronucleus assay in human bronchial epithe¬lial cells. While CNTs induced a dose-depen¬dent increase in DNA damage at all dose and treatment times, CNFs induced DNA strand breaks and chromosomal damage in human bronchial epithelial only after a long time of treatment with no dose dependence. However, CNFs containing iron impurities (<1.4% wt) showed a genotoxicity compa¬rable with asbestos and stronger than SWCNTs. (Fubini et al., 2011)

NIOSH (2013) has also reviewed in vivo test with CNFs and noted that exposure to CNFs can cause respiratory effects similar to those observed in animals exposed to CNTs. The longest duration study in which CNFs were tested in rats, in general the most sensitive species for respiratory insoluble particle overload, was a subchronic study with rats. Comparison of the results of this study with similar studies with other carbon nanoparticles, shows that CNFs are a less potent inflammatory agent than MWCNTs and of comparable potency as carbon black (CB).

Table 1 Comparison of the toxicity of CBNs in sub-chronic inhalation studies in rats

Parameter	CB	CNF	MWCNT	
			Baytubes	Nanocyl NC 7000
Adverse effects	Inflammatory effects like hyperplasia and interstitial fibrosis and impaired lung clearance (Elder et al., 2005)	Subacute to chronic inflammation of the terminal bronchiole and alveolar duct regions of the lungs, thickening of the interstitial walls and hypertrophy/hyperplasia of type II pneumocytes (Delorme et al, 2012)	Inflammatory changes in the bronchioloalveolar region and increased interstitial collagen staining, granulomatous changes, increase of a bronchioloalveolar hyperplasia (Pauluhn, 2010)	Pronounced multifocal granulomatous inflammation, diffuse histiocytic and neutrophilic inflammation, and intra-alveolar lipoproteinosis in lung and lung-associated lymph nodes (Ma-Hock et al, 2009)
NOAEL / BMD_{10} (µg deposited/lung)	226[a]	190[b]	28[c]	21[c]

[a] *NOAEL, calculated by Buist et al. (2016);* [b] *NOAEL, calculated by NIOSH (2013); $BMDL_{10}$, calculated by NIOSH (2013)*

Concluding, CNFs appear to be of comparable toxicity with CB and are less toxic than MWCNTs. Since MWCNTs are attributed to hazard band E and carbon black to hazard band D in Stoffenmanager Nano (Van Duuren-Stuurman et al., 2012), CNFs are placed in hazard band D.

Copper

No in vivo inhalation toxicity studies with metallic copper nanoparticles adequate for toxicological risk assessment were encountered in public literature. As metallic copper is insoluble in water, classification of the bulk material could be used to derive a hazard band for metallic copper nanoparticles. Bulk copper is not classified for human toxicological endpoints , which would mean it should be attributed hazard band C (Van Duuren-Stuurman et al., 2012). However, the ECHA registration dossier explicitly mentions the classification is only applicable to copper powders, with particle size > 10µm and <1 mm. Furthermore, like e.g. silver nanoparticles, copper nanoparticles are antimicrobials whose effectiveness increases with decreasing size (see e.g. Nuñez-Anita et al., 2014; Schrand et al., 2010) suggesting that nanocopper like nanosilver is more toxic than its bulk counterpart. Comparative in vitro evaluation of cytotoxicity showed nanocopper to even be slightly more cytotoxic than nanosilver (24h-IC50 in MTT assays with THP-1 cells 19 µg/mL for nanosilver and 1.7-6.5 µg/mL for nanocopper) (Lanone et al., 2009). Nanosilver has been attributed hazard band D (Le Feber et al., 2014), and based on the comparison mentioned above, nanocopper is attributed the same hazard band.

Graphene

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 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 (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). 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).

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 sulfate-coated cadmium selenide (CdSe(3)ZnS), and carbon nanotubes.

Intratracheal instillation of 50 µg GO in mice caused severe pulmonary distress after inhalation 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 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 (Seabra et al., 2014). Generalisations are therefore hard to make, but graphene nanostructures are not fibre-shaped and theoretically may be assumed to be more safe than carbon nanotubes (Seabra et al., 2014).

Based on the scarce available evidence, and in spite of its theoretical advantage in relation to carbon nanotubes, it cannot be excluded that some forms of graphene will be as potent a toxicant as carbon nanotubes. Therefore, graphene is assigned to hazard band E.

<u>Graphite nanoparticles</u>

Graphite is one of only three naturally occurring allotropes of carbon (the others being amorphous carbon and diamond and has a honeycomb lattice structure . According to Figarol et al. (2015), nanographite is synonymous with graphene, while Ma-Hock et al. (2013) make a distinction between graphene and graphite nanoplatelets, without being specific on how the one is distinguished from the other, both possessing the hexagonal graphite structure at the molecular level. As long the distinction between nanographite and graphene is not clear, it is considered to be one of the many forms of graphene and evaluated in that category (see section above).

<u>Iron oxide</u>

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.

<u>Molybdenum</u>

No toxicity studies on nanomolybdenum were encountered in public literature. It is insoluble in water (WHO, 2011). Due to this lack of data it therefore needs to be hazard banded based on the hazardous properties of its bulk parent compound (Van Duuren-Stuurman et al., 2012). Molydenum is classified by a considerable number of CLP-notifiers as a suspected reprotoxicant (category 2) . This is confirmed by the background data provided by the WHO, in which molybdenum is reported to impair male fertility at relatively high oral doses in rats and calves (ca. 4 mg/kg bw or more) (WHO, 2011). It should be noted it was not explicitly indicated that metallic molybdenum was dosed. Based on the self-classification of (bulk) molybdenum as a reprotoxicant, nanomolybdenum should be placed in hazard band E according to the criteria of Stoffenmanager Nano (Van Duuren-Stuurman et al., 2012).

Silicon carbide (SiC)

SiC occurs in several forms: (spherical) particles, fibres, and whiskers. SiC particles are manufactured (mostly for use as industrial abrasive) mainly by the Acheson process, with SiC fibres being unwanted by-products. SiC fibres are generally poly-crystalline and of variable length and diameter. They may include fibres that are indistinguishable from whiskers. SiC whiskers are intentionally produced by different processes as durable industrial substitutes for asbestos; they are physically homogeneous and mono¬crystalline, and their dimensions are similar to asbestos amphiboles (Grosse et al., 2014).

SiC nanoparticles were not genotoxic in an in vitro Comet assay nor were they cytotoxic (Barillet et al., 2009). However, SiC nanoparticles did cause oxidative stress reactions in vitro (Barillet et al., 2009; Pourchez et al., 2012) as well as inflammatory responses (Pourchez et al., 2012). Barillet et al. also investigated long and short CNTs as well as different nanoTiO2 compounds. SiC nanaoparticles were less potent than all the other particles on a per weight basis. The degree to which SiC nanoparticles caused these toxic reactions depended on surface area, crystallite size, nature of crystallite phase, and iron content (Pourchez et al., 2012).

The carcinogenicity of SiC fibres was investigated in two studies on workers who were exposed to fibrous and non-fibrous SiC, quartz, and cristobalite while involved in the production of SiC nanoparticles via the Acheson process. Based on these studies, occupational exposures associated with the Acheson process were classified IARC as carcinogenic to humans (Group 1) on the basis of sufficient evidence in humans that they cause lung cancer (Grosse et al., 2014). Since the correlation between exposures to SiC fibres and cristobalite made it difficult to disentangle their independent effects, IARC concluded that fibrous SiC is possibly carcinogenic to humans (Group 2B) (Grosse et al., 2014). No data on in humans exposed to SiC whiskers were available. In experimental animals, there was sufficient evidence for the carcinogenicity of SiC whiskers, with mesotheliomas observed in four studies in rats exposed by implantation or injection, or via inhalation study. Based on these studies, IARC classified SiC whiskers as probably carcinogenic to humans (Group 2A), on the basis that the physical properties of the whiskers resemble those of asbestos and erionite fibres, which are known carcinogens. In addition, the results of available mechanistic studies were consistent with proposed mechanisms of fibre carcinogenicity (Grosse et al., 2014). Grosse et al. (2014) did not explicitly discuss carcinogenicity of SiC nanoparticles.

Since SiC fibres and whiskers are persistent fibres and are suspected carcinogens, they should attributed hazard band E, according to Stoffenmanager Nano (Van Duuren-Stuurman et al., 2012). SiC nanoparticles are not genotoxic, be it based on scant evidence, but exhibit characteristics (ROS formation, inflammatory responses) similar to e.g. 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), consequently the same hazard band is attributed to SiC nanoparticles.

Silicon dioxide nanoparticles, crystalline

Classified by Stoffenmanager Nano in hazard band E (Van Duuren-Stuurman et al., 2012).

Silicon dioxide nanoparticles, synthetic amorphous

In an update on some oxide nanoparticles hazard band B was attributed to synthetic amorphous zinc oxide nanoparticles (Le Feber et al., 2014)

Titanium dioxide

In an update on some metal oxide nanoparticles hazard band C was attributed to titanium dioxide nanoparticles (Le Feber et al., 2014).

Tungsten Oxide

No toxicity studies on nano tungsten oxide were encountered in public literature. It is insoluble in water (ATSDR, 2005). Due to this lack of data it therefore needs to be hazard banded based on the hazardous properties of its bulk parent compound (Van Duuren-Stuurman et al., 2012). There is no official EU classification for tungsten oxide and most registrants have not (self)classified tungsten oxide, while some have classified it as possibly carcinogenic . In the registration dossier published by ECHA, no data supporting one or the other conclusion have been submitted . ATSDR has published a toxicity profile for tungsten (ATSDR, 2005) as well as an update of the earlier profile (ATSDR, 2015). Its sodium salt (sodium tungstate) is not mutagenic in the Ames test nor did it cause chromosome aberration in vitro, but it did prove to be mutagenic in the Chinese hamster lung V79 cell HGPRT forward mutation assay (ATSDR, 2005). Sodium tungsten dehydrate was negative in in vivo micronucleus tests in rats and mice, but positive in in vivo Comet assays in mice (ATSDR, 2015). Alloys with cobalt and tungsten carbide are carcinogenic when implanted in mice. It is unclear whether cobalt or tungsten is the causative agent. A drinking water carcinogenicity study with sodium tungstate dehydrate has been performed by the NTP (ATSDR, 2015), but so far the results have not been published (NTP site last checked on March 7, 2016). Epidemiological studies did not show an association between tungsten exposure (as measured by urinary tungsten levels) and carcinogenicity, however the power of the studies was too low to draw definitive conclusions (ATSDR, 2015). Concluding, there are indications tungsten oxide may be a mutagenic carcinogen and therefore tungsten oxide nanoparticles should be attributed hazard band E according to the criteria of Stoffenmanager Nano (Van Duuren-Stuurman et al., 2012).

<u>Vanadium pentoxide (divanadium pentaoxide)</u>

No toxicity studies on nanovanadium pentaoxide were encountered in public literature. It is soluble in water and can therefore be hazard banded based on the hazardous properties of its bulk parent compound (Van Duuren-Stuurman et al., 2012). Vanadium pentoxide is classified in the EU as reprotoxic and mutagenic and should therefore be assigned to the highest hazard band, E.

<u>Zinc oxide nanoparticles</u>

In an update on some metal oxide nanoparticles hazard band B was attributed to zinc oxide nanoparticles (Le Feber et al., 2014).

EXPOSURE ASSESSMENT

<u>Cement/lime concrete and mortars and other derivatives</u>

Concrete is widely used in the world. An ordinary concrete is a mixture of cement, sand, gravel and water. Additives are added to achieve some special properties, e.g. to increase strength, hardness or corrosion resistance. Among these additives, silica fumes are very important materials. By adding microsilica high performance concrete is produced, but by using nanosilica ultra-high performance concrete is formed, which is used increasingly . In addition, nanotitania particles have also been added in concrete due to its self-cleaning properties at the surface.

Furthermore, CNTs and CNFs are being incorporated in concrete, as both fill the pore spaces in concrete more effectively compared to more conventional fillers like sand. CNF are considered to be superior over CNTs because their stacked structure has exposed edges increasing surface area and thus improving bonding characteristics.

In "Stoffenmanager Nano" sets of exposure scenarios are assigned to exposure bands labelled 1 to 4 (1=low exposure, 4= highest exposure). As explained in the introduction, only respiratory exposure is considered here.

The likelihood of exposure to nanoparticles during handling cement, concretes etc. is highly dependent upon the type of process and the type of equipment involved in the process. Nevertheless, the usage (building phase e.g. mixing, dumping, transferring) of powder materials results in the highest exposure potential (4). If the nanomaterial is included in a liquid mixture (the cement/concrete, building phase) the exposure potential is highly reduced (2). If the nanomaterial is in a matrix (use phase, hardened cement/mortal) the exposure potential is low (1). During abrasive activities (demolition phase) on the cement/concrete the worker can be exposed to nanomaterials but the exposure potential is still relatively low (2).

<u>Steel: Nano-modified steel and nano-additions to steel</u>

In addition to carbon and iron, some compounds like copper, vanadium oxide and molybdenum may been added to steel as nanoparticles. The likelihood of exposure to nanoparticles during the handling of nano-additions in powder form results in the highest exposure potential (building phase, 4). If the nanomaterial is in the steel the exposure potential is low (use phase, 1). Abrasion of an object which includes nanomaterial may result in exposure to steel aerosols which include nanomaterials, resulting in an relative low exposure potential (demolition phase, 2).

<u>Glass: self-cleaning, energy-saving windows</u>

Nanomaterials (titanium dioxide) are used in glass for itself cleaning properties and to reduce the sunlight and heat entering the building. If the nanomaterial is in the glass the exposure potential is low (use phase, 1). Handling powder titanium dioxide to produce the glass results in an highest exposure potential (building phase, 4).

Heat insulation materials

The use of nanomaterials (e.g. nanoscale silica, graphite or silicon carbide) in this category include aerogels and vacuum insulation panels for heat insulation. In the occupational setting powder nanomaterials can be handled resulting in the highest exposure potential (building phase, 4). If the nanomaterial is in the matrix of the insulation material the exposure potential is low (use phase, 1).

Wood material

Nanomaterial based coatings applied to wood material or wood composites are improving the functionalities (durability, water resistance, fungi resistance) of wood as a construction material. However, this is described under coatings and paints below.

Coatings and paints

Paints or coatings are frequently used in construction to protect the surface from harmful weathering effects. In addition, they also provide beauty to the surface. Paints are composed of base, vehicle or binder, solvent or thinner, drier and colouring pigments. In addition, several nanomaterials (e.g. TiO_2, ZnO, SiO_2) are applied in coating for self-cleaning properties, better water resistance etc. Naturally, silica dioxide can be present as amorphous or crystalline nanoparticles, but in most applications the amorphous form is used (Kaiser et al., 2013). In the building phase, the exposure potential is relatively low (2) since the nanomaterial is dispersed in the coating, except when the coating is sprayed on a surface, then the exposure potential is high (4). If the coating is on the surface the exposure potential is again low (use phase, 1).

Sensors and self-healing materials

We did not received any information about nanomaterials in this category. We assume that in this category no nanomaterials are used and just nanotechnology is applied (that is, involving processes on nanoscale).

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 emphasized 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)

Roughly four phases can be discerned in the life cycle of construction materials: production, building, use and demolition. In principle, production is covered in the sector report on manufacturing, consequently this report is limited to the building, use and demolition phases. If in a phase different degrees of exposure may occur, the highest exposure scenario is taken into account in the risk assessment (worst case scenario).

The evaluation below is not applicable to wooden building materials, and sensors and self-healing materials; for the first category of building materials no nanomaterials were discovered in the market inventory, for the second category it is assumed they may contain nanostructures without the presence of nanomaterials. For all remaining categories, the building phase generates the highest exposure (worst case exposure always in band 4), the use phase the lowest (exposure band 1) and the demolition phase intermediate (exposure band 2). The resulting risk priority bands are listed in Table 2.

Table 3: Priority bands in the Stoffenmanager Priority bands for the construction sector

Nanomaterial	Hazard band	Exposure band		
		Building phase	Use phase	Demolition phase
		4	**1**	**2**
Carbon nanotubes/nanofibres	E	1	1	1
Copper	D	1	2	2
Graphene / nanographite	E	1	1	1
Iron oxide	D	1	2	2
Molybdenum	E	1	1	1
Silicon carbide, fibres and whiskers	E	1	1	1
Silicon carbide, spherical particles	C	1	3	2
Silicon dioxide (silica), crystalline	E	1	1	1
Silicon dioxide (silica), synthetic amorphous	B	1	3	3
Titanium dioxide (titania, rutile, anatase)	C	1	3	2
Tungsten oxide	E	1	1	1
Vanadium pentoxide	E	1	1	1
Zinc oxide	B	1	3	3

Due to the high expected exposure all nanomaterials reach the highest risk priority during the building phase.

In the use phase, amorphous silicon dioxide, titanium dioxide, spherical SiC and zinc oxide nanoparticles have a low risk priority while carbon nanotubes, molybdenum, nanographite, silicon carbide fibres and whiskers, crystalline silicon dioxide, tungsten oxide and vanadium pentoxide have the highest risk priority and the remainder of the nanomaterials has an intermediate risk priority. It should be noted that in the use phase all nanomaterials are contained in a solid matrix, meaning exposure will be negligible and thus health risks will be low.

In the demolition phase, risk management/evaluation of building materials containing carbon nanotubes, molybdenum, nanographite, silicon carbide fibres and whiskers, crystalline silicon dioxide, tungsten oxide and vanadium pentoxide should receive the highest priority, while amorphous silicon dioxide and zinc oxide have a low risk priority. The building materials containing the remainder of the listed nanomaterials should receive intermediate priority during the demolition phase.

REFERENCES

Bomhard, E.M., Gelbke, H., Schenk, H., Williams, G.M., Cohen, S.M., 2013. Evaluation of the carcinogenicity of gallium arsenide. Crit. Rev. Toxicol. 43, 436-466.

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.

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.

Foster, C.M., Collazo, R., Sitar, Z., Ivanisevic, A., 2013. Aqueous stability of Ga- and N-polar gallium nitride. Langmuir 29, 216-220.

Jewett, S.A., Makowski, M.S., Andrews, B., Manfra, M.J., Ivanisevic, A., 2012. Gallium nitride is biocompatible and non-toxic before and after functionalization with peptides. Acta Biomater. 8, 728-733.

Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles. TNO2014 R11884.

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.

Nezakati, T., Cousins, B.G., Seifalian, A.M., 2014. Toxicology of chemically modified graphene-based materials for medical application. Arch. Toxicol. 88, 1987-2012.

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.

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 prioritization of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

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.

Yang, K., Wan, J., Zhang, S., Zhang, Y., Lee, S., Liu, Z., 2011. In vivo pharmacokinetics, long-term biodistribution, and toxicology of pegylated graphene in mice. ACS Nano 5, 516-522.

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.

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