European Commission

NanoData Landscape Compilation

Manufacturing

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EXECUTIVE SUMMARY

Background

Nanotechnology manufacturing in this project includes both nanotools and nanomaterials. The tools can be used for manufacture at the nanoscale (e.g. lithography and imprint tools) or for measurement at the nanoscale (e.g. atomic force microscopes). Nanomaterials include solid particles, thin films, quantum dots, carbon nanotubes, graphene, nanostructured materials, etc. The processes for manufacturing nanomaterials may be bottom-up (synthesis from atoms or molecules through a physical or chemical reaction) or top-down (progressive removal of material to reduce material size).

Policies

National policies to support nanotechnology manufacturing in Europe are largely generic at Member State level in that they support nanotechnology within broad science and technology initiatives or support it as a designated priority but usually do not single out nanotechnology manufacturing specifically. Examples of nanotechnology initiatives in which nanotechnology manufacturing is specified include: the German NanoFab programme which began as early as 2001 and ran until 2014; the Austrian NanoInitiative, nano manufacturing being one of nine priority areas; the Spanish Strategic Action for Nanoscience and Nanotechnology, New Materials and New Industrial Processes (SANSNT); the French Agence National de la Recherche (ANR) with the P2N programme targeting national excellence in the areas of micro and nano-engineering; and the Dutch NanoNed, with its eleven independent programmes or flagships (amongst which were Bottom-up Nano-Electronics and NanoFabrication) and its successor NanoNextNL, with its strong support from manufacturing industry.

At European level, the main policies centre on the Framework Programmes (FPs), the first targeted initiative for nanotechnology being for Nanotechnologies and nanosciences, knowledge-based multi-functional materials and new production processes and devices (NMP) under FP6. Activities relevant to nanotechnology manufacturing continue to be supported under FP7, not just basic and applied research but also capacities, skills and mobility. European policies support numerous public-private partnerships including ENIAC[1], EuMat[2], Manufuture[3], M-era.net[4] and MANUNET[5].

Key Enabling Technologies (KETs)[6] are a priority for European industrial policy. The European Strategy for KETs aims to increase the exploitation of KETs in the EU and to reverse the decline in manufacturing to stimulate growth and jobs.

EU R&D projects

For projects at the European level, nanosciences and nanotechnologies (NT) were first provided for at a significant level in the European Sixth Framework Programme (FP6), taking about 10% of the budget (EUR 1,703 million for NT out of a total of EUR 16,692 million for FP6), mainly under the headings of NMP[7], Information Society, Life Sciences and Human Resources and Mobility.

The number of projects in FP6 and FP7 together that were related to nanotechnology manufacturing was 396, 11.2% of the NT total. The percentage of nanotechnology manufacturing projects was lower in FP7 (10.8%) than it was in FP6 (12.2%). FP7 participations make up 64% of total nanotechnology manufacturing participations and FP6 participations make up 36% for both nanotechnology manufacturing and for FP overall. For nanotechnology participations, FP7 make up 65% and FP6 35%, very similar to the overall FP participation percentages and those for

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[1] The ENIAC Joint Undertaking (JU) is a public-private partnership focusing on nanoelectronics http://www.eniac.eu/web/index.php

[2] The European Technology Platform for Advanced Engineering Materials and Technologies

[3] The European Technology Platform for the manufacturing of high-added-value products, processes and services and related high-skills employment

[4] An EU funded network established to support and increase the coordination of European research programmes and related funding in materials science and engineering

[5] A network supporting SMEs in new processes, adaptive manufacturing systems and the factory of the future

[6] KETs are: Advanced Materials, Nanotechnology, Nano & Microelectronics, Photonics, Biotechnology and Advanced Manufacturing

[7] Nanotechnologies and nanosciences, knowledge-based multi-functional materials and new production processes and devices

nanotechnology manufacturing.

The 396 nanotechnology manufacturing projects received an EC contribution of EUR 656 million, EUR 155 million (24% of nanotechnology manufacturing funding across the two FPs) in FP6 and EUR 501 million (76%) in FP7. In FP6, the EC contribution for nanotechnology manufacturing represented 9.1% of the total nanotechnology EC contribution, whereas in FP7 it was 10.8%.

In FP6, the Thematic Priorities of NMP and IST[8] together were the recipients of 73.5% of the funding for nanotechnology manufacturing. There was also an 8.2% allocation for Specific Activities such as Horizontal research activities involving SMEs (4.2%) and Policy support and anticipating scientific and technological needs (3.8%). 48 projects for Human Resources and Mobility received 12.8% of total nanotechnology manufacturing EC funding.

In FP7, the largest amount of funding for nanotechnology manufacturing (42%) was for NMP[9] with 46 projects. ERC had the next highest funding (22%,) followed by ICT (20%) and Marie Curie Actions (9%).

Five countries (DE, UK, FR, IT and NL) jointly received over half (58.2%) of the total funding for nanotechnology manufacturing, although over 30 countries engaged in some way.

Higher education institutes received close to half (48.8%) of the EU funding of nanotechnology manufacturing under the FPs, followed by research organisations (28.8%), small and medium sized companies (11.8%) and large companies (9.5%).

The organisations receiving the largest amounts of funding for nanotechnology manufacturing activities were the CNRS[10] (FR), Fraunhofer[11] (DE), the University of Cambridge (UK), the CNR[12] (IT) and the CEA[13] (FR). The most active companies in FP nanotechnology manufacturing projects by funding are led by Mapper Lithography of the Netherlands. The majority of company participants are large companies (6 of the top ten by funding) including IBM, Thales, Philips, Airbus and Johnson Matthey. STMicroelectronics occurs three times in the table, the three together having the highest number of projects (11) and the highest funding (EUR 3.87)[14]. Otherwise, the highest number of projects for any one company is seven (IBM and Micro Resist).

Publications

Approximately 30% of overall manufacturing publications in any year between 2000 and 2014 have nanotechnology-related content. In terms of geography, the most prolific publishers were in China and the USA, followed by Korea, India, Japan, Germany and France.

Within the EU28, researchers in Germany and France generated the largest number of publications in 2014, followed by the United Kingdom (UK), Italy, Spain and Poland. EU28 and EFTA higher education and research organisations were led by the University of Cambridge (UK) and the Polish Academy of Sciences (each with over 100 publications in 2014). Four of the top fifteen were based in Germany, two each the UK, Belgium and Sweden. There was, however, no normalisation of the data to take into account factors influencing publication output, such as the number of research personnel or the research budgets in those institutions.

Publishing also takes place in companies (mostly at a much lower level in terms of numbers of publications annually), those with the most nanotechnology manufacturing publications globally in 2014 being IBM and Samsung, both with around 40 publications, twice the number of the company with the next highest number of publications, NTT[15].

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[8] Information Society Technologies

[9] Nanosciences, Nanotechnologies, Materials and new Production Technologies

[10] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr

[11] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.www.fraunhofer.de

[12] Consiglio Nazionale Delle Ricerche, the Italian National Research Council https://www.cnr.it/en

[13] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr

[14] STMicroelectronics is shown in the eCorda database three times in the top 25 companies as ranked by funding received. While one of the three is in Italy, the other two are at the same location in France. The data have not been aggregated in the table in case of double counting.

[15] Nippon Telegraph and Telephone Corporation

Patenting

Applicants from the Netherlands, Germany, France and the United Kingdom are at the forefront of the European countries in terms of numbers of patents both granted and applied for (using patent families as the measure). Indeed, the same top ten countries led the ranking by number of applications as by patents granted, for EU and EFTA countries. Patenting globally is greatly dominated by the US, Japan and Korea.

In patent applications by EU28 & EFTA universities and public research organisations, French organisations perform the most strongly (with two in the top 10, CNRS and CEA). Similarly for patents granted (ranked by the highest number of EPO patents 1993 to 2011), of the top 15 universities and research organisations, the same two French organisations in evidence from the EU28/EFTA countries, together with Fraunhofer[16] (DE). Four of the organisations with patents granted are from the US, four from Korea and two from Japan.

Of the top ten companies with the highest number applications by patent families, four are in the United States, two in the Netherlands (ASML and Mapper Lithography) and one in Germany (Carl Zeiss).

Products and markets through nanotechnology[17]

The products identified, over 200 in number, were approximately one third nanotools and two thirds nanomaterials. The majority of nanotool products were for nanolithography (35), microscopy (18) and nano-manipulation (14) while the majority of the nanomaterials were solid nanoparticles (36), carbon nanotubes (30) and nanoscale thin films (25). Nanolithography products include gratings, focussed ion-beam systems and imprinting systems; microscopy tools include atomic force microscopes and related equipment; and nano-manipulation tools include actuators and positioning tools. Solid nanoparticles include powders, wires, fibres, rods and dots but, in this case, carbon nanotubes and graphene are considered separately.

In total, 89 companies were identified for nanotechnology manufacturing, 22 of them producing nanotools and 69 producing nanomaterials[18]. The largest number of companies in any category was producers of graphene, with 18 companies manufacturing 18 products.

The global market value of nanotechnology tools was estimated at USD 5.3 billion in 2014 and is forecast to grow to USD 11 billion in 2019, largely based on demand for and technological advances in current and novel nanolithography products. The applications of nanotools are estimated to reach an additional USD 6 billion by 2019.

The global market for nanomaterials was estimated to be USD 18 billion in 2013 and forecast to grown to USD 52.7 billion in 2019. The largest market value is for thin films while nanocomposites and carbon nanotubes are expected to have the highest growth rates.

Regulation and standards

There is no specific legislation that addresses manufacturing processes for nanomaterials. There are mandatory reporting schemes, known as nanomaterial registries, which monitor activity on manufacturing of nanomaterials (including their importation and distribution).

The EU is actively developing a set of regulations around nanotechnology. REACH[19] has been given a central role in regulating nanomaterials and, since the summer of 2013, there has been ongoing work to adapt the Annexes of REACH to specifically address nanomaterials. One of the milestones in the development of a European Regulatory Framework for nanotechnologies 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’.

In parallel to developments at European Union level, some Member States have sought to find additional ways to regulate nanotechnologies including databases and reporting schemes, which are relevant but not specific to nanotechnology manufacturing. Particularly active in the area are

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[16] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

[17] NanoData project (for products) and BCC Research (for markets)

[18] Two are in both categories

[19] Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals

Belgium, Denmark and France. Norway, Sweden and Italy are also considering options for a registration scheme for nanomaterials.

Environmental health and safety

Nanotechnology manufacturing was reviewed[20] with regard to the health risks occurring as a result of respiratory exposure to nanoparticles of workers and consumers. The respiratory route is the main one for exposure for many occupational scenarios. Nano-specific systemic toxicity via the skin is considered to be improbable in this sector as the nanoparticles as are very unlikely to penetrate it. The oral exposure route is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices.

The majority of the materials considered have a high priority (combined ranking of exposure and hazard), indicating the need to apply exposure control methods or to assess the risks precisely. Copper indium gallium arsenide, copper oxide, graphene, multi-walled and single-walled carbon nanotubes, nickel monoxide, crystalline silicon dioxide and vanadium pentoxide are of the highest priority ranking across all production methods considered here. Calcium carbonate, titanium dioxide, zinc oxide and zirconium dioxide showed the lowest priority profiles of the materials considered, although for some production methods most are still ranked as being of the highest priority.

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[20] Using the risk-banding tool Stoffenmanager Nano

1 BACKGROUND

1.1 Context

This report is concerned with nanotechnology manufacturing. This is a theme that underlies all the other sectors under consideration in the NanoData project as all sectors are concerned with the use of manufactured nanomaterials (e.g. for health, energy, transport and ICT).

Nanotools and nanomaterials are both covered in this report. Nanotools are used to manufacture and control manufacturing at the nanoscale (e.g. lithography and imprint tools, nano-positioning tools and nano-actuators) or for measurement at the nanoscale (e.g. atomic force microscopes). Nanomaterials include solid particles, thin films, quantum dots, carbon nanotubes, graphene, nanostructured materials, etc. The processes for manufacturing nanomaterials may be bottom-up (synthesis from atoms or molecules through a physical or chemical reaction) or top-down (progressive removal of material to reduce material size).

The abbreviation MF may be used in the report for nanotechnology manufacturing. In addition, the following abbreviations are used for the five groups of methods under consideration: BM (ball milling); GV (gas- and vapour-phase methods); LP (liquid-phase methods); SA (self-assembly); and TD (top-down). These methods are discussed in the section of the report on nanotechnology manufacturing methods (Section 2.2).

Unless otherwise stated in the text, the data has been extracted[21] from the NanoData project database compiled from a wide range of statistical sources (e.g. European Commission, publications databases, patent office databases, etc.) and primary research via literature review and other data collection methods (e.g. interviews).

The report examines nanotechnology manufacturing from the perspectives of:

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

The next section will consider the role of nanotechnology.

1.2 Introduction to nanotechnology manufacturing

1.2.1 Overview

This section draws on several reference documents[22, 23, 24, 25].

Nanotechnology manufacturing techniques have long been grouped into two categories: top-down and bottom-up. In bottom-up processes, the material is synthesised from atoms or molecules through a physical or chemical reaction. Top-down processes start with a bulk material and either break it into smaller pieces or selectively remove material to impart nanoscale features into or onto the bulk material (e.g. thermal evaporation of layers). Some top-down techniques are quite crude in their approach – e.g. milling and grinding – while others appear more refined – e.g. etching and lithography. Both bottom-up and top-down manufacturing processes can take place in solid, liquid or gas states as well as in vacuum. The UK Royal Society and Royal Academy of Engineering (2004)

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

[22] http://www.nano.gov/nanotech-101/what/manufacturing

[23] http://www.slideshare.net/NANOYOUproject/fabrication-methods-nanoscience-and-nanotechnologies

[24] http://www.azonano.com/article.aspx?ArticleID=1079

[25] https://sites.google.com/site/ionlaben/services/plazmenno-dugovoe-osazdenie

have classified bottom-up and top-down nanotechnology manufacturing approaches as shown in the diagram[26] below.

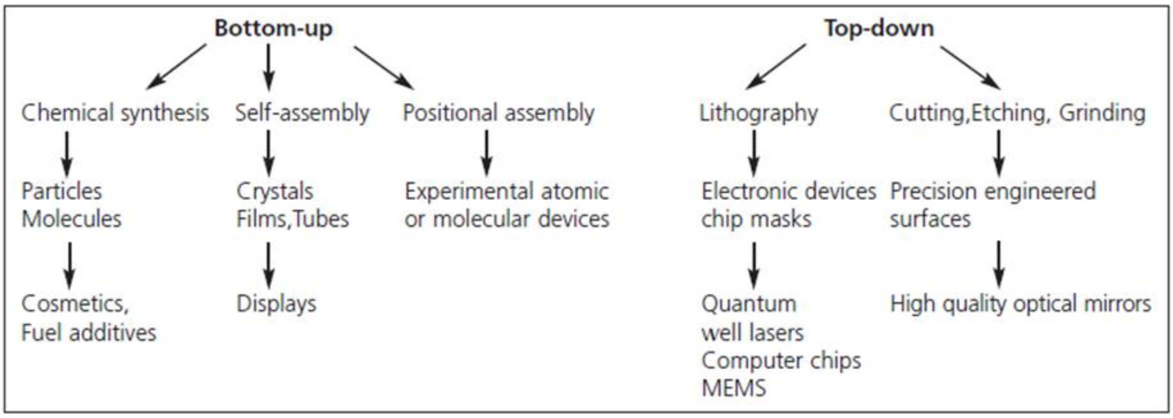

Figure 1-1: Bottom-up and top-down nanotechnology manufacturing approaches

1.3 Nanotechnology manufacturing methods

In this section, the bottom-up and top-down nanotechnology manufacturing processes will be described, together with an indication of the type of end-product resulting from each process.

1.3.1 Bottom-up processes

Bottom-up processes can be categorised as being either (i) gas- or vapour-phase processes; (ii) liquid-phase processes; or (iii) self-assembly.

GAS- AND VAPOUR-PHASE METHODS

There are several methods of producing nanomaterials by deposition from a gas or vapour.

- *Physical Vapour Deposition* (PVD) is the physical deposition of material from a gas or vapour (gaseous state) onto a surface by condensation. The starting material can be in solid or liquid form and is vaporised, often at a high-temperature in a vacuum, and then condensed onto a surface.

  Nanomaterials produced include: coatings, films

- *Chemical Vapour Deposition* (CVD) is a method by which a material is deposited from a gas or vapour (gaseous state) onto a substrate via a chemical reaction. The process is temperature activated – at high temperature (for thermal CVD) or a lower temperature if a plasma (an ionised gas) is used (Plasma-Enhanced CVD, PECVD). Metal oxides are routinely produced by the CVD method (also known as Metal-Oxide CVD or MOCVD). Atomic Layer Deposition is a form of CVD which results in the deposition of single layers of atoms which can be built up sequentially into a film or coating.

  Nanomaterials produced include: coatings, films, nanotubes, graphene, dendrimers, fullerenes, wires, rods

- *Plasma-arcing* uses a plasma (ionised gas) produced with a high current of electricity and contained within a vacuum chamber. The nanomaterial is deposited either as free particles (e.g. carbon nanotubes) or as a surface coating. In effect, the process is consuming one material and depositing it either as the same or a modified material in a different structural form.

  Nanomaterials produced include: particles, coatings, nanotubes

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[26] "Nanoscience and nanotechnologies: opportunities and uncertainties", Nanosciences and Nanotechnologies, the Royal Society and the Royal Academy of Engineering, July 2004. https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2004/9693.pdf

- *Molecular Beam Epitaxy (MBE*) is an evaporation method that uses beams of molecules focussed onto a surface to grow a structure such as a crystalline film. By minimising contamination, it is possible to produce a very pure layer of a uniform structure or high-purity, regular crystals.

Nanomaterials produced include: films, coatings, particles

- *Spraying* is a method in which a gas or liquid in aerosol form (or a mixture of both) is decomposed in a high-energy flame (plasma or laser-generated). The constituents decompose and typically form nanomaterials by nucleation and growth. Spraying can be used to dry the material and/or deposit it as a coating onto a surface which may be heated. Examples of this method include *thermal spraying, plasma spraying and flame spraying.*

Nanomaterials produced include: coatings, particles

LIQUID-PHASE METHODS

- In the *sol-gel* method, a colloid (a solid in suspension) is first created. Hydrolysis, condensation and polymerisation then take place, followed by agglomeration of the substance into a thickened gel. Sol-gel materials (e.g. silica gels) can also form precursors for other nanomaterials. Fibres can subsequently be produced from the colloid and powders from the gel. The gel can also be dried and sintered (heated) to form ceramics.

Nanomaterials produced include: gels, particles, fibres.

- *Solution phase synthesis* and *molecular seeding* can be used to grow materials out of solution by arrested precipitation.

Nanomaterials produced include: quantum dots, dendrimers

- *Electro-spinning* involves taking a drop of dilute polymer solution and charging it with a high voltage so that a cone of material forms and a fibre (or bundles of fibres) spins out of the end of the cone in the form of a fine jet.

Nanomaterials produced include: fibres

SELF-ASSEMBLY

Chemical and biological self-assembly are processes in which materials form by selective bonding between molecules (e.g. on surfaces), preferential self-ordering and self-docking, and bio-molecular recognition and attachment. In effect, the materials build themselves because of attractive forces due to their (largely chemical or biological) characteristics.

Nanomaterials produced include: dendrimers, biomaterials such as cells, lipids, peptides, micelles.

1.3.2 Top-down processes

Top-down processes include lithography, printing and etching.

- *Nanoimprint lithography* is used to create nanoscale features by printing onto a surface. There are several methods including
    - Thermoplastic nanoimprint lithography (T-NIL), in which a layer of thermoplastic polymer is put onto a surface, pressed onto a mould, heated and then cooled leaving a pattern on the polymer; and
    - Photo nanoimprint lithography (P-NIL), in which a light-curable liquid is applied to a surface, pressed onto a transparent mould and light is used to cure the material which retains the imprint of the mould.
- *Dip-pen lithography* uses an atomic force microscope (AFM) as a mechano–electrochemical pen to “write” with atoms on a surface.
- *Nanocontact printing*, in which a pattern is stamped onto a material. The stamps are prepared using lithography and a thin layer of material is used to coat them. The stamp is pressed onto the material, leaving a thin layer behind (some curing process may be required).
- *Reactive ion etching,* which uses a chemically-active plasma to selectively remove (etch) layers of material from a substrate.

Nanomaterials produced include: layers and coatings

Ball milling uses balls in a mill to progressively break down a material, such as a powder, into finer and finer particles by impact and attrition. The balls are typically made of steel or rubber. It is a rather crude technique and is often used to prepare material for a second production process. Ball milling can also be used to produce alloys through cold welding.

Nanomaterials produced include: particles

The next section reviews the policies relevant to nanotechnology manufacturing that are in place at European Union and Member State levels. The area of environmental health and safety will be considered in a later section (see the section on *The Wider Environment*).

2 EU POLICIES AND PROGRAMMES FOR NANOTECHNOLOGY MANUFACTURING

The actions being taken to support for public sector research and development (R&D) in the European Union are 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), Member State funding and 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 (formerly the Seventh Framework Programme (FP7), 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 Connecting Europe Facility[27], the Third Health Programme[28], Life[29], Erasmus+[30] and COSME[31].

This section will first examine the EU Framework Programmes.

2.1 The EU Framework Programmes: supports for nanotechnology

The Framework Programmes, being the largest source of EU funds for R&D, 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)[32]. NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had the largest amount of nanotechnology manufacturing funding at over 54% of the total.

The NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had the largest number of manufacturing nanotechnology projects and over 50% of the total FP6 manufacturing nanotechnology funding.

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

- Nanosciences and nanotechnologies - studying phenomena and manipulation of matter at the nanoscale and developing nanotechnologies leading to the manufacturing of new products and services;
- Materials - using the knowledge of nanotechnologies and biotechnologies for new products and processes;
- New production - creating conditions for continuous innovation and for developing generic production 'assets' (technologies, organisation and production facilities as well as human resources), while meeting safety and environmental requirements; and
- Integration of technologies for industrial applications - focusing on new technologies, materials and applications to address the needs identified by the different European Technology Platforms

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

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

[29] For environment, biodiversity and climate change.

[30] Supporting relocation for education and training purposes.

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

[32] 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.

(see also below).

Nanosciences and nanotechnologies - studying phenomena and manipulation of matter at the nanoscale and developing nanotechnologies leading to the manufacturing of new products and services;

- Materials - using the knowledge of nanotechnologies and biotechnologies for new products and processes;
- New production - creating conditions for continuous innovation and for developing generic production 'assets' (technologies, organisation and production facilities as well as human resources), while meeting safety and environmental requirements; and
- Integration of technologies for industrial applications - focusing on new technologies, materials and applications to address the needs identified by the different European Technology Platforms (see also re ETPs below).

There are many other initiatives under FP7 that can fund research and development (R&D) on nanosciences and nanotechnologies including those for ICT, health, energy, transport and the environment. These topics are also funded under other programmes within EU funding but the Framework Programme remains the largest designated source of R&D budget. Within FP7, non-specific basic research, People and Capacities are funded (in addition to the Co-operation Programme) and each of these provides potential funding for nanoscience and technology. Significant examples of these are:

- The European Research Council (ERC) funding of up to EUR 7.5 billion in FP7 (and EUR 13.1 billion in 2014-2020 under Horizon 2020[33]) for investigator-driven, bottom-up research ideas in science, engineering and interdisciplinary research, awarded through open competition;
- The Marie Curie Actions[34], with funding of up to EUR 4.7 billion FP7 in 2007-2013 (and EUR 6.16 billion Horizon 2020 funding in 2014-2020) for training, mobility and career development of researchers; and
- The Capacities Programme[35], with a budget of EUR 4.1 billion, funding for research infrastructures; for research for the benefit of SMEs; for regions of knowledge and support for regional research-driven clusters; for research potential of Convergence Regions; for science in society; for support to the coherent development of research policies; and for international co-operation.

Other mechanisms for collaboration on nanotechnology, *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. ERA-NET was continued under FP7. There have been two ERA-NETs on nano manufacturing: M-era.Net and MANUNET.

M-ERA.NET (2012 – 2016) started under FP7 in February 2012 as a network of 36 public funding organisations from 25 European countries, plus additional funding organisations which participate as observers. To date it has co-ordinated three joint calls across ministries and funding agencies, resulting in 71 projects with a total funding of over EUR 55 million. There was a fourth call in 2015 that was still pending at the time of this report.

MANUNET (2006-2010) was a network of 15 funding organisations from nine European countries with additional partners from associated countries such as Switzerland and Israel. MANUNET worked to promote and fund transnational research and development projects in the field of manufacturing, through annual calls for proposals. Since 2011, activities have been continuing under MANUNET II. With a duration of four years, MANUNET II is composed of 17 full partners and nine associated partners, representing 13 countries and 11 regions. During its first 18 months, MANUNET II launched two calls for proposals, resulting in 46 projects mobilising a total of EUR 224 million.

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[33] http://erc.europa.eu/

[34] http://ec.europa.eu/research/mariecurieactions/ Marie Curie Actions became Marie Skłodowska-Curie Actions under Horizon 2020.

[35] http://ec.europa.eu/research/fp7/index_en.cfm?pg=capacities

Networks of Excellence (NoE) were introduced in the Sixth Framework Programme (FP6) with the objective of combating fragmentation in the European Research Area by integrating the critical mass of resources and expertise needed to enhance Europe's global competitiveness in key areas relevant to a knowledge-based economy. These bottom-up initiatives are led by consortia targeting specific research or technological challenges. A Network of Excellence associated with the manufacturing sector is I*PROMOS (Innovative Production Machines and Systems). Its focus area is production research in four clusters: Advanced Production Machines (APM), Production Automation and Control (PAC), Innovative Design Technology (IDT) and Production Organisation and Management (POM)[36].

European research is also being strengthened through collaboration on the development, establishment and running of large research infrastructures, so large that they cannot easily be funded by one agency or country alone. Under the auspices of the European Strategic Forum on Research Infrastructures (ESFRI)[37], Member States are coming together to fund infrastructures related to energy, ICT, health, marine and other fields. EU grants support the preparatory phases of all selected projects and assist in implementation and operation of prioritised projects. The EU funding was EUR 1.85 billion in FP7 and is about EUR 2.5 billion in Horizon 2020. Research infrastructures relevant to manufacturing include the project Enabling Science and Technology through European Electron Microscopy (ESTEEM2)[38], the integrated infrastructure initiative Support of Public and Industrial Research using Ion-beam Technology (SPIRIT)[39], and the pan-European infrastructure for quality in nanomaterials safety testing (QNANO)[40], which all form part of the infrastructure needed to enable manufacturing applications of nanotechnology.

Other mechanisms to support research and innovation in nanotechnology and manufacturing 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.

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[36] http://cordis.europa.eu/news/rcn/102601_en.html
[37] http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=home
[38] http://ec.europa.eu/programmes/horizon2020/en/news/biospecimens-beyond-borders
[39] http://www.spirit-ion.eu/Start.html
[40] http://www.qualitynano.eu/

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

2.2.1 Overview

Project-related data was extracted from the eCorda database for the EU Sixth Framework Programme (FP6) and the EU Seventh Framework Programme (FP7)[41]. 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"[42] in the title or abstract of the project. Thus, nanotechnology projects form approximately 10% of the total FP projects. The share of nanotechnology projects increased slightly between FP6 (9.1%) and FP7 (10.4%).

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

Table 2-1:Number of projects and shares for total projects and for nanotechnology

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

Number and share of nanotechnology manufacturing projects

The number of projects (in FP6 and FP7 together) that were related to both manufacturing and nanotechnology was determined, by the use of a keyword search[43], to be 396, approximately 11% of the total number of projects related to nanotechnology. The percentage of nanotechnology manufacturing projects was lower in FP7 (10.8%) than it was in FP6 (12.2%) an indication that the relevance of manufacturing has increased within nanotechnology FP-activities from FP6 to FP7.

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[41] It should be noted that the FP7 projects may not represent the total number of projects that will take place during FP7 but include only the projects funded up until the date when the extraction of data from eCorda was made (January 2015).

[42] 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".

[43] See Annex for details

Table 2-2: Number of projects and shares for nanotechnology and nanotechnology manufacturing

	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
Nanotechnology manufacturing FP projects	396	285	111
	Shares (number of projects)		
	Total	**FP7**	**FP6**
Total FP projects, all topics	100%	71.6%	28.4%
Nanotechnology (NT) FP projects	100%	71.6%	28.4%
NT manufacturing FP projects	100%	74.4%	25.6%
NT manufacturing projects as % of all NT projects	11.2%	10.8%	12.2%
NT manufacturing projects as % of all FP projects	1.1%	1.1%	1.1%

FP7 participations make up 64% of total nanotechnology manufacturing participations and FP6 participations make up 36% for both nanotechnology manufacturing and for FP overall. For nanotechnology participations, FP7 make up 65% and FP6 35%, very similar to the overall FP participation percentages and those for nanotechnology manufacturing.

Funding of nanotechnology manufacturing projects

Project funding for nanotechnology manufacturing grew from EUR 155 million in FP6 (9.1% of the total for nanotechnology) to EUR 501 million in FP7 (10.8% of the total for nanotechnology). Thus, there was a growth in funding from FP6 to FP7 in both absolute and relative terms, as shown in the figure below.

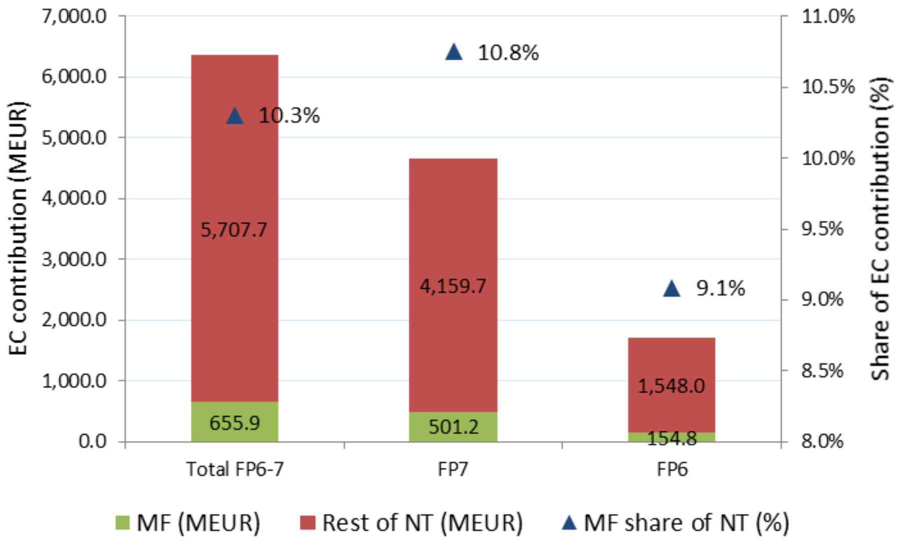

Figure 2-1: Funding of nanotechnology manufacturing for FP6 and FP7 together, for FP7 and for FP6

Participant type in nanotechnology manufacturing projects

Participation in FP6 and FP7 for nanotechnology manufacturing was similar across the two Programmes, as seen in the figure below. The higher education sector (HES) was responsible for approximately half of participations (as measured by funding, 47.5 to 52.8%) with other research organisations (REC) taking between 28 and 29%. Companies have so far been more engaged in FP7 than they were in FP6 mainly due to increased participation by SMEs (large companies (PCO) participations growing from 7.7% to 10% and SME participation growing from 7.7% to 13% from FP6 to FP7).

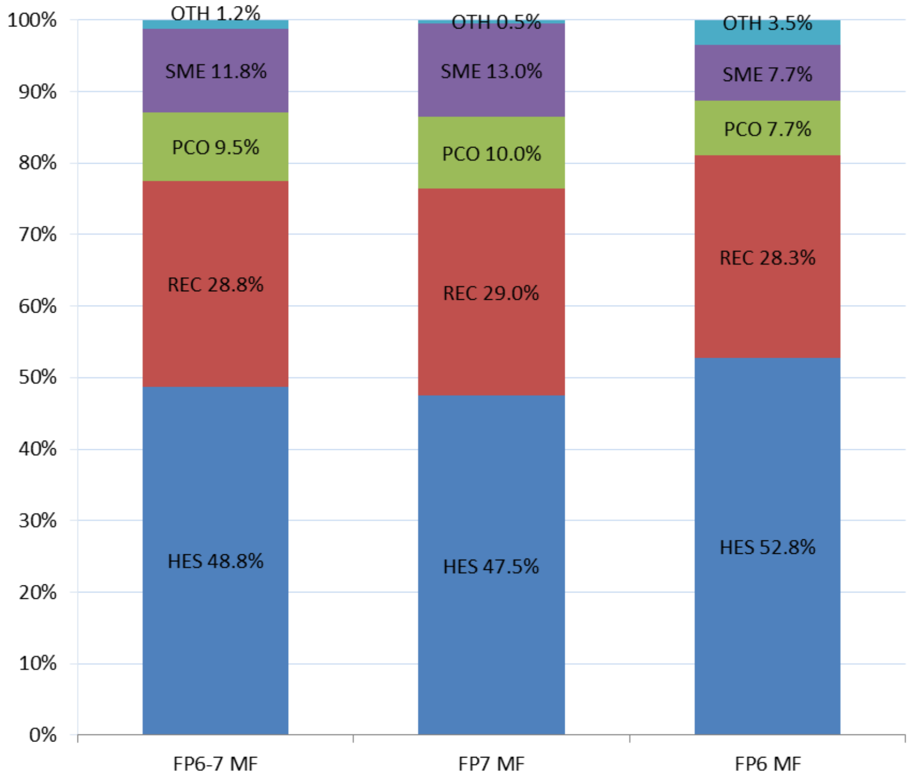

Figure 2-2: Shares of EC funding by organisation type for nanotechnology manufacturing

2.2.2 Activities by programme and sub-programme

2.2.2.1 FP6 nanotechnology manufacturing activities

Nanotechnology projects made up approximately 2% of the total number of projects in FP6 and, with 111 nanotechnology manufacturing projects, over 12% of FP6 NT projects.

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, activities specific to nanotechnology manufacturing made up approximately 9.1% of all nanotechnology activities as measured by EC funding allocation. They took place mainly under the two priorities of (i) Focusing and integrating the ERA and (ii) Structuring the ERA.

Within the Thematic Priorities of the former:

- NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had the largest number of nanotechnology manufacturing projects (40) and a total of EUR 98.8 million of EC funding (63.8% of total nanotechnology manufacturing funding);

- Information Society Technologies (IST) had 6 projects and EUR 15.1 million of EC funding (9.7% of total); and
- Life sciences, genomics and biotechnology for health and Aeronautics and space each took 1.4% of total FP6 funding for nanotechnology manufacturing.

There was also an allocation of EUR 12.6 million (8.2%) for Specific Activities such as Horizontal research activities involving SMEs (EUR 6.5 million, 4.2%) and Policy support and anticipating scientific and technological needs (EUR 5.8 million, 3.8%). The actions for Focusing and integrating the ERA therefore took over 84% of the total FP6 funding for nanotechnology manufacturing.

Within the priority of Structuring the ERA, 48 projects for Human Resources and Mobility received EUR 19.8 million (12.8%) and Research infrastructures took EUR 4.1 million (2.7%) of total nanotechnology manufacturing EC funding.

Table 2-3: FP6 nanotechnology manufacturing activities by programme and sub-programme

FP6 Summary	**Number of projects**			**EC contribution (MEUR)**			**Share of EC contribution**		
	FP6	**FP6 NT**	**FP6 MF**	**FP6**	**FP6 NT**	**FP6 MF**	**FP6**	**FP6 NT**	**FP6 MF**
I Focusing and Integrating ERA	4,735	455	60	13,445.0	1,383.6	130.8	80.5%	81.3%	84.5%
Thematic Priorities	3,374	389	48	12,027.5	1,314.8	118.2	72.1%	77.2%	76.4%
1. Life Sciences	602	20	1	2,336.5	54.1	2.2	14.0%	3.2%	1.4%
2. Information Society	1,089	80	6	3,798.9	346.1	15.1	22.8%	20.3%	9.7%
3. NMP	444	271	40	1,534.2	870.1	98.8	9.2%	51.1%	63.8%
4. Aeronautics and Space	241	5	1	1,066.1	11.6	2.1	6.4%	0.7%	1.4%
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	12	1,417.5	68.8	12.6	8.5%	4.0%	8.2%
Policy Support	520	29	4	604.2	40.7	5.8	3.6%	2.4%	3.8%
Horizontal Research Involving SMEs	490	29	7	463.1	24.7	6.5	2.8%	1.4%	4.2%
International Co-operation	351	8	1	350.3	3.4	0.3	2.1%	0.2%	0.2%
II Structuring the European Research Area	5,096	449	51	2,744.2	303.1	23.9	16.4%	17.8%	15.5%
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	48	1,723.1	219.2	19.8	10.3%	12.9%	12.8%
Research Infrastructures	147	17	3	717.6	74.3	4.1	4.3%	4.4%	2.7%
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	111	16,692.3	1,702.7	154.8	100.0%	100.0%	100.0%

2.2.2.2 FP7 Nanotechnology manufacturing activities

FP7 was structured around four blocks including Co-operation, Ideas, People and Capacities. "Co-operation" was focused on funding collaborative research projects, whereas "Ideas" and "People" supported individual researchers, former towards research excellence and latter aimed towards increased knowledge transfer through mobility of researchers. The "Capacities" programme financed projects related to research infrastructures and supporting specific areas of research support activities (e.g. regions, SMEs, internationalisation).

In FP7, the bulk (66%) of the MF EC contribution was allocated through the Co-operation programme. Like in FP6, the NMP sub-programme was the most important funding programme for MF projects in FP7 with 46 projects and 42% of the MF EC contribution. It was followed by ICT (26 projects and 20% of MF funding), Joint Technology Initiatives (3 projects, 1.7% of MF funding), Energy (2 projects and 1.3% of MF funding) and Food, agriculture and biotechnology and Space (1 project and less than 1% of MF funding each).

The second most important funding programme was Ideas with 63 projects and 22% of the MF funding. It was followed by People with 132 projects and 9% of the EC contribution. These two programmes together account for close to one-third of the MF funding, which is fully aligned with NT and FP projects. The last programme, Capacities, funded 11 projects mainly under the sub-programme targeted at SMEs.

Overall, the MF FP projects largely follow the patterns of NT FP7 projects with respect to funding allocation through different programmes, though Co-operation is a somewhat more important programme for MF than it is for NT, and People and Capacities are somewhat less important for MF than they are for NT.

Table 2-4: FP7 nanotechnology manufacturing activities by programme and sub-programme

FP7 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP7	FP7 NT	FP7 MF	FP7	FP7 NT	FP7 MF	FP7	FP7 NT	FP7 MF
COOPERATION	7,834	756	79.0	28,336.3	2,803.8	328.9	63.1%	60.2%	65.6%
Health	1,008	33	0	4,791.7	157.0	0.0	10.7%	3.4%	0.0%
Food, Agri and Bio	516	25	1	1,850.7	97.1	2.8	4.1%	2.1%	0.6%
ICT	2,328	175	26	7,877.0	561.3	99.4	17.5%	12.0%	19.8%
NMP	805	412	46	3,238.6	1,595.6	210.5	7.2%	34.2%	42.0%
Energy	368	24	2	1,707.4	81.5	6.3	3.8%	1.7%	1.3%
Environment	494	10	0	1,719.3	26.9	0.0	3.8%	0.6%	0.0%
Transport	719	12	0	2,284.2	61.5	0.0	5.1%	1.3%	0.0%
Socio-economic Sciences	253	0	0	579.6	0.0	0.0	1.3%	0.0%	0.0%
Space	267	14	1	713.3	31.7	1.5	1.6%	0.7%	0.3%
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	3	1,966.4	177.0	8.4	4.4%	3.8%	1.7%
IDEAS	4,525	572	63	7,673.5	1,026.1	110.3	17.1%	22.0%	22.0%
European Research Council	4,525	572	63	7,673.5	1,026.1	110.3	17.1%	22.0%	22.0%
PEOPLE	10,716	1,158	132	4,777.5	579.9	45.1	10.6%	12.4%	9.0%
Marie-Curie Actions	10,716	1,158	132	4,777.5	579.9	45.1	10.6%	12.4%	9.0%
CAPACITIES	2,025	149	11	3,772.0	249.9	16.8	8.4%	5.4%	3.4%
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	7.7	2.8%	1.8%	1.5%
Regions of Knowledge	84	4	0	126.7	7.3	0.0	0.3%	0.2%	0.0%
Research Potential	206	27	4	377.7	55.1	9.1	0.8%	1.2%	1.8%
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	285	44,917.3	4,660.8	501.2	100.0%	100.0%	100.0%

2.2.3 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 nanotechnology manufacturing.

Table 2-5: Participations in FP6 and FP7 including funding and share of funding[44]

	Total FP6 and FP7			NT in FP6 and FP7			NT Manuf. in FP6 and FP7		
	Particip.	**EC Funding**	**Share of Funding**	**Particip.**	**EC Funding**	**Share of Funding**	**Particip.**	**EC Funding**	**Share of Funding**
HES	76,777	25,736.0	41.8%	7,671	3,019.5	47.5%	738	319.6	48.8%
REC	53,384	17,304.4	28.1%	4,696	1,778.1	28.0%	451	188.8	28.8%
PCO	25,067	7,021.3	11.4%	2,275	615.4	9.7%	251	62.2	9.5%
SME	29,428	6,882.6	11.2%	3,239	769.1	12.1%	324	77.1	11.8%
Other	24,961	4,626.8	7.5%	1,059	174.2	2.7%	44	7.8	1.2%
Total	**209,617**	**61,571.1**	**100.0%**	**18,940**	**6,356.2**	**100.0%**	**1,808**	**655.5**	**100.0%**

Organisations in the higher education sector receive 48.8% of FP nanotechnology manufacturing funding. The figure for nanotechnology is slightly lower at 47.5% and for FP overall it is lower still at 42%.

Research organisations (REC) receive a slightly higher share of funding for nanotechnology manufacturing (28.8%) than in nanotechnology in general (28.0%) or in FP overall (28.1%) but the figures are too similar to draw any conclusions from them.

The participation of companies is similar for nanotechnology manufacturing and nanotechnology. For SMEs it is 11.8% for nanotechnology manufacturing and 12.1% for nanotechnology while for large companies it is 9.5% for nanotechnology manufacturing and 9.7% for nanotechnology, again too similar to draw any conclusions. When comparing those figures with FP overall, it is seen that the participation by large companies is higher in FP (11.4%) than in either nanotechnology (9.7%) or nanotechnology manufacturing (9.5%).

2.2.4 Activity by organisations receiving funding

The largest amounts of funding for nanotechnology manufacturing activities were received by the CNRS (Centre National de la Recherche Scientifique)[45] in France, participating in projects and receiving funding of over EUR 21 million. Fraunhofer (Germany) is in second position with 25 projects and EUR 16 million.

Six of the top ten recipients are research organisations (nine of the 25) while the other four are from the higher education sector (16 of the top 25). The top ten organisations are from France (2), Germany (2), the UK, Italy, Finland (2), the Netherlands and Sweden.

Only one organisation appears in the top ten European organisations for both publications and projects in nanotechnology manufacturing – the University of Cambridge (UK). Some, such as the CEA (FR), EPFL (CH) and Imperial College (UK), appear in both tables. Others, such as the organisations in Finland, the CNRS (FR) and Fraunhofer (DE), are seen here in projects but not in publication data.

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[44] 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.

[45] Researchers associated with the CNRS may be located within any of its ten research organisations throughout France.

Table 2-6: Organisations participating in FP6 and FP7, top 25 ranked by funding received

	Manufacturing - Top participants	Country	No. of Projects	EC Funding (MEUR)	Share of Manuf. Funding
1	CNRS[46]	FR	42	21.02	3.21%
2	Fraunhofer[47]	DE	25	15.67	2.39%
3	University of Cambridge	UK	21	13.84	2.11%
4	CNR[48]	IT	34	13.78	2.10%
5	CEA[49]	FR	18	11.23	1.71%
6	Aalto University	FI	12	9.00	1.37%
7	VTT[50]	FI	11	8.78	1.34%
8	University of Utrecht	NL	8	8.09	1.23%
9	Max Planck[51]	DE	20	7.64	1.17%
10	Chalmers University of Technology[52]	SE	14	7.01	1.07%
11	CSIC[53]	ES	12	6.92	1.06%
12	IMEC[54]	BE	10	6.85	1.04%
13	Technical University Delft	NL	13	6.83	1.04%
14	University College Cork	IE	11	6.69	1.02%
15	University of Sheffield	UK	6	6.58	1.00%
16	Hebrew University of Jerusalem	IL	7	6.38	0.97%
17	Technical University of Denmark	DK	9	6.23	0.95%
18	University of Twente	NL	12	6.21	0.95%
19	Technical University Eindhoven	NL	12	5.56	0.85%
20	Lund University	SE	7	5.35	0.82%
21	Imperial College London	UK	14	5.33	0.81%
22	Institute of Physics, Polish Academy of Sciences[55]	PL	2	5.15	0.79%
23	EMPA[56]	CH	11	5.10	0.78%
24	EPFL[57]	CH	13	4.91	0.75%
25	Ruhr University Bochum	DE	4	4.57	0.70%

The table below indicates the most active companies in FP nanotechnology manufacturing projects by funding, led by Mapper Lithography of the Netherlands, the majority being large companies (16 out of the 25, 6 out of the top 10) including IBM, Thales, Philips, Airbus and Johnson Matthey. STMicroelectronics occurs three times in the table, the three together having the highest number of

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[46] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr

[47] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de

[48] Consiglio Nazionale Delle Ricerche, the Italian National Research Council www.cnr.it

[49] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr

[50] Teknologian Tutkimuskeskus, Technical Research Centre of Finland www.vtt.fi

[51] Max-Planck-Gesellschaft, the Max Planck Society www.mpg.de

[52] http://www.chalmers.se/en/About-Chalmers/Pages/default.aspx

[53] Consejo Superior de Investigaciones Cientificas, the Spanish National Research Council www.csic.es

[54] Interuniversitair Micro-Elektronica Centrum Vzw, www.imec.be

[55] Instytut Fizyki Polskiej Akademii Nauk

[56] Eidgenössische Materialprüfungs- und Forschungsanstalt, Swiss Federal Laboratories for Materials Science and Technology www.empa.ch

[57] École Polytechnique Fédérale de Lausanne, the Swiss Federal Institute of Technology in Lausanne www.epfl.ch

projects (11) and the highest funding (EUR 3.87)[58]. Otherwise, the highest number of projects for any one company is seven (IBM and Micro Resist).

Table 2-7: Companies participating in FP6 and FP7, top 25 ranked by funding received

	Manufacturing - Top Company Participants	Country	SME	No. of Projects FP6-7	EC Funding (MEUR)
1	Mapper Lithography B.V.	NL		2	3.56
2	IBM Research GmbH	CH		7	3.18
3	Micro Resist Technology	DE	SME	7	2.11
4	Thales SA	FR		5	2.08
5	Aixtron SE	DE		4	1.85
6	Beneq OY	FI	SME	4	1.78
7	ION-TOF Technologies GmbH	DE	SME	1	1.77
8	Micron Semiconductor Italia SRL	IT		5	1.74
9	MBN Nanomaterialia SpA	IT	SME	2	1.72
10	STMicroelectronics S.A.[59]	FR		1	1.64
11	Infineon Technologies AG	DE		2	1.60
12	ASML Netherlands B.V.	NL		2	1.59
13	Obducat Technologies AB	SE	SME	5	1.51
14	Fluigent SA	FR	SME	2	1.51
15	Airbus Defence and Space GmbH	DE		6	1.50
16	Philips Electronics Nederland B.V.	NL		4	1.28
17	Profactor GmbH	AT	SME	3	1.19
18	Flisom AG	CH	SME	1	1.15
19	STMicroelectronics Crolles 2 SAS	FR		4	1.12
20	STMicroelectronics SrI	IT		6	1.11
21	IMS Nanofabrication AG	AT	SME	1	1.07
22	BASF SE	DE		5	1.07
23	Johnson Matthey Plc.	UK		3	1.07
24	The Swatch Group	CH		1	1.04
25	EVGroup E. Thallner GmbH	AT		3	0.98

2.2.5 Participation by country

In total, over 30 countries took part in nanotechnology manufacturing projects funded under FP6 and FP7. The top five countries received over half (58.2%) of the total funding: Germany (19%), the UK (13%), France (10%), Italy (8%) and the Netherlands (8%). The top fifteen countries (with over 90% of the nanotechnology manufacturing funding) are shown in the table below.

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[58] STMicroelectronics is shown in the eCorda database three times in the top 25 companies as ranked by funding received. While one of the three is in Italy, the other two are at the same location in France. The data have not been aggregated in the table in case of double counting.

[59] STMicroelectronics is shown in the eCorda database three times in the top 25 companies as ranked by funding received. While one of the three is in Italy, the other two are at the same location in France. Combining the figures for the three parts of STMicroelectronics, it has both the highest number of projects (11) and the highest funding (EUR 3.87 million). The data have not been aggregated in the table in case of double counting.

Table 2-8: Top fifteen countries for FP participation ranked by funding received

Rank	Country	Manuf. NT funding (MEUR)	% of funding
1	DE	125.2	19.1%
2	UK	83.7	12.8%
3	FR	66.4	10.1%
4	IT	53.5	8.2%
5	NL	52.4	8.0%
6	ES	42.4	6.5%
7	CH	35.7	5.4%
8	SE	31.4	4.8%
9	FI	28.9	4.4%
10	BE	22.8	3.5%
11	AT	17.7	2.7%
12	IL	14.1	2.1%
13	DK	13.2	2.0%
14	IE	10.0	1.5%
15	PL	8.5	1.3%
	TOTAL	**609.5**	**92.4%**

Comparison can be made with the data for the country of origin of the participants for both NT funding and for FP funding overall. In the table below, the data is ordered by the ranking for nanotechnology manufacturing funding received by the country. The same four countries are at the top of the ranking in terms of their share of funding for FP overall. Germany, the United Kingdom, France and Italy are the top four most active countries for participation in both FP activities and nanotechnology manufacturing activities measured as country share of total funding. In all cases (FP, NT and NT manufacturing), the top ten countries take approximately 80% of funding.

Table 2-9: Country ranking by FP funding for top ten in FP, NT and nanotechnology manufacturing

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

	FP Total			Nanotechnology			Nanotechnology Manufacturing		
	MEUR	Rank	Share of FP	MEUR	Rank	Share of NT	MEUR	Rank	Share of MF
DE	10,164.1	1	16.5%	3,112	1	17.6%	125.2	1	19.1%
UK	9,295.2	2	15.1%	2,346	2	13.3%	83.7	2	12.8%
FR	7,319.3	3	11.9%	1,981	3	12.0%	66.4	3	10.1%
IT	5,046.5	4	8.2%	1,689	4	7.9%	53.5	4	8.2%
NL	4,438.4	5	7.2%	1,044	6	7.0%	52.4	5	8.0%
ES	4,200.6	6	6.8%	1,566	5	7.6%	42.4	6	6.5%
CH	2,503.2	8	4.1%	848	7	5.3%	35.7	7	5.4%
SE	2,386.7	9	3.9%	711	8	4.3%	31.4	8	4.8%
FI	1,216.4	13	2.0%	436	11	2.4%	28.9	9	4.4%
BE	2,518.0	7	4.1%	715	9	4.1%	22.8	10	3.5%
TOTAL	**49,088.4**		**79.8%**	**14,448**		**81.5%**	**542.4**		**82.8%**

As shown in the figure below, Germany, the Netherlands, Switzerland, Sweden and Finland have higher budget share in nanotechnology manufacturing than they have in FP activities in general. However, countries such as the UK and France have lower country shares of EC contribution in nanotechnology manufacturing than they have in nanotechnology or FP indicating that, although in absolute terms these countries receive a large amount of funding for nanotechnology manufacturing, in relative terms it is less than these countries receive for their FP or NT projects.

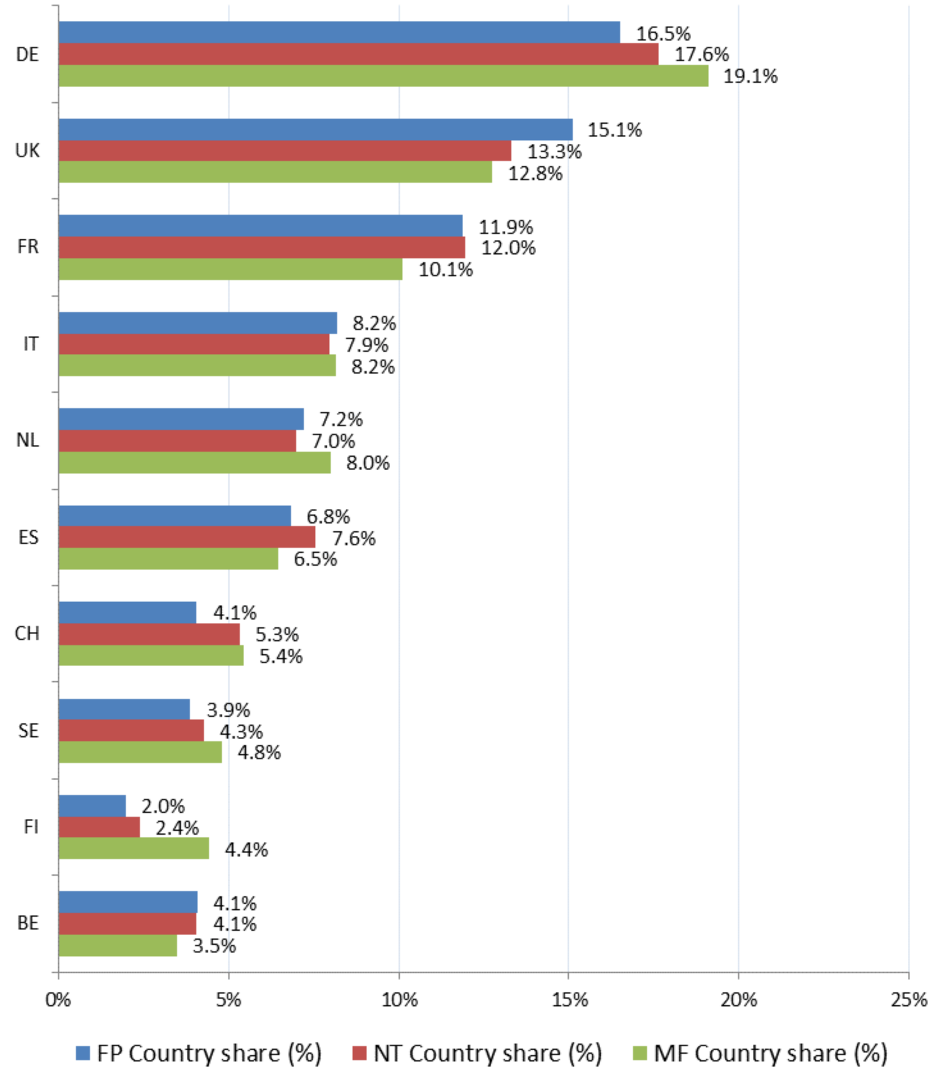

Figure 2-3: Percentage shares of FP funding by country in FP, NT and nanotechnology manufacturing

The figure below indicates the EC funding for nanotechnology manufacturing in FP6 and FP7 in terms of millions of euros (blue bars and left axis) and the country shares of nanotechnology manufacturing EC contribution in FP6 (red circle, right axis) and in FP7 (green diamond, right axis) for the ten countries receiving the most funding.

For Germany, UK and France, the absolute EC contribution has tripled from FP6 to FP7 but their country share has remained rather unchanged. For the Netherlands, Spain and Belgium, the country share of nanotechnology manufacturing funding has increased whereas this funding has decreased for Italy and Sweden (and decreased slightly for the UK and Finland) from FP6 to FP7.

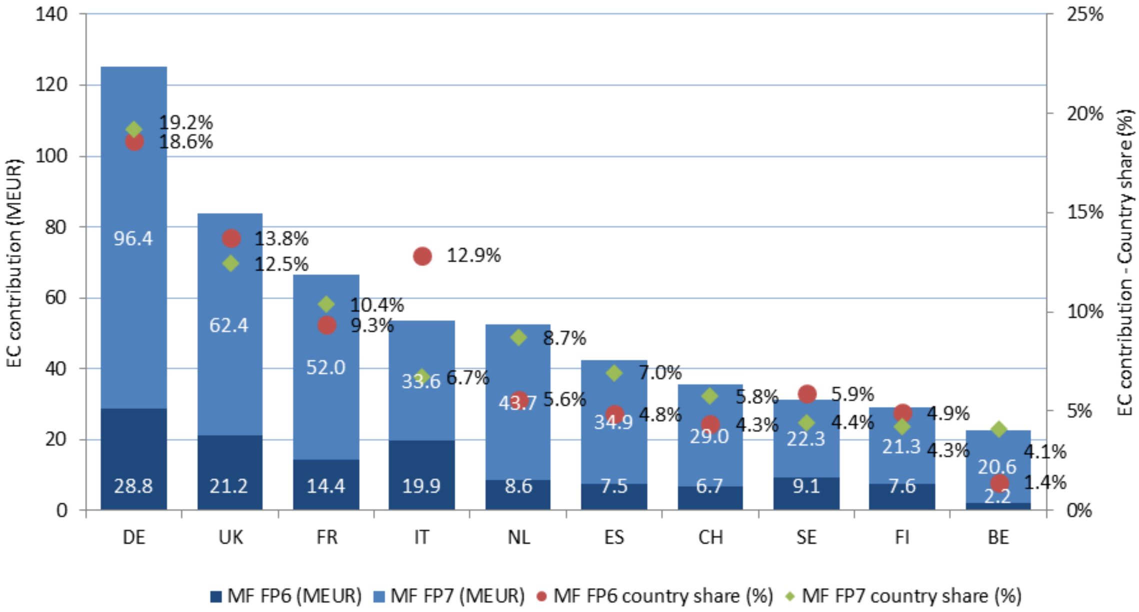

Figure 2-4: EC funding for nanotechnology manufacturing activities in FP6 and FP7 in MEUR and country shares

2.2.6 Snapshot of outputs from FP7

A review was undertaken of 106 FP7 nanotechnology projects reported on via the SESAM system in which participants report themselves 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 here to present the information 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 report, 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, 33 were classified by review as being related to manufacturing nanotechnology. Those 33 projects reported outputs of:

- 629 publications, an average of 19 publications per project, higher than for nanotechnology overall; and
- 30 patent applications, an average of almost one per project, higher than for nanotechnology overall.

Thus, of the projects under review, manufacturing nanotechnology projects under FP7 produce more than the average number of publications and patents per project than for nanotechnology overall.

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

2.3 Other EU policies and programmes

2.3.1 EU policies and programmes: Industry

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

Key Enabling Technologies (KETs) are a priority for European industrial policy. The European Strategy for KETs aims to increase the exploitation of KETs in the EU and to reverse the decline in manufacturing to stimulate growth and jobs. In 2012, the European Commission tabled its strategy to boost the industrial production of KETs-based products, e.g. innovative products and applications of the future. The strategy seeks for the EU to keep pace with the its main international competitors in industrial capabilities and capacities, restoring growth in Europe and creating jobs in industry, at the same time addressing current key societal challenges. The European Commission also identified KETs as a priority within its Europe 2020 strategy, and they are seen as essential to Flagship Initiatives, e.g. the Innovation Union, the Digital Agenda.

Research by companies in the EU is also supported through the EUREKA Eurostars initiative established under Article 185 of the Treaty on the Functioning of the European Union (TFEU), in partnership between the European Commission, the Member States and the countries associated with the Framework Programmes. Eurostars supports European R&D performing SMEs to commercialise their research. It helps them to accelerate the time to market of products, processes and services to the market. It also encourages them to develop and internationalise their business. Funding of up to EUR 100 million was made available through EUREKA for the period 2008-2013, the EU contribution comprising a maximum of one third of the funding provided by the participating countries. Funding for Eurostars has continued with a total public budget of EUR 1.14 billion in 2014-2020, EUR 861 million of national funding and EUR 287 million of EU funding from H2020. In the 39 Eurostars success stories, three are related to nanotechnology.

Another type of mechanism is the European Technology Platform (ETP), including the ETPs EuMaT and Manufuture, bottom-up, industry-led stakeholder fora, the aim of which is to increase interaction between research actors and to facilitate the development of medium to long-term research and technological goals and associated roadmaps. They do not fund research projects but are a co-ordination mechanism. ETPs now exist across the themes of production and processes, energy, environment, ICT, transport and the bio-based economy.

EuMaT (the European Technology Platform for Advanced Engineering Materials and Technologies) was launched in 2006 in order to assure optimal involvement of industry and other important stakeholders in the process of establishing of R&D priorities in the area of advanced engineering materials and technologies.

Manufuture was initiated in 2003 and has currently 1,700 members including 1,300 SMEs, 230 large companies, 120 research institutes, 20 associations and 30 governmental bodies. The mission of Manufuture is to propose, develop and implement a strategy based on research and innovation, capable of speeding up the rate of industrial transformation of research into high-added-value products, processes and services. The Manufuture Platform launched the Initiative EFFRA, the European Factories of the Future Research Association, and the European Platform for Micro and Nano Manufacturing (MINAM) that aims to support industrial growth in this field by enabling the definition of a common European Strategic Research Agenda for this key area. MINAM has extended the micro- and nano-manufacturing community through European, national and regional initiatives, such as European clusters, Networks of Excellence (NoEs) and ETPs in an application-driven approach.

Photonics21, whose main focus is photonics, is also related to manufacturing as it can be derived from its seven priority areas (e.g. working groups): Industrial Manufacturing and Quality; Design and Manufacturing of Components and Systems; Emerging Lighting, Electronics and Displays; Information and Communication; Life Sciences and Health; Security, Metrology and Sensors; Photonics Research, Education and Training.

Another related ETP is EUROP (European Robotics Technology Platform). One of its objectives is the competitiveness and the industrial leadership of "manufacturers, providers and end users of robotics technology-based systems and services".

In 2008, a Public Private Partnership (PPP) related to manufacturing was launched, namely Factories of the Future (FoF). FoF has continued also under H2020 as a contractual PPP (FoF 2020) and focuses on fields that relies on nanotechnology such as advanced manufacturing processes; adaptive and smart manufacturing systems; digital, virtual and resource-efficient factories; and collaborative and mobile enterprises.

2.3.2 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 including those on manufacturing:

- 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.

2.3.3 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) [60] aim to focus regional innovation policies on regional priorities based on existing areas of strength; competitive advantage; and potential for excellence in each region.

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

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

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

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[60] 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.

3 POLICIES AND PROGRAMMES IN MEMBER STATES FOR NANOTECHNOLOGY MANUFACTURING

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 manufacturing, specific initiatives at Member State level, past[61] or present, include:

Austria: The Austrian NanoInitiative[62] (2004-2011, total funding EUR 70 million) was administered by the Austrian Research Promotion Agency (FFG)), nano-manufacturing being one of nine priority areas. The initiative worked on a collaborative basis across Austria and transnationally with consortia of research institutes, universities and firms working on problem-driven basic research questions with a medium-term perspective (5-7 years). The focus of the programme, matching the remit of its funding agency FFG, was to invest in projects with considerable market potential, relevant to Austrian companies. The type of activities begun under the programme are now continuing under the thematic areas FFG's research funding programmes. Since 2012, NT is supported via FFG's thematic research funding (e.g. 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[63] aims to strengthen national excellence in the areas of micro and nano-engineering (ranging from core technologies to systems), and to speed up technology transfer to French firms to exploit the potential of nanotechnology.

Germany: Germany was the first country in Europe to recognise a need for specific funding measure for nano manufacturing, introducing the lead innovation programme "Nanofab" as early as 2001. Even earlier - in 1999 - the German Federal Ministry of Education and Research (BMBF) launched the Framework Concept for the Production of Tomorrow. The Nanofab programme ran until 2014 with an overall budget of EUR 403 Million. The main rationale was to foster the manufacturing industries of Germany in an increasingly dynamic and competitive European and global environment, with enhanced mobility of goods, capital and information. The Framework Concept comprised four thematic fields of action amongst which was the area of production processes and production equipment (including primary shaping and recasting, chipping, surfaces and layers, heat treatment, assembling, and measurement engineering).

In 2011, the German Ministry for Education and Research (BMBF) published the Action Plan Nanotechnology 2015 outlining the strategy for responsible development, innovation and public dialogue on nanotechnology for the period 2010-2015. In parallel, there are the Innovation Alliances, 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, among which were bottom-up nano-electronics and nanofabrication. In 2011, NanoNed was followed by

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

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

[63] http://www.agence-nationale-recherche.fr/en/projects-and-results/calls-for-proposals-2013/aap-en/nanotechnologies-and-nanosystems-p2n-2013/

NanoNextNL[64], a consortium of more than a hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities. Stakeholders collaborate 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*[65] 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[66] (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. Amongst the key research activities at INL are nano-machines and nano-manipulation as well as nano-electronics.

Spain: In Spain, nano-manufacturing was explicitly prioritised in the Sixth National Scientific Research, Development and Technological Innovation Plan (2008-2011). Within that, the Strategic Action for Nanoscience and Nanotechnology, New Materials and New Industrial Processes (SANSNT) addressed seven priorities, amongst which were knowledge-based intelligent materials with individually-tailored properties and high performance materials and coatings; advances in technology and processing of materials; and exploitation of convergent technologies. 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, (e.g. R+I+i projects, innovation and technology modernisation projects).

The United Kingdom (UK): In 2002, the UK Government, after issuing the Taylor Report which recognised the increase of investment in nanotechnology worldwide, allocated GBP 90 million (EUR 131.4 million)[67] of funding for the Micro and Nano Technology Manufacturing Initiative. This funding was committed between 2003 and 2007. 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 are 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.[68]

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

[65] http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/smart-industry

[66] http://inl.int/

[67] Average yearly conversion rate, 2003-2007 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-gbp.en.html)

[68] However, following to an evaluation in 2010, the initiative was judged quite unsuccessful (*source*: http://www.cientifica.com/why-has-the-uk-given-up-on-nanotechnology/)

The UK Enabling Technologies Strategy 2012-2015[69] also addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having a significant underpinning role across most of these technology areas, particularly in the health-care and life sciences sectors.

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

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

- From France, the web site of Campus France[70] 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."

- The German Trade and Invest Agency[71] website provides the information that:
  "Approximately half of the nanotechnology companies in Europe are from Germany; the country is number one in Europe in the nanotechnology industry. German companies manufacture products in the areas of nanomaterials, nanotools, nanoanalytics, and nanotools accessories (e.g. vacuum and cleanroom technology, plasma sources, etc.). They also manufacture and utilise nano-optimised components and systems, and they provide services in the areas of consulting, contract coating, technology transfer, and commissioned analysis and research …"

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

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

Table 3-1: 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[72] (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)
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
FI	FinNano[73]	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	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[74]	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	All	BMBF	24 over 3 years
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 enable an intensive dialogue with	All	BMBF	640 over 5 years

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[72] https://www.ffg.at/nano-aktuell ; https://www.ffg.at/11-ausschreibung-produktion-der-zukunft
[73] www.tekes.fi
[74] http://www.agence-nationale-recherche.fr/

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
				the public.			
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)	2002-2004	Targeting NT	In September 2014 MISE issued the call for industrial R&D projects of the FCS, covering the fields of advanced manufacturing, ICTs, nanotechnology, advanced materials, biotechnology, technologies associated to the EU Horizon 2020 programme.	Mainly SMEs	MISE	300
NL	NanoNed	2004-2011	Directly Targeting NT	NanoNed was organised into eleven independent flagships based on regional R&D strength and industrial relevance.	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.	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. Top sector technologies in materials, electronics/optics and sensors, etc. are used for applications like energy, health and water. 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 in the Top Consortia for Knowledge and Innovation (TKIs) for an amount of at least EUR 500 million by 2015, 40% of which from trade and industry.
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
UK	Micro and Nanotechnology Manufacturing	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

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
	Initiative[75]						
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

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

4 POLICIES AND PROGRAMMES IN OTHER COUNTRIES[76]

4.1 Europe

4.1.1 Non-EU Member States

4.1.1.1 Norway

From 2002 to 2011, Norway addressed nanotechnology through its Programme on Nanotechnology and New Materials (NANOMAT)[77]. In 2012, a follow-on programme (to run until 2021) was initiated, the Nanotechnology and Advanced Materials Programme (NANO2021)[78]. Managed by the Research Council of Norway[79], this large-scale programme covers research on nanoscience, nanotechnology, micro-technology and advanced materials. The programme is designed to further raise the level internationally of the Norwegian knowledge base in nanotechnology and advanced materials. NANO2021 receives funding from the Ministry of Education and Research and the Ministry of Trade and Industry. The annual budget in the period 2013-2021 has been set at NOK 92.1 million (EUR 10 million at the current exchange rate, October 2015)[80].

Within the thematic priority area three of NANO2021, the programme addresses nanoscience, nanotechnology, micro-technology and advanced materials[81].

4.1.1.2 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[82]) but this dropped to USD 2.6 billion (EUR 1.9 billion[83]) 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,

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[76] 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)

[77] http://www.forskningsradet.no/prognett-nano2021/Artikkel/About_the_programme/1253970633592?lang=en

[78] http://www.forskningsradet.no/servlet/Satellite?c=Page&pagename=nano2021%2FHovedsidemal&cid=1253969916237&langvariant=en

[79] http://www.forskningsradet.no

[80] Nanotechnology and Advanced Materials – NANO2021: Work Programme

[81] Nanotechnology and Advanced Materials – NANO2021: Work Programme

[82] Average yearly conversion rate, 2008-2009 (*source*: www.wolframalpha.com)

[83] Average yearly conversion rate, 2010 (*source*: www.wolframalpha.com)

education, standards and certification. Its research projects fall under six clusters, some of them relevant to manufacturing, such as the mechanical engineering and metalwork clusters. As of October 2010, out of 83 industrial projects, ten were on nanomaterial production technologies and equipment, and 32 (over a third) on nanomaterials[84].

4.1.1.3 Switzerland

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

CTI funds the Swiss MNT network (micro and nanotechnology) as one of the core innovative themes of national and international importance[85]. 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[86]. 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[87], and Nano-Cluster Bodensee[88]. Most activities are strongly focused on R&D to support industry.

4.2 The Americas

4.2.1 North America

4.2.1.1 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.

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[89]) in market share for nano-enabled commerce by 2020. One of the main areas of action is *industrial technologies*.

Quebec

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

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[84] Anatoly Chubais, RUSNANO Chief Executive Officer, "RUSNANO: fostering Innovations in Russia through Nanotechnology", USRBC 18th Annual Meeting, October 2010, San Francisco, California, USA, https://www.usrbc.org/pics/File/AM/2010/Presentations/Chubais_GB_830.ppt.pptx

[85] https://www.kti.admin.ch/kti/en/home/unsere-foerderangebote/Unternehmen/internationale-netzwerke-und-forschungskooperationen-neu/spezialthema-japan-schweiz1/foerderlandschaft-schweiz.html

[86] http://www.swissmntnetwork.ch/content/

[87] http://www.i-net.ch/nano/

[88] http://www.ncb.ch/wordpress_neu/

[89] Current conversion rates, October 2015

Quebec's advanced materials research and innovation hub.

Quebec's Nano Action Plan 2013-2018[90] specifically targets four priority sectors: industrial materials, microsystems, health 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[91]). 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.

4.2.1.2 The United States of America (US)

The National Nanotechnology Initiative[92] 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 Nano-manufacturing, Industry Liaison, & Innovation; Nanotechnology Environmental & Health Implications; Global Issues in Nanotechnology; and Nanotechnology Public Engagement and Communications. As can be seen from the above listing, manufacturing is mainly dealt in the first working group.

In February 2014, the National Nanotechnology Initiative released a Strategic Plan[93] 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) are also relevant to manufacturing (for example, sustainable nano-manufacturing, and nanotechnology for sensors and sensors for nanotechnology).

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[90] http://www.nanoquebec.ca/media/plan-action_en1.pdf

[91] Current conversion rates, October 2015.

[92] http://www.nano.gov/

[93] http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf

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, for example:

- The Department of Commerce: Economic Development Administration (additive manufacturing);
- The National Institute of Standards and Technology (NIST) (advanced manufacturing); and
- The Department of Homeland Security (DHS) (manufacturing techniques for low-cost sensor platforms) and others.

The NNI's budget supplement proposed by the Obama administration for Fiscal Year 2015 provided for USD 1.5 billion (EUR 1.2 billion[94]) of funding. Cumulative NNI investment since fiscal year 2001, including the 2015 request, totals almost USD 21 billion (EUR 17 billion[95]). Cumulative investments in nanotechnology-related environmental, health, and safety research since 2005 is nearly USD 900 million (EUR 680 million[96]). 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 nanoscience and nanotechnology (including Nanofabrication, Nanomanufacturing, and Nanoprocessing) as well as to manufacturing. Manufacturing at NIST[97] encompasses subject areas including nanomanufacturing, green manufacturing, robotics, systems integration, etc. NIST provides facilities to support production, through the Centre for Nanoscale Science and Technology (CNST)[98], established in 2007. The CNST facilitates access to commercial state-of-the-art nanoscale measurement and fabrication tools through its NanoFab[99].

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[100]) (FY 2015), funds approximately 24% of all federally-supported basic research (except for medical sciences) conducted by America's colleges and universities[101].

With particular reference to the manufacturing sector, the Directorate for Engineering, Division of Civil, Mechanical and Manufacturing Innovation (CMMI) at the NSF has a programme on Advanced Manufacturing[102]. Its aim is to support "research leading to transformative advances in manufacturing and building technologies across size scales from nanometres to kilometres". There is a dedicated programme on Manufacturing Machines and Equipment (MME).

Like the NSF, the US Department of Energy (DoE) supports nanoscience and nanotechnology in the field of manufacturing. The Centre for Nanoscale Materials, a joint partnership between the DOE and the State of Illinois, is one of offices of the DoE[103] with the main goal of conducting basic research. Among its research areas is nanofabrication and devices and among its key capabilities is atomic layer deposition (ALD).

In additional to these Federal initiatives, there exist also several policy initiatives at US State level[104]. Programmes for the promotion of nanotechnologies currently exist in 23 states. Notable examples are the Texas Emerging Technology Fund[105], the Oklahoma Nanotechnology Initiative[106], the Illinois Nanotechnology "Collaboratory"[107], and the Oregon Nanoscience and Micro-technologies Institute (ONAMI)[108]. The State-level organisations typically undertake some or all of the following activities:

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[94] Average yearly conversion rate, 2015 (*source*: www.wolframalpha.com)

[95] Average yearly conversion rate, 2001-2015 (*source*: www.wolframalpha.com)

[96] Average yearly conversion rate, 2005-2015 (*source*: www.wolframalpha.com)

[97] http://www.nist.gov/manufacturing-portal.cfm

[98] http://www.nist.gov/cnst/index.cfm

[99] https://www.nist.gov/cnst/nanofab

[100] Current conversion rate, November 2015 (*source*: www.wolframalpha.com)

[101] http://www.nsf.gov/about/

[102] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503287&org=CMMI&from=home

[103] http://www.anl.gov/cnm/about-us

[104] http://www.nano.gov/initiatives/commercial/state-local

[105] 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.

[106] http://www.oknano.com /

[107] http://nano.illinois.edu/collaboration/index.html

[108] http://onami.us/

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.

4.2.2 South America

4.2.2.1 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[109]) 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)[110] was initiated in 2005 by the Economy and Production Ministry, with the aim of stimulating training and developing technical infrastructure to promote advances in nanotechnology and the adoption of nanotechnology by industry. It also aimed to encourage the participation of researchers, institutions and companies from Argentina in international networks.

While previous national programmes had differentiated between funding either for the public sector (essentially the research networks) or for the private sector (projects of the FAN), the nanotechnology sector funds (FS-NANO) launched in 2010 provided funding to projects dedicated to basic and applied science via public-private partnerships.

In 2011, the Ministry of Science, Technology and Productive Innovation published the Argentina Innovadora 2020 (Innovative Argentina Plan 2020): National Plan of Science, Technology and Innovation. The plan focuses on three general-purpose technologies (nanotechnology, biotechnology and information and communication technology (ICT) and addresses six strategic sectors, including industry for automotive parts (innovation in the field of metallurgy) and electronic components[111].

4.2.2.2 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[112]) over four years to form Co-operative Networks of Basic and Applied Research on Nanosciences and Nanotechnologies. Four national research networks were established: molecular nanotechnologies and interfaces; nano-devices; semiconductors and nano-structured materials; 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[113]) 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

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[109] http://www.agencia.mincyt.gob.ar/frontend/agencia/fondo/agencia

[110] http://www.fan.org.ar/en/

[111] http://www.argentinainnovadora2020.mincyt.gob.ar/?page_id=194

[112] Average yearly conversion rate, 2001(*source*: www.wolframalpha.com)

[113] Average yearly conversion rate, 2004-2007 (*source*: www.wolframalpha.com)

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[114]) to c. USD 30 million (EUR 24 million[115]) 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 was 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[116] 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 they submit a good research proposal – while scientists working in industry are able to access specialist equipment and expertise at highly subsidised rates. The laboratories offers facilities fundamental for improving nano-manufacturing, especially for lithography, chemical vapour deposition (CVD), atomic layer deposition (ALD), molecular beam epitaxy (MBE).

In 2013, MCTI launched the Brazilian Nanotechnology Initiative (IBN) with funding estimated to be BRL 440 million (EUR 148 million[117]) for the 2013-2014 period. The implementation of IBN was an effort to further strengthen nanotechnology in Brazil by strengthening academic and industry linkages thereby to promote the scientific and technological development of the nanotechnology sector.

4.3 Asia

4.3.1 Eastern Asia

4.3.1.1 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[118] 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

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[114] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[115] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[116] Sistema Nacional de Laboratórios em Nanotecnologias ftp://ftp.mct.gov.br/Biblioteca/39717-SisNANO.pdf
[117] Average yearly conversion rate, 2013-2014(*source*: www.wolframalpha.com)
[118] 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.

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[119]. 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. Manufacturing is listed among the priority topics. The MLP, in identifying the frontier technologies, stresses the key role of nanotechnology in advanced manufacturing (in particular for extreme manufacturing technology). As the MLP is implemented in the context of the Five-Year Plan for S&T Development (2011-2015), it is relevant that it also emphasises key technologies for strategic and emerging industries (including nanotechnology with manufacturing, photonics, ICT and agriculture).

With specific regards to nano-manufacturing, China established a State Key Laboratory of Tribology (SKLT) at the Tsinghua University in 1986. It focuses on "fundamental research on theory and application of tribology and micro/nano manufacturing".[120]

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".

4.3.1.2 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 manufacturing technology and materials, as well as energy and nanotechnology, ICT, environmental sciences and life sciences, and the cross-cutting areas of infrastructure and frontier research. Nanotechnology was seen as being relevant to a broad range of fields and it was expected to help Japan to maintain its technological edge. Total governmental funding of this field grew in these years from JPY 85 billion (EUR 782 million)[121] in 2001 to JPY 97 billion (EUR 709 million[122]) in 2005.

In the subsequent STBP[123], 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

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

[120] http://www.tsinghua.edu.cn/publish/dpien/7819/2012/20120903141457094331781/20120903141457094331781_.html

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

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

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

trillion (EUR 200 billion)[124]. 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.

4.3.1.3 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)[125] 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[126]); phase 2, 277.2 billion Won (EUR 1,541.8 million[127]).

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[128] (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)[129].

In total, 24 nanotechnology-related centres now exist in Korea. The Korean Institute of Science and Technology (KIST)[130] has a Material and Life Science Division, covering nanotechnology, biotechnology and ICT. In addition, by 2010, over forty universities had nanotechnology departments.

Under the Nanotechnology Development Promotion Act 2002, Korea also established in 2004 the

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

[125] http://www.nstc.go.kr/eng/

[126] Average yearly conversion rate, 2001-2005 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)

[127] Average yearly conversion rate, 2006-2010 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)

[128] http://www.kanc.re.kr/kancEnglish/center/center_overview.jsp

[129] https://www.ibs.re.kr/eng/sub02_04_03.do

[130] 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

Korean Nano Technology Research Society (KoNTRS)[131] 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.[132]

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[133] the national vision for Korea to be "the world's number one nanotechnology power" and the four goals:

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

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

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

2012 saw the creation of the Nano-Convergence Foundation (NCF)[134] 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[135]) 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[136]) each.

4.3.1.4 Taiwan (Chinese Taipei)[137]

The National Nanoscience and Nanotechnology Programme[138] was approved for a period of six years by the National Science Council (NSC) in 2002. The funding agencies include the Atomic Energy Council[139]. With a budget envelope of USD 700 million (EUR 740 million[140]) and actual expenditure estimated to be USD 625 million (EUR 486 million[141]) over 2003-2008, the programme targeted

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[131] http://kontrs.or.kr/english/index.asp
[132] http://www.nanotechmag.com/nanotechnology-in-south-korea/
[133] http://www.nnpc.re.kr/htmlpage/15/view
[134] http://www.nanotech2020.org/download/english_brochure.pdf
[135] Current exchange rate, November 2015 (*source*: www.wolframalpha.com)
[136] Current exchange rate (November 2015) (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[137] http://www.twnpnt.org/
[138] http://www.twnpnt.org/english/g01_int.asp
[139] http://www.facs-as.org/index.php?page=nanotechnology-program-in-taiwan
[140] Average yearly conversion rate, 2002 (*source*: www.wolframalpha.com)
[141] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2768287/

areas such as energy and environment and its aim was to foster nanotechnology research and development in research institutes, universities and private companies, achieving academic excellence and supporting commercialisation. The Academic Excellence (first theme) part of the programme includes physical, chemical and biological properties of nanostructures, nano-sensors (nano-probes), nano-devices and nano-biotechnology.

The second theme (industrialisation programme) includes nanotechnology for energy applications. Industrial applications are the remit of the Industrial Technology Research Institute (ITRI). ITRI has 13 research laboratories and centres in areas including mechanical and systems, optoelectronics, electronics, applied materials, biomedicine, chemistry and mechanics. The Mechanical and Systems Research Laboratories, in particular, is a centre of excellence for advanced machines.[142]

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-materials and nano-biotechnology, nano-optoelectronics, nano-electrics, energy and environmental nanotechnology and applied nanotechnology in traditional industries.

4.3.2 Southern Asia

4.3.2.1 India[143]

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[144]) 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)[145] 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

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[142] https://www.itri.org.tw/eng/Content/Messagess/contents.aspx?SiteID=1&MmmID=617751556732477253

[143] 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

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

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

standards for nanotechnology at national level.

The continuation of the Nano Mission was approved by the Government in February of 2014 and EUR 91 million (INR 650 crore) were sanctioned for the time period 2012 to 2017[146]. 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)[147] 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.[148]
- 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[149].
- The MST's Science and Engineering Research Council (SERC)[150] supports frontier and interdisciplinary research. Support for nanotechnology projects has been provided through its R&D schemes for basic science and engineering science.

4.3.2.2 Iran[151]

The Islamic Republic of Iran ranked 23rd in the world in nanotechnology in 2007, second to Korea in citations in Asia[152], but, by 2012, it had moved to 10th place[153, 154]. 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, biotechnology, aerospace, information technology and environment.

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)[155], 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[156] (EUR 9 million[157]).

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

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[146] http://timesofindia.indiatimes.com/home/science/Govt-approves-Rs-650-crore-for-Nano-mission/articleshow/30722422.cms
[147] www.csir.res.in/
[148] http://www.csir.res.in/external/heads/collaborations/NM.pdf
[149] http://www.teriin.org/div/ST_BriefingPap.pdf
[150] www.dst.gov.in/about_us/ar05-06/serc.htm
[151] See also http://www.sciencedev.net/Docs/Iran_Nano.pdf (2010)
[152] http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file11959.pdf
[153] http://statnano.com/report/s29
[154] http://www.nanotech-now.com/news.cgi?story_id=45237
[155] http://nano.ir/index.php?lang=2
[156] http://www.nanotech-now.com/news.cgi?story_id=36557
[157] Average yearly conversion rate, 2004-2010 (*source*: www.wolframalpha.com)

in Iran[158]. 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[159].

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, important areas for manufacturing.

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)[160], a body established in 2006 as a collaboration between the INIC and the Institute of Standard and Industrial Research of Iran (ISIRI)[161].

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[162].

4.3.3 South-Eastern Asia

4.3.3.1 Malaysia

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

The Malaysian National Nanotechnology Initiative (NNI) was established in 2006 to advance nanotechnology and related sciences by clustering local resources and knowledge of Malaysian researchers, industry and the government. The NNI paved way for the establishment in 2010 of the National Nanotechnology Directorate under the Ministry of Science, Technology and Innovation (MOSTI). The National Nanotechnology Directorate (NND)[163] 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[164] 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. Among these are the Institute of Nanoelectronics and Engineering (INEE)[165], and the Institute of Micro Engineering and Nanoelectronics (IMEN), at UKM[166].

4.3.3.2 The Philippines[167]

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

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[158] http://blogs.scientificamerican.com/guest-blog/science-and-sanctions-nanotechnology-in-iran/

[159] http://nano.ir/index.php?ctrl=static_page&lang=2&id=397&section_id=22

[160] http://nanostandard.ir/index.php?lang=2

[161] http://www.isiri.com/

[162] http://statnano.com/strategicplans/1

[163] http://www.mosti.gov.my/en/about-us/divisions-departments/national-nanotechnology-directorate-division-nnd/

[164] http://www.nanomalaysia.com.my/index.php?p=aboutus&c=whoweare

[165] http://inee.unimap.edu.my/

[166] www.ukm.my/

[167] http://www.techmonitor.net/tm/images/d/d1/10jan_feb_sf3.pdf

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; food and agriculture; health and information and communications technology and semiconductors.

4.3.3.3 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[168] was developed. Thirteen technology scanning panels were established, including one on 'Exploiting Nanotechnologies'. There were also foresight panels on manufacturing, materials and infrastructure, intelligent systems, the grid, energy, environmental technologies, semiconductors, broadband, information storage, 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[169], and the Roadmap (ITR5) of the Infocomm Development Authority[170]. 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, environmental and engineering, ICT, electronics, chemicals and food. The Plan also indicates nanotechnology is fundamental and horizontal to these clusters.

The main funding agency for nanoscience and nanotechnology (NST) in Singapore is the Agency for Science, Technology & Research (A*STAR)[171]. 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 include the Institute of Manufacturing Technology (SIMTech); the Advanced Remanufacturing and Technology Centre (ARTC)[172]; the Institute of Materials Research and Engineering (IMRE)[173]; and the Institute of Microelectronics (IME)[174].

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.[175]

In Singapore, nanotechnology is also a key area for the Science and Engineering Research Council (SERC).

4.3.3.4 Thailand

Thailand has been active in nanotechnology since at least 2003 when it established NANOTEC[176] 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

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[168] https://www.mti.gov.sg/ResearchRoom/Pages/Science-and-Technology-Plan-2010.aspx

[169] www.edb.gov.sg

[170] www.ida.gov.sg

[171] www.a-star.edu.sg/

[172] http://www.a-star.edu.sg/artc/

[173] www.a-star.edu.sg/imre

[174] https://www.a-star.edu.sg/ime/

[175] 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

[176] http://www.nanotec.or.th/th/wp-content/uploads/2013/05/NANOTEC-brochure11.pdf

Park. These covered areas including nano-characterisation; engineering and manufacturing characterisation; nanomaterials for energy and catalysis, hybrid nanostructures and nanocomposites; integrated nano-systems; nanoscale simulation; and functional nanomaterials and interfaces.

In 2012, the National Nanotechnology Policy Framework (2012-2021)[177] and the Nanosafety and Ethics Strategic Plan (2012-2016)[178] 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 energy and environment, electronics, food and agriculture, and defines seven flagship products including nanoelectronics. 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 focusing on product development through nanotechnology. To this end, NANOTEC is addressing national and NSTDA priorities under the Framework through ten flagship programmes.

4.3.4 Western Asia

4.3.4.1 Israel

The first nanotechnology policy initiative in Israel was the establishment of the Israel Nanotechnology Initiative (INNI)[179] in 2002 as a shared action of the Forum for National Infrastructures for Research & Development (TELEM)[180] and the ministry for the economy (now called the Ministry for Industry, Trade and Labour)[181]. 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[182] 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[183]) per annum for basic NST equipment plus another almost USD 10 million (EUR 8 million[184]) per annum for new infrastructure and facilities.[185] 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

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[177] http://www.nanotec.or.th/en/wp-content/uploads/2012/02/The-National-Nanotechnology-Policy-framework-exe-sum.pdf

[178] http://www.nanotec.or.th/en/

[179] http://www.nanoisrael.org/

[180] http://www.trdf.co.il/eng/fundinfo.php?id=2846

[181] http://www.economy.gov.il/English/Pages/default.aspx

[182] 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.

[183] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)

[184] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)

[185] Figures for funding under the programme to 2012.

be able to generate the required returns in terms of technology development and deployment.

In addition, the Triangle Donation Matching (TDM) programme[186] 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[187]) 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[188, 189], in 2005 (before the official launch of the programme), the other five research universities receiving support in 2006. One of them is the Hebrew University Centre for Nanoscience and Nanotechnology whose focus areas includes nanomaterials for industrial applications and also has a specialisation in sol-gel-based nanomaterials.

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[190]. The catalogue of equipment includes pricing for the use of the equipment and contact information. Industry users are supported by the university nano-centres to enable them to be effective in using their R&D equipment.

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

4.3.4.2 Saudi Arabia[191]

The King Abdul Aziz City for Science and Technology (KACST) was established in 1985 as the Kingdom's main agency for promoting research and development. In 2002, Saudi Arabia decided to build further on the work of KACST by putting in place a National Policy for Science and Technology (NPST) with plans to increase R&D funding to 1.6% of GDP. KACST was made responsible for implementing the policy which included five-year strategic plans (missions) in eleven research areas prioritising areas including advanced materials, oil and gas, petrochemicals, information technology, energy and environment, water, electronics, photonics, biotechnology, space and aeronautics. The National Nanotechnology Programme (NNP) was established to deliver the plan.

During the implementation of the NNP, nanotechnology centres began to be established, such as the Centre of Excellence in Nanotechnology (CENT) established 2005 at the KFUPM[192]; and the CNT established in 2006 at the KAU[193] that covers engineering, electromechanical devices and fabrication and assembly fields. These centres operated in the context of the multidisciplinary programme of Strategic Priorities for Nanotechnology 2008-2012, put in place by the Saudi Arabian Ministry of Economy and Planning in 2008.

Additional nanoscience and nanotechnology centres followed. The Centre of Excellence of Nano-manufacturing Applications (CENA) was established in 2009 at KACST (active in the area of fabrication of sensors) and the King Abdullah Institute for Nanotechnology (KAIN)[194] established in 2010 at the KSU in the Riyadh Techno Valley. The KAIN covers areas including manufacturing of nanomaterials, energy, food and environment, water treatment and desalination, and telecommunications. 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

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[186] http://www.nanoisrael.org/category.aspx?id=1278

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

[188] 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.

[189] Israel Institute of Technology http://www.technion.ac.il/en/

[190] http://www.nanoisrael.org/category.aspx?id=13671

[191] A review of nanotechnology development in the Arab World, Bassam Alfeeli et al., Nanotechnology Review, 2013 (05/2013; 2(3):359-377)

[192] King Fahd University of Petroleum and Minerals, Riyadh

[193] King Abdul Aziz University, Jeddah

[194] http://nano.ksu.edu.sa/en

nanotechnology centres. There are more than 20 projects in the field of nanotechnology for these two organisations alone.

4.3.4.3 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) nano-fabrication; (ii) nano-characterisation; (iii) nanomaterials; (iv) nano-photonics, nano-electronics and nano-magnetism; (v) nano-biotechnology; (vi) nano-sized quantum information processing; and (vii) fuel cells and energy. 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[195] that nanotechnology received State support of about one billion Turkish Lira, or c. USD 500 million (EUR 367 million[196]). Over 20 nanotechnology research centres, departments and graduate schools have been established including NanoTam[197] and Unam[198] at Bilkent University; Sabanci University Nanotechnology Research and Application Centre (SUNUM)[199]; and the Micro and Nanotechnology Department at the Middle East Technical University[200].

4.4 Oceania

4.4.1.1 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[201]), 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[202] was prepared by the Australian Academy of Science, using funding from the National Enabling Technologies Policy Section, Department of Industry, Innovation, Science, Research and Tertiary Education. The Research Strategy highlighted how manufacturing techniques and advanced engineering manufacturing processes at the nanoscale have led to a nanotechnology revolution. One of the recommendations is to involve SMEs in nano manufacturing[203]. In addition, it identified the Australian nanomaterials research focus as one of the major drivers for advances in advanced manufacturing.

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

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[195] http://www.issi2015.org/files/downloads/all-papers/0720.pdf

[196] Average yearly conversion rate, 2007-2014 (*source*: www.wolframalpha.com)

[197] http://www.nanotam.bilkent.edu.tr/eng/main.html

[198] http://unam.bilkent.edu.tr/?page_id=576

[199] http://sunum.sabanciuniv.edu/

[200] http://mnt.metu.edu.tr/

[201] Average yearly conversion rate, 2010-2013 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-aud.en.html)

[202] https://www.science.org.au/publications/national-nanotechnology-research-strategy

[203] https://8-science.cdn.aspedia.net/sites/default/files/user-content/resources/file/nanotech-research-strategy.pdf

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[204]. 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.

4.4.1.2 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[205]. 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[206]) funding for 2003-2006 from the Ministry of Education and, in early 2006, developed a "Nanotechnology Initiative for New Zealand"[207] identifying where capability in nanotechnology could be developed in the country. The Initiative identified six programmes for nanoscience and nanotechnology research: nanomaterials for industry; nano- and micro-fluidics; nanotechnology for energy; nano-photonics, nano-electronics and nano-devices; bio-nanotechnologies; and social impacts of nanotechnology.

Also in 2006, the New Zealand government released a Nanoscience and Nanotechnologies Roadmap (2006-2015)[208]. 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 Roadmap noted the crucial importance of the programme on nano-photonics, nano-electronics and nano-devices, included in the Nanotechnology Initiative for New Zealand. 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 energy and minerals, high-value manufacturing and services, health and society, as well as biological sciences, hazards and infrastructure, and the environment[209].

4.5 Africa

4.5.1.1 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)[210] 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)[211] by the Department of Science and Technology (DST);

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[204] http://www.ausnano.net/index.php?page=home
[205] http://www.macdiarmid.ac.nz/
[206] Average yearly conversion rate, 2003-2006 (*source*: www.wolframalpha.com)
[207] http://www.macdiarmid.ac.nz/a-nanotechnology-initiative-for-new-zealand/
[208] http://statnano.com/strategicplans/13
[209] http://www.mbie.govt.nz/
[210] http://www.sani.org.za/
[211] http://www.esastap.org.za/download/natstrat_advmanu_mar2005.pdf

- In 2005, the publication of the National Strategy on Nanotechnology (NSN)[212] 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[213] and MINTEK[214]. Each centre has developed collaborative research programmes, often with other national institutions, including programmes in designing and modelling of novel nano-structured materials, at the CSIR-National Centre for Nano-structured Materials (NCNSM)[215], 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[216] enables joint projects and mobility[217] between S&T departments in those countries.

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

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[212] http://chrtem.nmmu.ac.za/file/35e56e36b6ab3a98fac6fc0c31ee7008/dstnanotech18012006.pdf
[213] http://www.csir.co.za/
[214] http://www.nic.ac.za/
[215] http://ls-ncnsm.csir.co.za/
[216] http://www.ibsa-trilateral.org/
[217] http://www.ibsa-trilateral.org/about-ibsa/areas-of-cooperation/people-to-people

5 PUBLICATIONS IN NANOTECHNOLOGY MANUFACTURING

5.1 Overview

Around 1.8 million publications were identified[218] from the Web of Science as being related to nanoscience and technology (NST)[219] between 2000 and 2014. Nanotechnology manufacturing comprises between approximately 30% of overall manufacturing publications in any given year in that time period. The numbers of publications identified[220] from the Web of Science for the World and for the EU 28 and EFTA countries (EU28&EFTA, includes Switzerland and Norway) are shown in the table below, presented as nanotechnology manufacturing (with "nano" as a core term[221]) and as a percentage of total manufacturing publications.

Table 5-1: Manufacturing publications with and without nano as a core term, 2000-2014

Year	EU 28 & EFTA		World	
	Nanotechnology manufacturing	% of total manufacturing	Nanotechnology manufacturing	% of total manufacturing
2000	2,925	58.1%	7,670	58.2%
2001	3,201	58.7%	8,607	59.7%
2002	3,348	58.9%	9,520	61.0%
2003	3,604	59.0%	10,670	61.7%
2004	3,962	59.8%	12,283	62.9%
2005	4,219	60.4%	13,905	65.5%
2006	4,688	61.8%	15,643	66.5%
2007	4,970	62.0%	16,343	66.4%
2008	4,979	61.2%	17,510	66.9%
2009	5,116	60.1%	17,891	66.2%
2010	5,307	62.0%	18,739	67.8%
2011	6,019	62.8%	20,737	67.7%
2012	5,693	60.3%	21,180	67.0%
2013	6,153	60.2%	23,206	66.6%
2014	6,201	60.3%	24,173	66.6%
TOTAL	**70,385**		**238,077**	

Source: Derived from Web of Science

The evolution over time of publications in nanotechnology manufacturing, as well as the whole of manufacturing (both for (i) EU28 and EFTA and (ii) the World), is depicted in the figure below, indexed by year 2000 (=1). In both Europe and in the World as a whole, the growth of nanoscience and nanotechnology (NST) manufacturing publications is somewhat faster than in the field of manufacturing as a whole.

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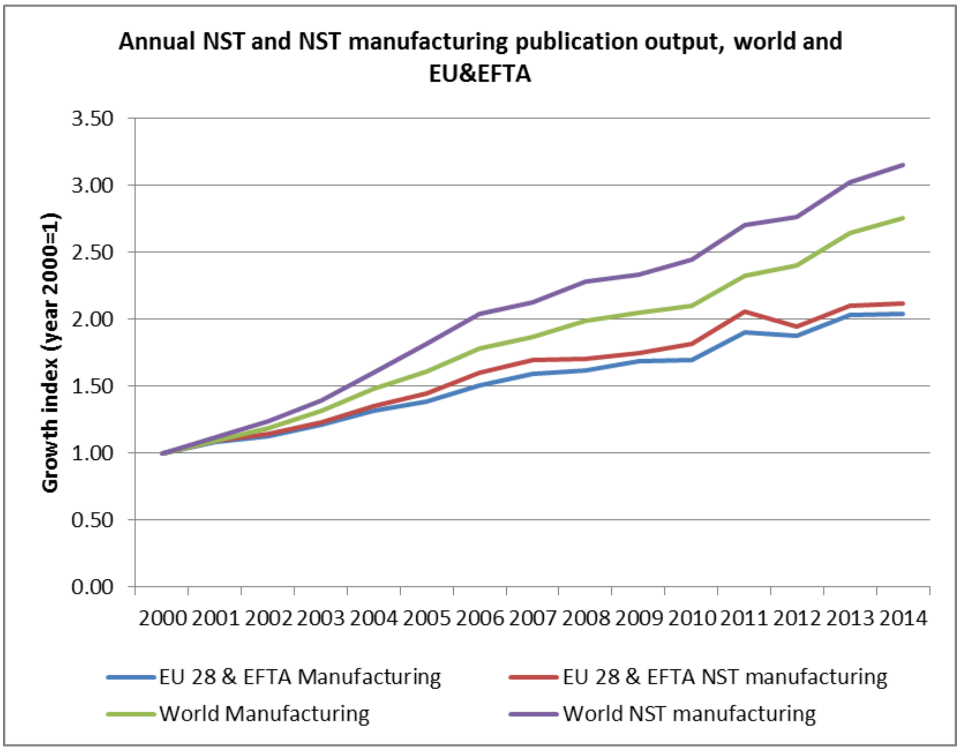
[218] http://www.vosviewer.com/Publications

[219] 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.

[220] http://www.vosviewer.com/Publications

[221] The term "nanosecond" has been omitted as not being relevant to the study



Source: Derived from Web of Science

Figure 5-1: Annual NST manufacturing publication output, worldwide and EU28&EFTA, 2000-2014 (indexed to Year 2000(=1))

5.2 Activity by region and country

The most prolific countries for nanotechnology manufacturing publications globally in 2014 (most recent year available) were China (PRC) and the USA, followed by Korea, India, Japan and Germany (by numbers of publications, npub). In terms of regions, based on the data for the top 25 publishing countries for nanotechnology manufacturing, Asia leads in publications in 2014, followed by the EU28 & EFTA. The distributions are presented in the table and figures below.

Table 5-2: Most prolific regions for nanotechnology manufacturing publications, 2014

Region	npub
Asia	13,314
EU28 & EFTA	6,201
North America	3,798
Middle East	988
South and Central America	681

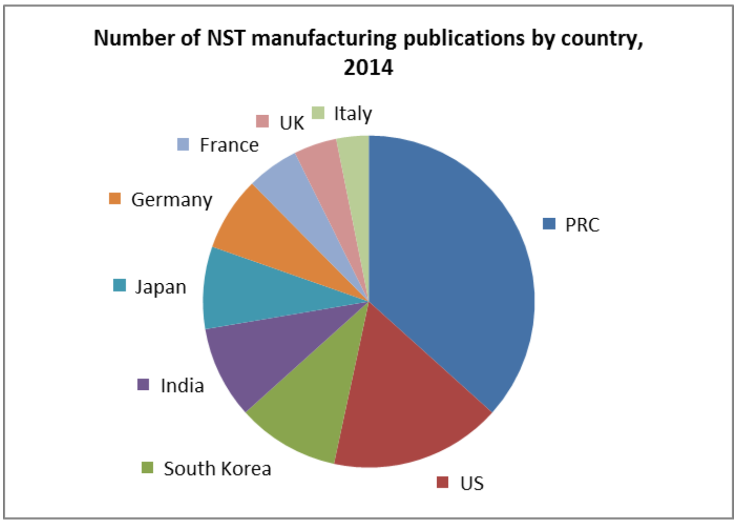


Figure 5-2: Nanotechnology manufacturing publications by country, 2014

Table 5-3: Nanotechnology manufacturing publications by country (top 25), 2014

Country	Region	npub
PRC (CN)	Asia	7,502
USA (US)	North America	3,420
Korea (KR)	Asia	2,042
India (IN)	Asia	1,838
Japan (JP)	Asia	1,641
Germany (DE)	EU28 & EFTA	1,477
France (FR)	EU28 & EFTA	1,038
United Kingdom (UK)[222]	EU28 & EFTA	859
Italy (IT)	EU28 & EFTA	646
Spain (ES)	EU28 & EFTA	621
Australia (AU)	Oceania	462
Canada (CA)	North America	436
Singapore (SG)	Asia	430
Poland (PO)	EU28 & EFTA	385
Turkey (TR)	Asia/ Europe	368
Brazil (BR)	South and Central America	326
Malaysia (MY)	Asia	324
Saudi Arabia (SA)	Asia	293
Switzerland (CH)	EU28 & EFTA	281
Sweden (SE)	EU28 & EFTA	266
Belgium (BE)	EU28 & EFTA	247
Netherlands (NL)	EU28 & EFTA	235
Mexico (MX)	South and Central America	206
Czech Republic (CZ)	EU28 & EFTA	200
Portugal (PT)	EU28 & EFTA	190

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[222] The database used for this section on publications reports on ‘Great Britain’ but includes Northern Ireland in that and is therefore, by definition, reporting on the United Kingdom (UK) and not just Great Britain. The original terminology has been retained as it is standard in this research area.

In the EU28&EFTA, Germany and France generated the largest number of publications in 2014, followed by Great Britain (UK), Italy and Spain (see figure below).

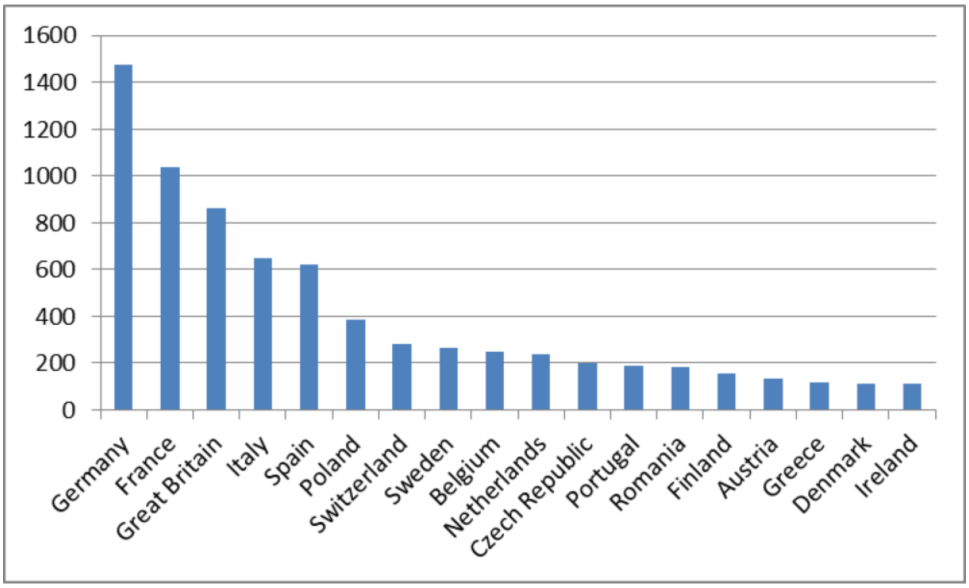

Figure 5-3: Number of NST manufacturing publications by EU&EFTA countries, 2014
Data for the top NST manufacturing publishing countries only

5.3 Activity by organisation type

Identified from the publication data, the main players in the R&D landscape of nanotechnology manufacturing are higher education institutions (HEIs), research and technology organisations (RTOs) and private companies (PCO) (including some SMEs). The distribution of their contribution in terms of publication output differs marginally if the sector is compared to the entire NST output and when comparing the EU28 plus EFTA with the world.

The most active organisations in NST manufacturing publications in 2014 are shown in the table below. The higher education organisations with the most nanotechnology manufacturing publications globally in 2014 were predominantly Asian universities as shown in the table below of the top 25 publishing organisations. The highest performing non-Asian universities was Massachusetts Institute of Technology (MIT) in the USA.

Table 5-4: Publication numbers for nanotechnology manufacturing for higher education and research organisations, 2014

Country	University/ Research Institute	npub
PRC	Chinese Academy of Science	1179
PRC	Zhejiang University	262
PRC	Tsing Hua University	245
PRC	Jilin University	228
India	Indian Institute of Technology	212
PRC	University of the Chinese Academy of Sciences	206
Singapore	Nanyang Technology University	204
PRC	Shanghai Jiao Tong University	182
Korea	Sungkyunkwan University	181
PRC	Peking University	171
PRC	University of Science and Technology, China	167
Singapore	National University Singapore	167
Korea	Seoul National University	165
Korea	Yonsei University	155
PRC	Tianjin University	150
PRC	Nanjing University	149
PRC	South China University of Technology	147
PRC	Harbin Institute of Technology	146
PRC	Shandong University	144
Korea	Korea University	143
PRC	Huazhong University of Science and Technology	143
Japan	Tohoku University	140
US	MIT[223]	140
PRC	Fudan University	139

The top sixteen higher education and research organisations in the EU28 and EFTA publishing in nanotechnology manufacturing are listed below. These are led by the University of Cambridge (UK) with over 100 publications and the Polish Academy of Sciences (PL) and École Polytechnique Fédérale de Lausanne, EPFL (CH) each with more than 80 publications. Four each of the eighteen are based in France and the UK, and three in Germany.

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[223] Massachusetts Institute of Technology http://web.mit.edu/

Table 5-5: Number of nanotechnology manufacturing publications by EU&EFTA organisation, 2014

Organisation	Country	npub
University of Cambridge	UK	118
Polish Academy of Sciences	PL	101
EPFL[224]	CH	84
Catholic University of Leuven	BE	73
Uppsala University	SE	66
Karlsruhe Institute of Technology	DE	66
University College London	UK	65
Technical University of Dresden	DE	64
Aalto University	FI	64
Academy of Sciences of the Czech Republic	CZ	63
Linkoping University	SE	63
ETHZ[225]	CH	62
Eindhoven University of Technology	NL	60
Ruhr University Bochum	DE	57
IMEC	BE	55
FAU Erlangen-Nürnberg[226]	DE	55

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST manufacturing (2014) are shown in the table below. This list is much less dominated by Asian actors. The companies with the most nanotechnology manufacturing publications globally in 2014 were IBM and Samsung as shown in the table of the top publishing companies worldwide.

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[224] École Polytechnique Fédérale de Lausanne
[225] Eidgenössische Technische Hochschule Zürich, Swiss Federal Institute of Technology in Zurich www.ethz.ch
[226] Friedrich-Alexander-Universität Erlangen-Nürnberg

Table 5-6: Number of nanotechnology manufacturing publications by company (top 16), 2014

Company	npub
IBM Corporation	37
Samsung Electronics Company[227]	30
NTT[228]	17
Intel Corporation	13
Diamond Light Source Ltd	12
Samsung Advanced Institute of Technology	12
STMicroelectronics SA	10
Panasonic Corporation	9
Advanced Technology and Materials Corporation	8
General Motors Corporation	8
Micro Resist Technology GmbH	8
Applied Materials Inc.	7
Seagate Technology Inc.	7
SINTEF Materials and Chemicals	7

The next section looks at patenting activity in nanotechnology and manufacturing, over time, by country of applicant, by applicant organisation and by patents granted.

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[227] Samsung is represented in the table as four organisations/companies with a total of 177 publications. Some of these publications may be the same (i.e. authors from more than one part of Samsung).

[228] Nippon Telegraph and Telephone Corporation

6 PATENTING IN NANOTECHNOLOGY MANUFACTURING

6.1 Overview

This section looks at patenting activity in nanotechnology manufacturing by patent filings and patents granted at the leading global patent offices and by country of applicant and country of inventor, and by organisation, including companies, over the time period 1999-2011.

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. B82, or B82Y for manufactured nanomaterials) and those related to the sector under consideration (manufacturing, energy, etc.)[229]. 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[230] 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[231] that are members of the treaty.

6.2 Number and evolution over time of patent families

Using the above methodology, 44,391 (simple) nanotechnology patent families[232, 233] of granted patents and patent applications were found in the period 1993-2011[234]. 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)[235].

In the same period, the number of manufacturing-related patent families identified among the nanotechnology patents is 2,378, 5.4% 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 nanotechnology and manufacturing is in the US (90.7%) and the lowest at the EPO (36.2%), the difference being more than a factor of two.

Table 6-1: Absolute numbers and percentages of patents on nanotechnology manufacturing

Nanotechnology Manufacturing Applications (1993-2011)	Absolute Number	Percentage
Total Patent Families	2,378	100%
PCT Applications	1,290	54.2%
EP Applications	860	36.2%
US Applications	2,157	90.7%

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[229] 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.

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

[231] 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

[232] The definition of simple family is used, in which 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.

[233] 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/

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

[235] 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.

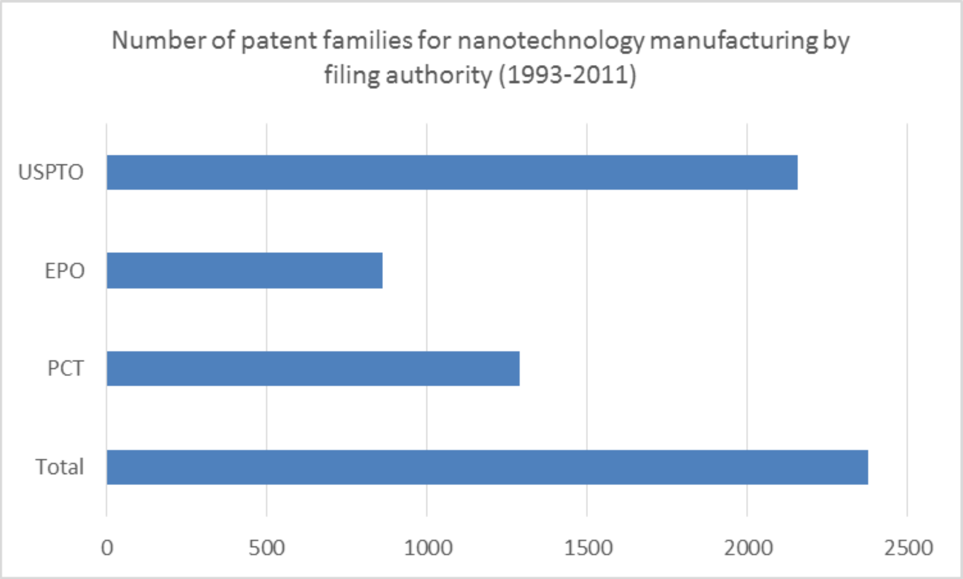

Figure 6-1: Number of patent families by filing authority (PCT, EPO, and USPTO)

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.

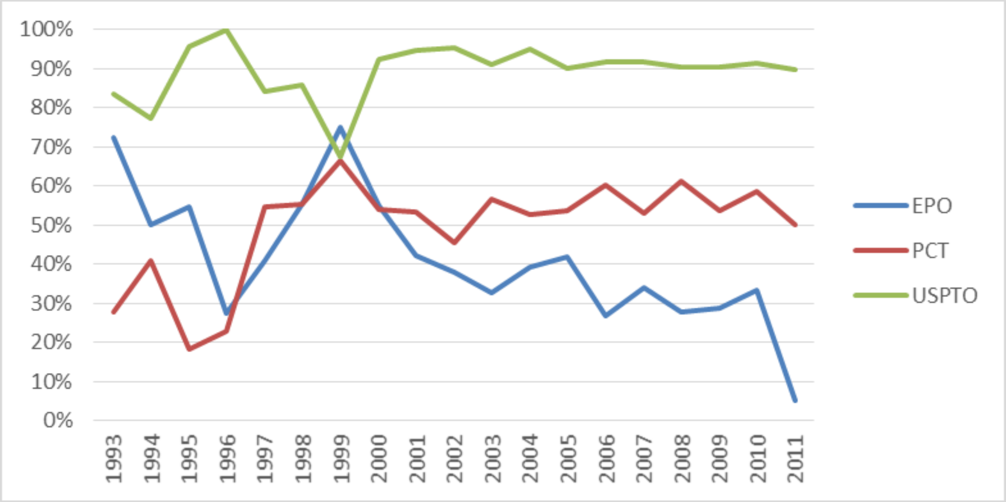

Figure 6-2: Evolution over time of WIPO (PCT), EPO and USPTO nanotechnology manufacturing patenting

The percentages of nanotechnology manufacturing patent applications for the USPTO and PCT (WIPO) has remained quite constant in more recent years (2000-2011) while that of the EPO has dropped. This trend may indicate that patent filing in the US has remained important, as has filing of PCTs while the importance of filing in Europe at the EPO. The US trend may also reflect the fact that the majority of patentees are from the US, as indicated in the following sections.

6.3 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 and Europe (EPO). There are four EU28 countries in the table (FR, UK, NL, and DE). The next highest placed is Spain with seven patent families. The sum of the figures for the European patent offices in this top ten table and the EPO is just 279, considerably less than in the US. Even if all the remaining EU countries are allocated the figure of Spain (as they will not have more patent families than Spain with seven), the total for the EU28 plus the EPO is 608, less than the US.

Table 6-2: Number of nanotechnology manufacturing patent families by PCT receiving authority

Receiving Authority	No. of Patent Families (1993-2011)
United States	656
Japan	184
European Patent Office (EPO)	161
France	44
United Kingdom	38
Korea	37
International Bureau (WIPO)	35
Netherlands	21
Canada	17
Germany	15

6.4 Activity by country of applicant

PATENT APPLICATIONS

Within the group of all nanotechnology manufacturing patent families, there is at least one EU28 or EFTA applicant in a quarter of them while there is participation from the rest of the world in almost three-quarters of cases.

Table 6-3: Origin of patent applicants, EU/EFTA and Rest of world (1993-2011)

	EU28 & EFTA	Rest of World
Number of nanotechnology manufacturing patent families	714	2,112
Percentage of nanotechnology manufacturing patent families	25.3%	74.7%

By far the highest number of patent families is found where the country of the applicant is the US (1,112 patent families), more than twice that of the next placed, Japan (487). Korea, the Netherlands and Germany have the next highest number of applicants but less than half those of Japan. In terms of applicants from Europe, the Netherlands (185 patent families) and Germany are followed by France (103) and the United Kingdom (73). Sweden, Italy and Spain each have around 20 patent families.

For Asia, the lead country for applicants, Japan (487), is followed by Korea (210), Taiwan (Chinese Taipei, 87), China (68) and Singapore (20). No South American country applicants feature, nor those from Oceania.

Table 6-4: Patent families by country of applicant, numbers and percentages (1993-2011)

	Country of applicant	No. of Patent Families	PCT	US	EP
1	United States	1,112	62%	91%	31%
2	Japan	487	42%	86%	28%
3	Korea	210	20%	86%	24%
4	**Netherlands**	185	42%	86%	37%
5	**Germany**	182	54%	76%	61%
6	**France**	103	69%	80%	71%
7	Taiwan (Chinese Taipei)	87	0%	98%	5%
8	**United Kingdom**	73	75%	52%	52%
9	China	68	29%	66%	15%
10	Canada	35	57%	86%	26%
11	Switzerland	32	72%	72%	66%
12	**Sweden**	26	50%	88%	62%
13	**Italy**	24	54%	83%	46%
14	Singapore	20	50%	85%	60%
15	**Spain**	18	78%	56%	28%
16	Israel	15	60%	80%	27%
17	India	14	71%	57%	29%
18	**Austria**	14	43%	79%	50%
19	Russian Federation	13	62%	46%	38%
20	**Belgium**	10	20%	80%	60%

91% of patents of US applicants are filed with the USPTO while 62% are filed as PCTs. Only 31% are filed by US applicants at the EPO.

The applicants in the top three European countries (NL, DE, FR) file more in the US than as either as PCTs or at EPO while applicants in the fourth top EU country (UK) file more as PCT than in either the EPO or the USPTO. The figure below shows the top ten countries in the EU28 and EFTA ranked by number of patent families.

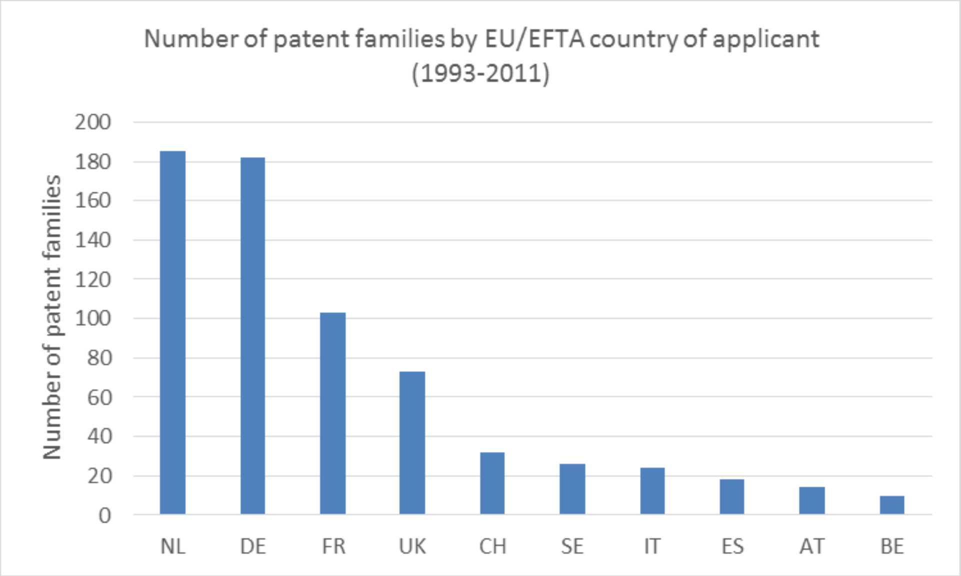

Figure 6-3: Number of patent families by country of applicant EU28/EFTA

GRANTED PATENTS

Applicants from the same EU and EFTA countries perform strongly in patents granted, namely those from the Netherlands, Germany, France and the UK. For all four of these countries, there are more patents granted by the USPTO than by the EPO, the first three (NL, DE, FR) also having had more applications in the US than EPO. The UK may have a higher success rate with its US applications than its EPO applications, or there may be a time lag in the data.

Table 6-5: Country of applicant and number of patents granted at EPO and USPTO

	Country of applicant	No. of Patents Granted (1993-2011)	
		EPO	USPTO
1	Netherlands	27	96
2	Germany	31	82
3	France	22	41
4	United Kingdom	14	20
5	Switzerland	6	10
6	Italy	4	9
7	Sweden	5	9
8	Austria	3	7
9	Spain	0	5
10	Belgium	1	4
11	Denmark	1	3
12	Finland	2	3
13	Czech Republic	0	2
14	Poland	2	2
15	Ireland	0	1

For the countries of the EU and EFTA shown in the table, there are generally significantly more patents granted by the USPTO than the EPO.

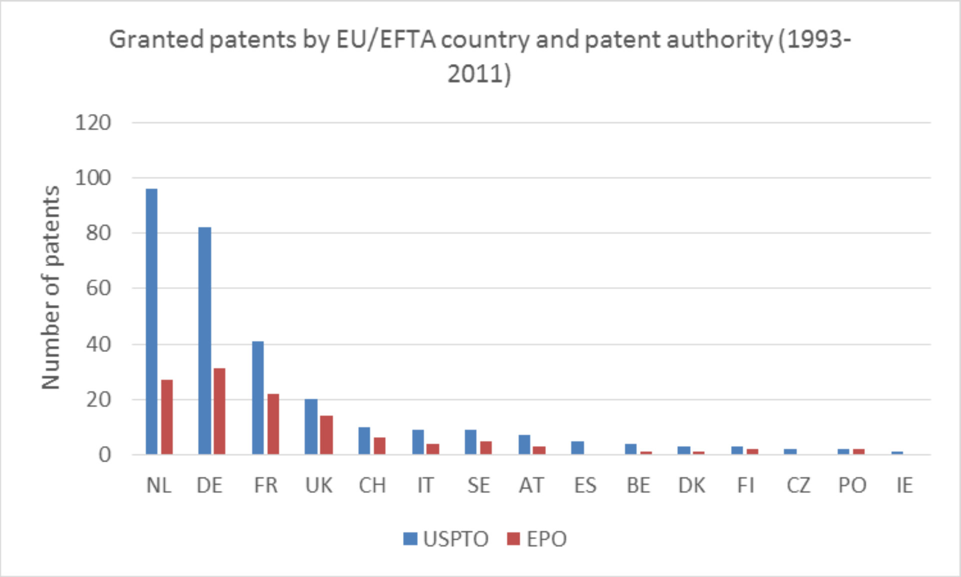

Figure 6-4: Granted patents by country of applicant for EU28/EFTA

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, the first five being in the same rank order.

Table 6-6: Comparison of patent filings and patents granted by country of applicant (1993-2011)

	Country of applicant	No. of Patent Families
1	NL	185
2	DE	182
3	FR	103
4	UK	73
5	CH	32
6	SE	26
7	IT	24
8	ES	18
9	AT	14
10	BE	10

	Country of applicant	No. of Patents Granted[236]
1	NL	123
2	DE	113
3	FR	63
4	UK	34
5	CH	16
6	IT	13
7	SE	14
8	AT	10
9	ES	5
10	BE	5

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[237]. This shows a high success rate for Austria, the Netherlands, Germany and France.

Table 6-7: Estimate of relative patenting success by country of applicant

	Country of applicant	Granted/ Applied
1	Austria	71%
2	Netherlands	66%
3	Germany	62%
4	France	61%
5	Italy	54%
6	Sweden	54%
7	Switzerland	50%
8	Belgium	50%
9	United Kingdom	47%
10	Spain	28%

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. In addition, inventions from inventors in the US are patented elsewhere and patent applications in the US may originate from work done elsewhere.

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[236] Total of patents granted at USPTO and EPO for nanotechnology manufacturing

[237] 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 6-8: Country of applicant and country of inventor table for cross-comparison

INVT	US	JP	NL	KR	DE	UK	CN	CA	SG	TW
APPL										
US	1063	43	13	24	23	14	11	9	6	8
JP	52	465	0	3	2	3	6	0	1	0
NL	28	2	158	1	12	1	0	1	1	0
KR	24	3	0	206	1	2	6	0	0	0
DE	22	2	15	1	172	6	2	2	0	0
UK	20	1	1	2	4	61	1	1	2	0
CN	11	6	0	7	2	1	66	1	2	6
CA	9	0	1	0	2	1	1	35	0	1
SG	9	2	1	0	0	1	2	0	16	0
TW	7	0	0	0	0	0	19	1	0	71

6.5 Patenting activity by organisation type

6.5.1 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), four are in the United States. France is the only EU28 country that features in the table, marked in bold, with both the CEA[238] and CNRS[239]. The top EU and EFTA universities and PROs as measured by patent families were CEA (FR), CNRS (FR), Fraunhofer (DE), CSIC (ES), IMEC (BE), Max Planck (DE), ETHZ (CH), TU Dresden (DE) and TU Delft (NL).

Table 6-9: 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	58	74.1%	70.7%	22.4%
2	FR	CEA	37	67.6%	59.5%	54.1%
3	US	Northwestern University	26	80.8%	80.8%	19.2%
4	US	MIT	24	83.3%	75.0%	12.5%
5	US	University Of Texas	22	4.5%	68.2%	63.6%
6	FR	CNRS	20	70.0%	65.0%	60.0%
7	TW	Industrial Tech Research Institute	16	0.0%	100.0%	0.0%
8	CN	Tsinghua University	16	0.0%	93.8%	6.3%
9	KR	Electronics & Telecomms Res Inst	14	0.0%	92.9%	21.4%
10	JP	AIST	13	92.3%	0.0%	0.0%

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[238] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr

[239] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr

GRANTED PATENTS

Of the top 15 universities and research organisations for patents granted (ranked by the highest number of EPO patents 1993 to 2011), three are from the EU28/EFTA countries as shown in the table below. Four of the organisations are from the US, four from Korea and two from Japan.

Table 6-10: Universities / research organisations granted patents, top fifteen by EPO patent numbers

Rank	Country	Organisation	EP	US
1	**FR**	**CEA**	7	20
2	**FR**	**CNRS**	5	6
3	US	University of Texas	5	8
4	**DE**	**Fraunhofer**	4	0
5	US	Northwestern University	3	16
6	US	Harvard College	3	7
7	US	University of California	3	33
8	AU	CSIRO	2	1
9	IN	Council of Scientific and Industrial Research	2	1
10	JP	Japanese Science and Technology Agency	2	5
11	JP	AIST	2	5
12	KR	ETRI	2	12
13	KR	KIST	2	6
14	KR	KIER	2	3
15	KR	KIMM	2	5

Of the top 15 universities and research organisations for patents granted (ranked by the highest number of USPTO patents 1993 to 2011), two (CEA, CNRS) are from a EU28/EFTA country (FR) as shown in the table below. Seven of the organisations are from the US, two from Korea and two from Japan.

Table 6-11: Universities / research organisations granted patents, top fifteen by USPTO patent numbers

Rank	Country	Organisation	US	EP
1	US	University of California	33	3
2	**FR**	CEA	20	7
3	US	Northwestern University	16	3
4	US	MIT	15	1
5	KR	ETRI	12	2
6	CN	Tsinghua University	11	1
7	TW	ITRI[240]	10	0
8	US	University of Texas	8	5
9	US	Caltech[241]	8	1
10	US	Harvard College	7	3
11	**FR**	CNRS	6	5
12	KR	KIST	6	2
13	US	Wisconsin Alumni Research Foundation	6	0
14	JP	Japanese Science and Tech Agency	5	2
15	JP	AIST[242]	5	2

6.5.2 Activity of companies[243]

PATENT APPLICATIONS

Of the top ten companies (two being equally ranked tenth) with the highest number of patent families (with percentages for PCT, US and EP applications), four are in the United States. The Netherlands and Germany are the two EU28 countries that feature in the table, marked in bold.

Table 6-12: Number of patent families for top ten companies (1993-2011)

	Country	Company	No. of Patent families	PCT	US	EP
1	US	Molecular Imprints Inc.	102	86.3%	97.1%	38.2%
2	**NL**	ASML Netherlands BV	82	24.4%	85.4%	14.6%
3	KR	Samsung Elect Co Ltd	49	0.0%	83.7%	16.3%
4	US	IBM Corporation	43	48.8%	93.0%	37.2%
5	**NL**	Mapper Lithography IP BV	36	88.9%	72.2%	69.4%
6	JP	Asahi Glass Co Ltd	36	97.2%	83.3%	63.9%
7	US	Applied Materials Inc.	34	58.8%	85.3%	32.4%
8	US	D2S Inc.	24	58.3%	91.7%	25.0%
9	JP	KK Toshiba	22	9.1%	95.5%	4.5%
10=	JP	Fujitsu Ltd	21	23.8%	95.2%	9.5%
10=	**DE**	Carl Zeiss SMT AG	21	42.9%	47.6%	28.6%

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[240] Industrial Technology Research Institute https://www.itri.org.tw/eng/

[241] California Institute of Technology www.caltech.edu

[242] National Institute of Advanced Industrial Science and Technology www.aist.go.jp/index_en.html

[243] It should be noted that some companies may be holding companies rather than research companies or manufacturers.

Five EU28 companies are in the top twenty companies with the highest number of patent families (with percentages for PCT, US and EP applications), three from the Netherlands and two from Germany as shown in the table below.

Table 6-13: Number of patent families EU & EFTA companies in the top twenty (1993-2011)

World Rank	Country	Company	No. of Patent families	PCT	US	EP
2	NL	ASML NL BV	82	90%	60%	90%
5	NL	Mapper Lithography IP BV	36	13%	31%	100%
10	DE	Carl Zeiss SMT AG	21	36%	0%	100%
14	NL	KON Philips Elects NV	18	91%	36%	73%
17	DE	Infineon Tech AG	17	60%	40%	60%

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[244]. 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. Three companies from the Netherlands and one from Sweden are in the top ten for patents granted by the EPO. Two of the same companies from the Netherlands, Mapper Lithography and ASML, are also in the top ten for patents granted by the USPTO.

Table 6-14: USPTO and EPO granted patents by company, sorted by EP patents (1993-2011)

Country	Company	EP	US
US	IBM Corporation	9	35
JP	Asahi Glass Co Ltd	8	25
US	Molecular Imprints Inc.	8	56
NL	Mapper Lithography IP BV	8	17
JP	Hitachi LTD	6	12
NL	KON Philips Elects NV	5	5
SE	Obducat AB	5	5
US	Applied Materials Inc.	4	25
US	Lucent Tech Inc.	4	7
NL	ASML Netherlands BV	4	39

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[244] 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 6-15: USPTO and EPO granted patents by company (sorted by US patents)

Country	Company	US	EP
US	Molecular Imprints Inc.	56	8
NL	ASML Netherlands BV	39	4
KR	Samsung Elect Co Ltd	35	3
US	IBM Corporation	35	9
JP	Asahi Glass Co Ltd	25	8
US	Applied Materials Inc.	25	4
US	D2S Inc.	20	0
JP	KK Toshiba	18	1
NL	Mapper Lithography IP BV	17	8
US	Hewlett Packard Dev Co Ltd	16	1

The next section of the report looks at industry, products and markets.

7 INDUSTRY, PRODUCTS AND MARKETS FOR NANOTECHNOLOGY MANUFACTURING

7.1 Overview of the industry

The manufacturing techniques and nanomaterials discussed in this report are largely used in the chemical industry, the metals industry, the ceramics industry and the photolithography industry. The manufactured products of those industries can subsequently be used in other industries (e.g. automotive, construction).

The table below presents an overview of economic data for the sectors that are most relevant to the manufacturing of engineering nanomaterials and nanostructures as defined under NACE 2.2[245].

Table 7-1: Economic data on manufacturing industry relevant to nanotechnology in the EU28 (2012)

	Value added at factor cost	Total persons employed	Number of enterprises	Turnover
	MEUR[246]	**'000s**		**MEUR**
Manufacture of chemicals and chemical products (C20.00[247])	110,000	12,000	28,320	490,000 (2010, EU-27)
Manufacture of other porcelain and ceramic products (C23.40)	3,314	1,071	13,288	8,822
Manufacture of basic metals (C24.00)	60,000	10,000	17,343	370,000
Manufacture of fabricated metal products (except machinery & equipment) (C25.00)	159,229	35,983	382,816	468,253
Manufacture of electronic components (C26.11)	12,323	2,041	6,742	44,034

Source: Eurostat, Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)

The five sub-sectors of the manufacturing industry in the table above vary substantially in size in terms of turnover, number of enterprises, persons employed and value added. The largest (in terms of enterprises and employment) is the manufacturing of fabricated metal products. This is a sector dominated by SMEs, with more than 80% of the employment and generating more than three quarters of the value added. In the manufacturing of chemicals and chemical products, large firms are dominant (50 to 60% of employment and value added). The smallest sub-sector is the manufacturing of other porcelain and ceramic products.

Only Value4Nano[248] gives an estimation of employment in the nanomaterial sector in Europe with 300,000 to 400,000 directly employed. However, it is unclear how the estimation has been made and on what data it is based.

The next part of this chapter looks at products and markets for nanotechnology manufacturing.

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[245] Statistical Classification of Economic Activities in the European Community

[246] MEUR = millions of euro

[247] The number in brackets is the NACE code equivalent to the text. For example, C20.00 is Manufacture of chemicals and chemical products. For this, and the other codes in brackets in the column, see http://ec.europa.eu/competition/mergers/cases/index/nace_all.html.

[248] http://value4nano.eu/

7.2 Products and markets for nanotechnology manufacturing

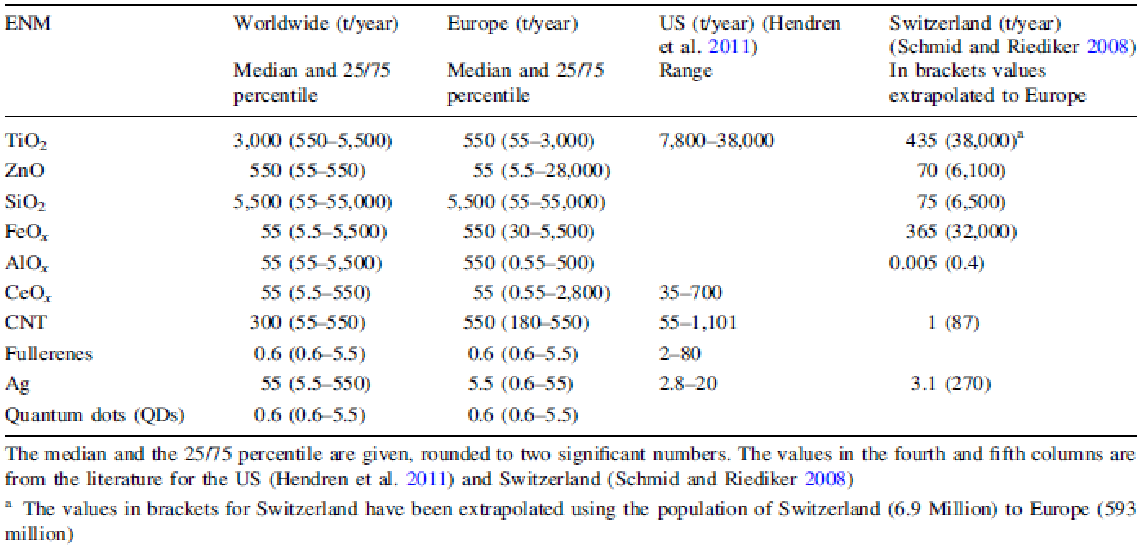
7.2.1 Overview

Nanomanufacturing can be looked upon as the building block for high performance products associated with a wide range of industries such as aerospace and defence, automotive and transportation, information and communication technologies, energy and healthcare. In order to realise the advantages of nanomanufacturing and apply the technologies to support those industries, an economy of scale is needed in order to address national and global industry requirements. The transition of advanced nanotechnology from the laboratory to high-volume production depends on appropriate product design, manufacturing process integration, supply chain management, and appropriate safety precautions in handling. Benefits that could accrue from the integration of nanotechnology into high added-value products include growth in the materials supply chain, nano-intermediates, equipment, and instrumentation markets as the technologies gets gradually merged in the established infrastructure, as well as a broad range of employment opportunities.

The data below on market values and forecasts has been gathered in part from existing reports and in part from additional work.

An article, by Piccinno et al (2012) presents first estimates of production quantities of engineered nanomaterials in Europe, based on a survey sent to companies producing and using engineered nanomaterials (see table below).

Table 7-2: Production/ utilisation quantities of ten nanomaterials worldwide and in Europe



ENM	Worldwide (t/year) Median and 25/75 percentile	Europe (t/year) Median and 25/75 percentile	US (t/year) (Hendren et al. 2011) Range	Switzerland (t/year) (Schmid and Riediker 2008) In brackets values extrapolated to Europe
TiO_2	3,000 (550–5,500)	550 (55–3,000)	7,800–38,000	435 (38,000)[a]
ZnO	550 (55–550)	55 (5.5–28,000)		70 (6,100)
SiO_2	5,500 (55–55,000)	5,500 (55–55,000)		75 (6,500)
FeO_x	55 (5.5–5,500)	550 (30–5,500)		365 (32,000)
AlO_x	55 (55–5,500)	550 (0.55–500)		0.005 (0.4)
CeO_x	55 (5.5–550)	55 (0.55–2,800)	35–700	
CNT	300 (55–550)	550 (180–550)	55–1,101	1 (87)
Fullerenes	0.6 (0.6–5.5)	0.6 (0.6–5.5)	2–80	
Ag	55 (5.5–550)	5.5 (0.6–55)	2.8–20	3.1 (270)
Quantum dots (QDs)	0.6 (0.6–5.5)	0.6 (0.6–5.5)		

The median and the 25/75 percentile are given, rounded to two significant numbers. The values in the fourth and fifth columns are from the literature for the US (Hendren et al. 2011) and Switzerland (Schmid and Riediker 2008)

[a] The values in brackets for Switzerland have been extrapolated using the population of Switzerland (6.9 Million) to Europe (593 million)

Note: TiO2 = Titanium (IV) oxide; ZnO = zinc oxide; SiO2 = liquid glass; FeOx = iron oxide; AlOx = aluminium oxide; CeOx = cerium oxide; CNT = carbon nanotubes; Ag: silver.

Source: Piccino et al. (2012) Industrial production quantities and uses of ten engineered nanomaterials in Europe and the world, Journal of Nanoparticle Research (2012) 14:1109

The survey was sent to 239 recipients, of whom 46 answered the survey (45 from Europe and 1 from the USA). Most replies came from manufacturers (23), followed by downstream users (9) and others involved in nanotechnology (14). The estimations of the production and utilisation quantities of ten nanomaterials worldwide and in Europe are presented in the table below. The authors also included insights from the literature of production worldwide, in Europe, in the US and in Switzerland for comparison. The estimates are of actual production amounts not production capacities.

The responses for several materials differ substantially and should be treated with caution. One reason for this is that, for some materials (e.g. nano-SiO_2 and nano-TiO_2), not all companies would name them nano as they can easily agglomerate into larger particles. Moreover, at the time of the survey, a precise definition and measurement were unavailable and some materials have been produced for many decades, long before nanotechnology gained attention and therefore they are not always seen as nanomaterials.

According to Charitidis et al (2014), fullerenes are already being produced in tonnes per year, mainly via the gas combustion method. The first commercial usage of fullerenes was reported in 2003 as a coating on bowling balls. The Nanowerk.com database counts 122 fullerene products and 24 companies, of which 11 are based in the USA. The prices for fullerenes are relatively high and unit sales sizes are relatively small. Carbon nanotubes are mainly produced by chemical vapour deposition because of the relative ease of scale-up. However, higher yields often result in lower purity.

The worldwide production of carbon nanotubes is estimated to be approximately 300 tonnes per year. There are two main types of carbon nanotubes: single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). SWCNTs require tighter process control and are therefore more expensive. There are several companies worldwide producing carbon nanofibres (Charitidis et al, 2014). The Nanowerk.com database mentions 77 companies supplying carbon nanotubes, but in an article (2011) on carbon nanotubes Nanowerk.com reported that there were more than 100 companies worldwide manufacturing carbon nanotubes and that the figure was expected to double within five years[249]. Two-thirds of production was identified as being by four large-scale manufacturers. In the article, it is also mentioned that the production capacity of CNTs had increased significantly to hundreds of tonnes per year. In 2010 only 25% of the global capacity was actually produced. This huge gap between supply and demand was due to low volume utilisation of CNTs by end-users, but demand was expected to grow.

Metallic nanoparticles, especially the non-precious metals, can be produced via various methods such as sonochemical reduction, pulsed laser ablation, plasma, chemical vapour deposition or mechano-chemical and thermo-mechanical processes, but gold and silver nanoparticles can only be synthesised by liquid phase methods. Gold nanoparticles are widely available in different forms such as organic gold, redispersible powders, silica coated gold nanoparticles etc. Silver nanoparticles are also widely available (Charitidis et al, 2014).

The most commonly used methods to produce metal oxides are vapour phase, but the hydrothermal techniques is increasingly being used as it results in higher yields and speed of production, ease of operation, lower costs with higher purity and homogeneity. About 8o% of the nanopowder market in 2009 was metal oxides (Charitidis, et al. 2014).

The table below shows market values for nanotechnology manufacturing processes.

Table 7-3: Market values for nanotechnology manufacturing processes

	Market value USD (year specified)	Future market value USD (for year specified)	CAGR
Physical processes[250]	4.2bn (2011)	7.5bn (2016)	12 %
Chemical processes[251]	5.1bn (2011)	7.4bn (2016)	8 %
Thermal spraying[252]	0.9bn (2011)	1.3bn (2016)	8 %
Physical vapour deposition [253]	08.4m (2011)	294.6m (2016)	7 %
Electron beam lithography systems[254]	90m (2013)	n/a	n/a
Molecular beam deposition equipment[255]	225m (2013)	n/a	n/a

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[249] http://www.nanowerk.com/spotlight/spotid=23118.php

[250] Evaporation, sputtering, ion-deposition, nano.DE-Report 2013 Nanotechnology in Germany today www.bmbf.de/pub/nanoDE_Report_2013_englisch_bf.pdf

[251] Gas-phase/liquid-phase deposition, plating, nano.DE-Report 2013 Nanotechnology in Germany today www.bmbf.de/pub/nanoDE_Report_2013_englisch_bf.pdf

[252] BCC 2014: "High-Performance Ceramic Coatings: Markets and Technologies", Market report abstract, http://www.bccresearch.com/market-research/advanced-materials/ceramic-coatings-markets-avm015g.html

[253] Ibid

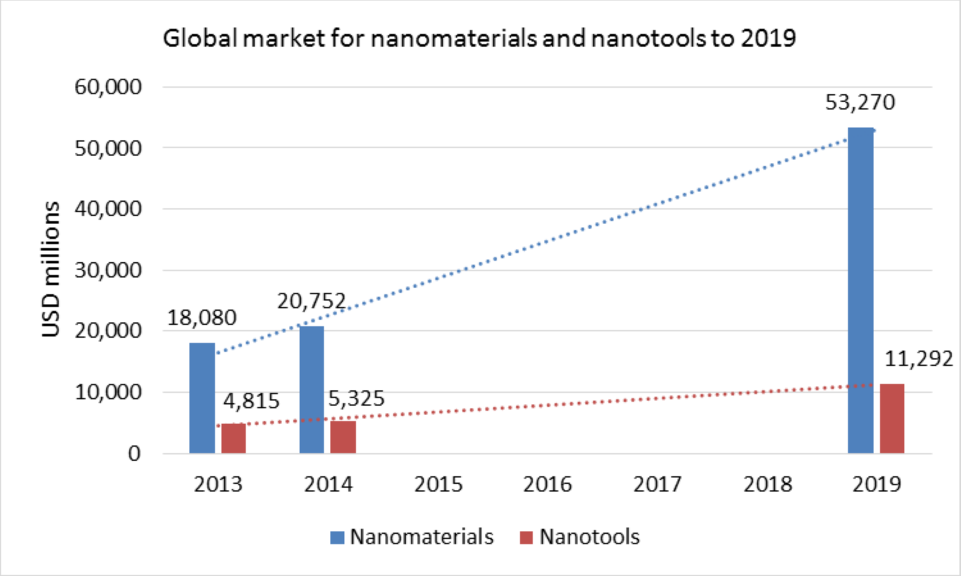
[254] VDI TZ 2013: Unternehmensbefragung nano. DE-Report 2013, June 2013

[255] Ibid

The market data presented below is based mainly on reports by BCC Research[256].

The commercial applications of nanotechnology identified in the NanoData project in the field of manufacturing include nanotools (such as nano-manipulators, near-field optical microscopes, nanomachining tools and nanolithography tools) and nanomaterials (such as solid nanoparticles, nanostructured monolithics, nanocomposites, nanoscale thin films and graphene).

Global sales for nanotechnology products in the manufacturing sector were estimated at USD 22.8 billion in 2013 and USD 64 billion in 2019. The figure below shows the forecast growth in nanotools (to USD 11.3 billion in 2019) and in nanomaterials (to USD 52.7 billion in 2019). It is seen that much of the growth is expected to be driven by nanomaterials.



Source: BCC Research, 2014

Figure 7-1: Global market for nanomaterials and nanotools to 2019

Shares of nanotools and nanomaterials are expected to remain almost stable from 2013 to 2019. The nanomaterials share of the market will remain close to 80 % (at USD 64 billion in 2019) and the nanotools share will remain close to 20%.

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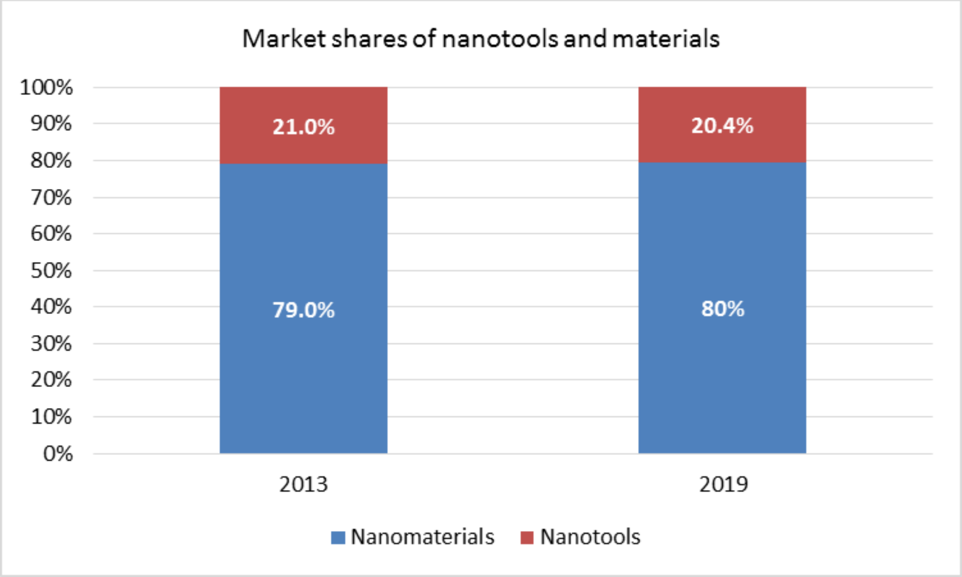
[256] It should be noted that market estimates and forecasts undertaken by different organisations are based on different assumptions and methodologies, sample a different set of expert opinions and use different models to arrive at the data they present. By using data from one organisation, and linking it to original NanoData work on products, the aim is to minimise the error between datasets. However, there is no evidence that these data are more correct than other data. In order to address this, future work of the NanoData project will involve stakeholder interviews and workshops having the goal of evaluating the data, working towards its validation.



Source: BCC Research, 2014

Figure 7-2: Market shares of nanomaterials and nanotools, 2013 and 2019

7.2.2 Commercialised products for nanotechnology manufacturing

The products identified, over 200 in number, were approximately one third nanotools and two thirds nanomaterials.

The 69 nanotool products included:

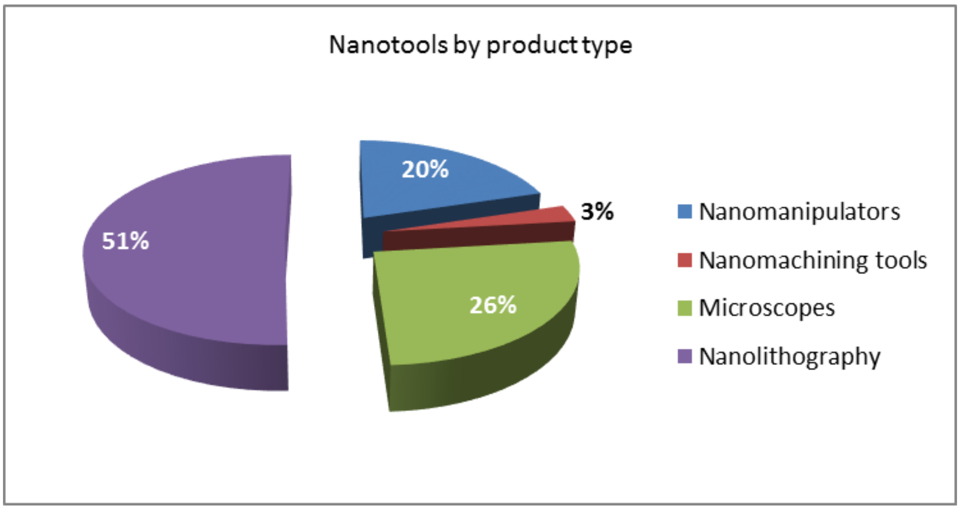
- 14 products for nanomanipulation (such as actuators and positioning tools) produced by four companies;
- 2 nanomachining tools (for mask repair and micro-nano-machining) produced by two companies;
- 18 products related to microscopy (AFMs and related equipment) produced by four companies; and
- 35 nanolithography products (including gratings, focussed ion-beam systems and imprinting systems) produced by 13 companies.

Of the 134 nanomaterials identified, the largest numbers of products were solid particles, carbon nanotubes and thin films. The nanomaterials included:

- 36 solid nanoparticle products, including powders, wires, fibres, rods and dots, produced by seven companies;
- 18 graphene products produced by 18 companies;
- 30 products that are some form of carbon nanotube, produced by eleven companies;
- 16 nanostructures monoliths, including aerogels and membranes, produced by fourteen companies;
- 9 nanocomposites, produced by nine companies;
- 25 nanoscale thin films, including protective coatings and sputtering targets, produced by thirteen companies.

In total, 89 companies were identified for nanotechnology manufacturing, 22 of them producing nanotools and 69 producing nanomaterials (with two companies producing both).

The figure below shows the breakdown of nanotools by type of product.

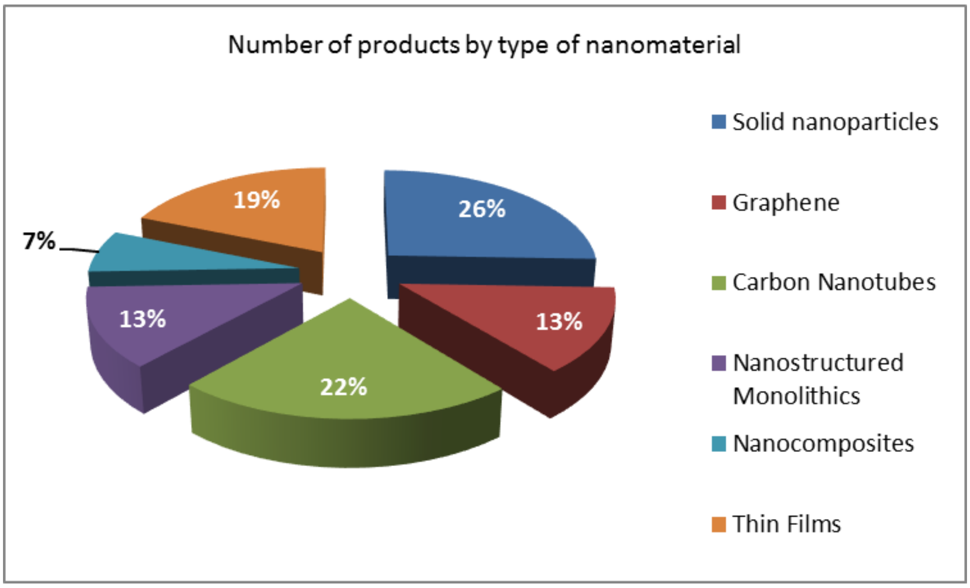


Source: JIIP, 2015

Figure 7-3: Nanotools by product type

Nanolithography accounts for the largest share (51%) of the commercially available products identified, as shown in the figure above. Further shares worth mentioning are microscopes (26%) and nano-manipulators (20%).

In terms of materials, solid nanoparticles (26%) account for the largest share of products as shown in the figure below, followed by carbon nanotubes (22%). Further shares worth mentioning are thin films (19%), graphene and nanostructured monolithics (13% each).



Source: JIIP, 2015

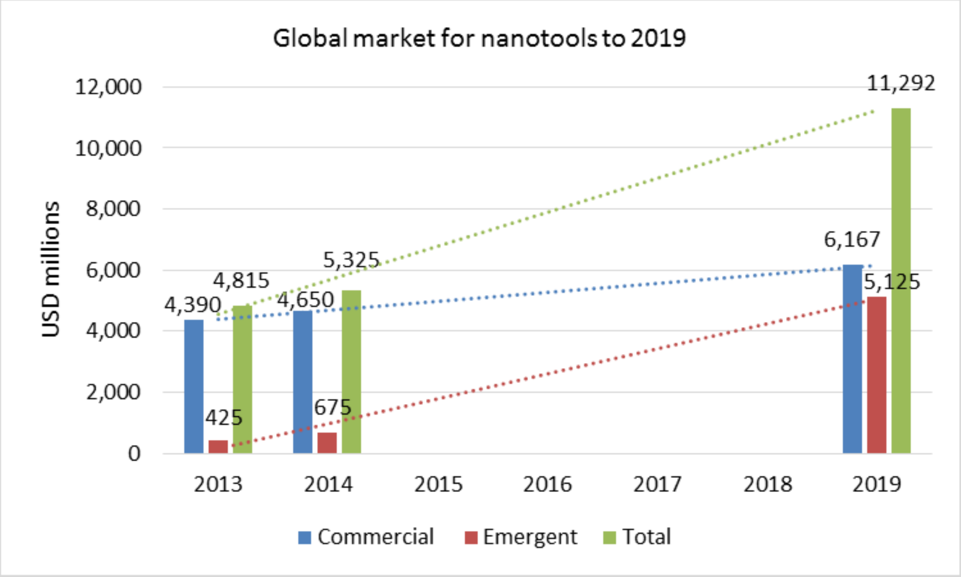
Figure 7-4: Number of products by nanomaterial

Nanotools and nanomaterials will now be considered, identifying in each case the product type and the estimated and forecast markets.

7.2.3 Nanotools

Global market data and forecasts [257]

The global market for commercialised nanotools includes nano-manipulators, near-field optical microscopes, nanomachining tools and nanolithography tools. This market is expected to grow from USD 4.8 billion in 2013 and USD 5.3 billion to about USD 11.3 billion in 2019.



Source: BCC Research 2014

Figure 7-5: Global market for nanotools to 2019

The total market for commercialised nanotool applications was worth about USD 4.4 billion in 2013. This figure is expected to increase to USD 4.6 billion in 2014 and nearly USD 6.2 billion in 2019, for a CAGR of 5.8% between 2014 and 2019.

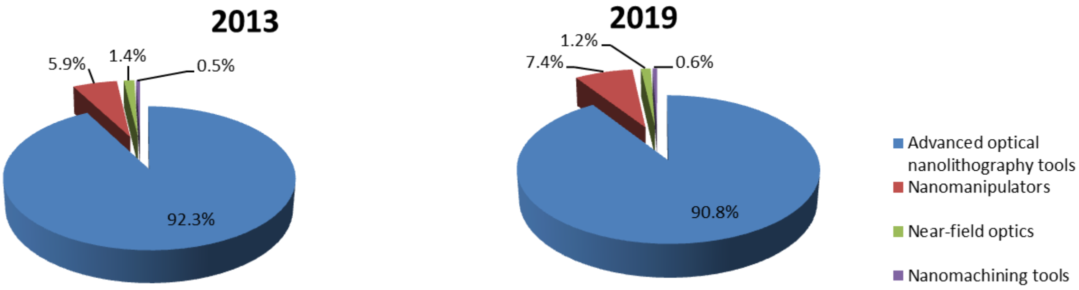


Figure 7-6: Structure of the global market for commercialised nanotools, 2013 and 2019

A comparison of global sales estimates by type of nanotool shows that advanced optical lithography tools account for the largest share in 2013 and that is expected to decrease slightly to 2019. In comparison, the share of nano-manipulators is expected to grow in the same period.

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[257] BCC Research (2014), Nanotechnology: A Realistic Market Assessment

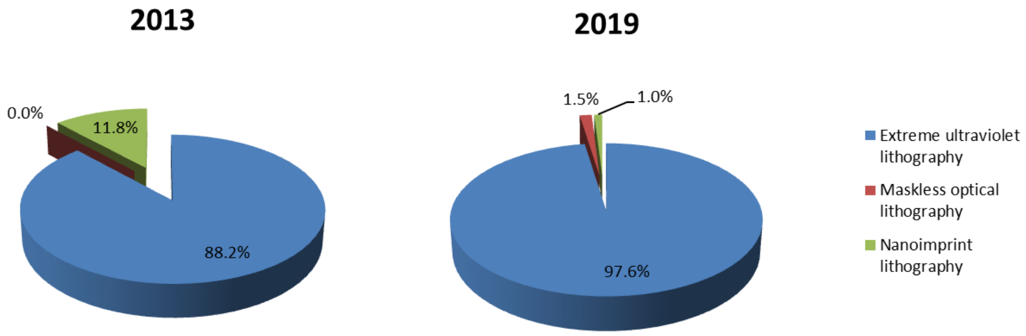

Figure 7-7: Structure of the global market for emerging nanotools, 2013 and 2019

Emerging nanolithographic technologies include a wide range of technologies, of which three (EUVL, mask-less optical lithography and nanoimprint lithography) are most likely to have an impact on the market in the years through 2019. EUVL have in 2013 a share of 88 % that is expected to increase to 98 % in 2019. The share of nanoimprint lithography accounts for 12% in 2013 but is projected to shrink dramatically to 1 % in 2019.

7.2.3.1 Products by application market

Under the heading of nanotools, the products are divided here into

- Advanced optical lithography nanotools;
- Nano-machining tools;
- Nano-manipulators; and
- Near-field optical microscopes.

A ADVANCED OPTICAL LITHOGRAPHY NANOTOOLS

TECHNOLOGY TRENDS

Optical lithography is the patterning of masks and samples with photoresist prior to other processing steps (e.g. deposition, etching, doping)[258]. The technology has enabled the size-reduction of semiconductor devices and integrated circuits[259]. Until recently, chip manufacturers have been able to keep pace with shrinking feature sizes by modifying existing optical lithography technologies through constant refinements in light sources, lens design and photomask technology. Now, as semiconductor manufacturers pass the 28-nm node and begin reaching the 26-nm node on the technology road map, they are moving to adopt advanced optical lithography technologies developed specifically for the creation of nanoscale patterns and structures on semiconductor chips, particularly optical immersion lithography and optical (laser) mask-less lithography[260].

Immersion lithography - the more established of these two technologies - is a technology in which lithographic exposure is applied to a resist-coated wafer via purified water that is introduced between the projection lens of a semiconductor exposure system (scanner) and the wafer[261]. This technique effectively shortens the wavelength of the light involved while retaining resolution, and it has the potential to extend the capabilities of optical lithography much farther than previously thought. Intel reportedly plans to continue using immersion lithography at the 22-nm node and even down to the 11-nm node[262]. The only manufacturers that are currently offering immersion lithography systems are ASML, Canon, and Nikon[263].

Mask-less optical lithography is enabling the development of a competing technology. In mask-less

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[258] http://lnf-wiki.eecs.umich.edu/wiki/Optical_lithography#Processes

[259] Rothschild M et al. (2003), Recent Trends in Optical Lithography, LINCOLN LABORATORY JOURNAL VOLUME 14, NUMBER 2, 2003: 221

[260] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.98

[261] http://www.nikon.com/about/technology/rd/core/optics/immersion_e/index.htm

[262] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p. 98

[263] EE Times: ASML, Canon, Nikon tip immersion tools, October 7 2006

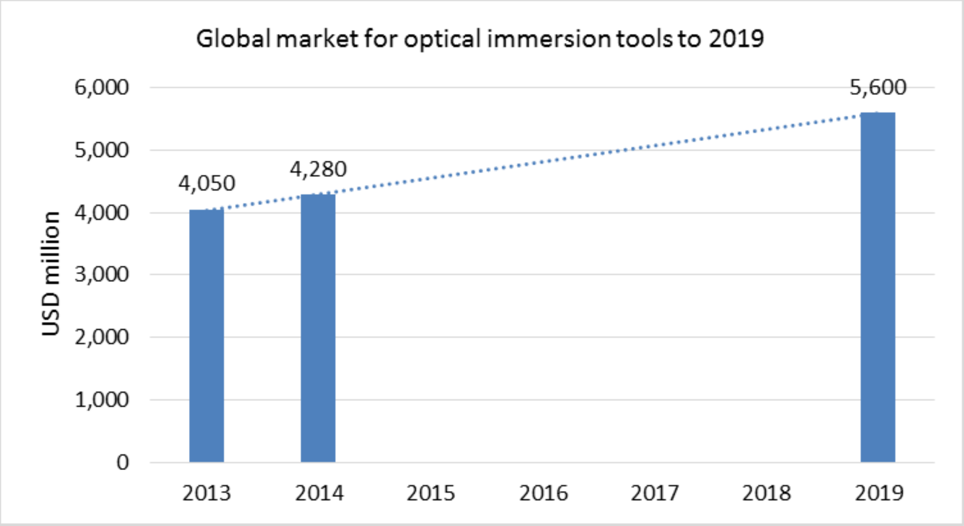
lithography, the radiation used to expose a photosensitive material is in the form of a narrow beam[264]and no mask is needed. The beam is used write the image into the photoresist, one or more pixels at a time. The forms of mask-less lithography include: scanning electron-beam lithography (SEBL), focused ion-beam (FIB) lithography, multi-axis electron-beam lithography (MAEBL), interference lithography (IL), mask-less optical-projection lithography (MOPL), zone-plate-array lithography (ZPAL), scanning-probe lithography (SPL), and dip-pen lithography (DPL)[265]. At present, several companies, such as Heidelberg Instruments of Germany and Mycronic of Sweden, have mask-less optical lithography systems on the market, but their products are generally used to generate non-nanoscale features on photomasks[266].

The FP7 project MAGIC (MAsk-less lithoGraphy for integrated circuits (IC) manufacturing) has supported the development of e-beam based mask-less lithography (ML2) technology in Europe with a focus on two parallel lithography tool developments and aiming to develop the required infrastructure for the usage of these tools in an industrial environment[267].

Mapper Lithography[268] (Delft, Netherlands) has developed a new, patented technology for making chips without a mask and using electron beams. This approach enables improved performance and reduces costs. The company´s major innovation is the use of one system through which more than 10,000 parallel electron beams can pass. MAPPER uses fibre-optics, which is capable of transporting a large quantity of information.

MARKET DATA AND FORECASTS

It is estimated that optical immersion tool manufacturers delivered about 90 immersion lithography tools in 2013. At a cost of about USD 45 million each, these tools represented a USD 4.1 billion market in 2013. It is expected that the delivery of new optical immersion tools will peak at 127 units (USD 5.7 billion) in 2017, then level off or even decline slightly by 2019, as next-generation nano-lithographic technologies such as nano-imprint and extreme ultraviolet lithography begin to come online[269].



Source: BCC Research, 2014

Figure 7-8: Global market for optical immersion tools

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[264] http://www.definitions.net/definition/MASKLESS%20LITHOGRAPHY

[265] Menon R et al. (2005), Maskless lithography, Materials Today Volume 8, Issue 2, February 2005, p. 26.

[266] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.98

[267] MAGIC Project info Sheet, FP7 ICT – Nanoelectronics

[268] http://www.mapperlithography.com/

[269] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.190

Case study: Rudolph Technologies

Rudolph Technologies, Inc.[270] *(New Jersey, US) was established in 1940. Its field is process control metrology systems used in semiconductor device manufacturing. The company specialises in design, development and manufacturing of semiconductor devices. Other services include defect inspection, advanced packaging lithography, thin film metrology, data analysis and software (for microelectronics device manufacturers).*

In order to expand its portfolio of products and maintain its stronghold on the advanced packaging market, the company acquired NanoPhotonics GmbH (Germany) in June 2012. This acquisition has been valued at around USD 7.8 million (EUR 5.86 million). The deal enabled Rudolph to include NanoPhotonics' inspection technology and associated intellectual property in its portfolio. The activity revolves around adding tools for inspection of unpatterned wafers and mask blanks. The acquisition also benefitted the portfolio of Rudolph Technologies by bringing it Reflex TT™, a table-top, manually-loaded wafer inspection tool for detecting particles, scratches, area defects and micro-roughness on unpatterned wafers and mask blanks.

Through the deal Rudolph acquired all-surface inspection systems (wafer edge, backside and front side) for 200, 300 and 450 mm wafers, along with mask blank inspection systems [3]. This enabled the company to readily penetrate the customer base for unpatterned wafer inspection. This customer base generally comprises of semiconductor manufacturers who require these tools for quality assurance and yield improvement purposes, silicon wafer manufacturers and substrate suppliers for compound semiconductors].

It may be expected that the highly evolving and rapidly growing advanced packaging market will soon require expertise in all-surface inspection, which in turn, will be met by adding the NanoPhotonics operations into existing inspection offerings. The expertise in back-end manufacturing environment has been combined with NanoPhotonics' sub-micron resolution capability in order to deliver high precision solution for customers.

The acquisition was carried out in the second quarter of 2012, which, at that time, was expected to result in a revenue increment of USD 2 million per quarter, so USD 8 Million per annum (EUR 6.2 Million). Revenue in 2012 was USD 218 million (EUR 163.9 million), implying that the NanoPhotonics component was approximately 3.8% of overall revenues on an annualised basis.

At the end of the Financial Year 2014-2015, the revenue was USD 181.2 million (EUR 136.2 million). In the same period, the R&D spending accounted for almost USD 40 million (EUR 30.1 million) and it is estimated that around 30% i.e. USD 12 million (EUR 9 million) was dedicated to nanotechnologies.

One of the newest additions to the product line of Rudolph Technologies is the macro defect inspection tool, the NSX®330 Series. The NSX 330 Series enables swift macro-defect inspection and 2D and 3D metrology for advanced packaging applications directed towards various components of the mobility and the growing Internet of Things (IoT) markets.

The introduction of the new line of products can be looked upon as the next generation of the previous product line i.e. the NSX 320. According to the company sources, the NSX 330 Series brings a 30% 2D inspection throughput improvement as compared to the NSX 320 System. This new line of products is dedicated to meet the inspection and metrology requirements for advanced packaging applications from foundries, integrated device manufacturers (IDMs) and outsourced assembly and test (OSAT) manufacturers. The product line facilitates 3D capability, precise ability to simultaneously measure topography and thickness with nanometre-level repeatability.

Rudolph Technology has been active in licensing technologies from various institutes and corporates e.g. Rudolph's PULSE technology for opaque film metrology, originally licensed from Brown University. The technology uses an ultrafast flash of laser light to generate a sound wave which penetrates an opaque film stack. When the sound wave encounters a film interface, an echo returns to the surface. The time between sound induction and echo detection provides a direct measurement of film thickness.

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[270] http://www.rudolphtech.com/

The customer base consists of manufacturers of logic, memory, data storage, flat panel and application-specific integrated circuit devices. Rudolph Technologies has closed a number of deals in 2015 and moved further in acquiring technologies from other companies. For example, during Q3 2015, Rudolph acquired the inspection technology of Stella Alliance, LLC, a patented illumination, auto-focus and image acquisition technology for the identification of defects that are not visible with current techniques. Also, in June 2015, the company closed a deal with Robert Bosch GmbH to supply configurations of its F30 inspection system for steps in the front- and back-end fabrication processes of MEMS (microelectromechanical systems) devices. The systems will help Bosch handle a wide range of substrates used in complex MEMS processes and provides handling solutions for frameless, ultrathin, film-frame and thicker non-traditional substrates. It is further expected that Rudolph Technologies will utilise the expertise sourced from NanoPhotonics GmbH in all-surface inspection systems.

See also: http://www.rudolphtech.com/

B NANO-MACHINING TOOLS

TECHNOLOGY AND PRODUCTS

Photomask repair technology has lagged well behind the capability requirements listed in the International Technology Roadmap for Semiconductors[271]. Until recently, there were only two options for photomask repair, focused ion-beam (FIB) or laser, both of which are limited in their ability to perform production repairs on certain types of materials. Specific limitations include imaging, substrate damage control, edge placement, and transmission of repaired areas[272].

Nano-machining is a new option for the repair of photomasks. It is an extremely precise method of removing opaque mask defects, using an AFM for edge placement and depth control. Activities in this area include:

- Nano-machining was pioneered by Rave LLC, US, which foresees other applications for nano-machining tools in silicon wafer repair and LCD panel repair[273].
- Tokyo Instruments, Japan, also provides commercial nanomachining systems. Their femtosecond laser micro-nanomachining system is designed for submicron-scale materials treatment with applications in semiconductor mask repair, micro-opto-electronics, biotechnology and other fields[274].
- The Micro and Nano Machining Research Group, Department of Mechanical Engineering, National University of Singapore, has developed a miniature machine tool for multiple types of micro machining in one set-up. The set-up, which is equipped with an in-situ measuring system, is capable of carrying out micro-turning, micro-milling, micro-electro-discharge machining (EDM), micro-wire-cut EDM and their combination. The on-machine measuring device ensures high dimensional accuracy of the machined micro-structures[275].

Company snapshot: Tokyo Instruments, Inc.

Tokyo Instruments, Inc.[276] was founded in 1981 in Japan. It has a capital of JPY 99 million (USD 1.2 million) and employs 44 workers. Their business activities are based on manufacturing and sales of opto-electronics products and systems; import and sales of opto-scientific instruments and measuring systems; and research and development. The company is headquartered in Tokyo, Japan, and has another office in Osaka, Japan. It also has partner distributors in Korea and Taiwan and has joint venture companies in Belarus and the US, co-operating as TII group. In 2010, Unisoku Co., Ltd. Became a group company of Tokyo Instruments Inc. forming the primary company in Japan in nanotechnology measurement

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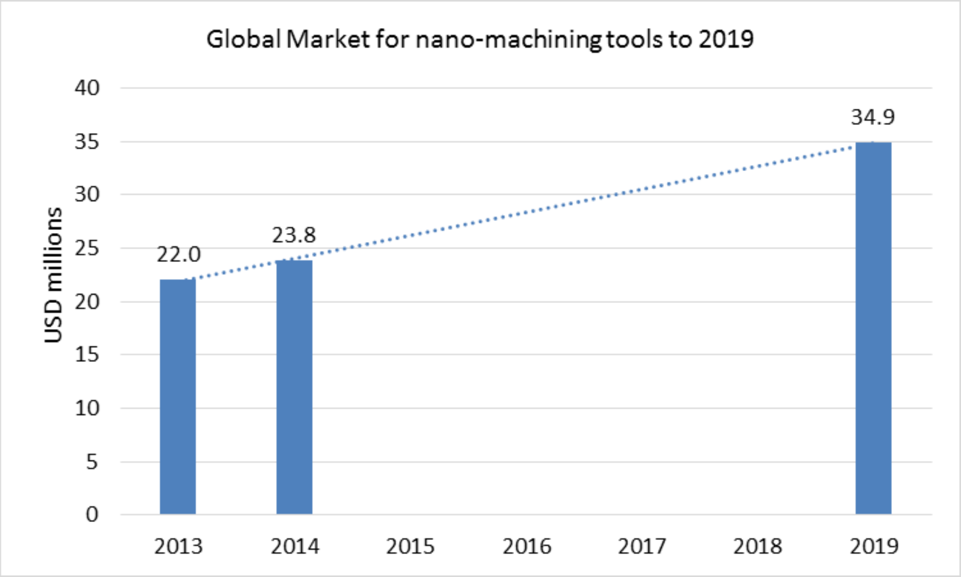
[271] http://www.itrs.net/
[272] Brinkley D, et al. (200?), Investigation of Nanomachining as a Technique for Geometry Reconstruction, mimeo
[273] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.97
[274] Ibid
[275] http://www.eng.nus.edu.sg/EResnews/0302/hl/highlight.html
[276] www.tokyoinst.co.jp/en

and photonics.

Its core technologies are based on customised "System" development for research laboratories, with expertise in spectroscopy, laser systems, optical measurement systems, and related fields. Tokyo Instruments, Inc. has installed more than 100 of their systems developed in-house.

MARKET DATA AND FORECASTS[277]

Sales of nanomachining systems by companies such as Rave LLC and Tokyo Instruments could not be quantified, but it has been estimated that the total market was worth USD 22 million in 2013. The global photomask market is projected to grow at a CAGR of around 4% through 2019. However, the main market for nanomachining systems is in high-end photomasks because of throughput limitations. Since consumption of high-end photomasks is expected to grow somewhat faster than the market as a whole, it is reasonable to expect that the market for nanomachining systems will grow somewhat faster (e.g., at a CAGR of 8% between 2014 and 2019).



Source: BCC Research

Figure 7-9: Global market for nano-machining tools to 2019

C NANO-MANIPULATORS

TECHNOLOGY AND PRODUCT TRENDS

Nano-manipulation can be defined as the manipulation of nanometre-sized objects with a nanometre-size end effector and with (sub)nanometre precision. In the manipulation, nano-sized objects can be moved, cut, deformed, assembled, etc. using external forces with sensory feedback[278]. Nano-manipulators can be of either contact or non-contact type, with atomic force microscopes (AMFs) and scanning tunnel microscopes (STMs) being the most widely used[279].

Nano-manipulators employ different types of actuators. Companies in this area include:

- Klocke Nanotechnik GmbH (Achen, Germany), with its nanorobotics platform which employs a piezo-driven linear motor. Klocke's Nanomotor uses a piezo tube for fine positioning and a pulse

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[277] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.190
[278] Sittin M (2001), Survey of Nanomanipulation Systems, University of California, Berkeley, mimeo. p.1
[279] Ibid

wave produced by the same piezo tube for coarse movements[280].

- Piezosystems Jena GmbH (Jena, Germany)[281] also with a piezo-based manipulator
- Imina technologies SA (Lausanne, Switzerland) with its piezo-based miBot™ manipulator.
- Oxford Instruments (UK), with its piezo-based OmniProbe nano-manipulators for FIB and SEM since 1995[282].

Innovation on Demand Inc. (US), with its TiNi nano-actuator which incorporates a metal alloy that returns to a memory state when heated. When the shape-memory alloy elements in the micro-actuator are heated with a scanning electron microscope or laser, they grip and manipulate nanoscale objects[283].

Company snapshot: Klocke Nanotechnik GmbH

Klocke Nanotechnik GmbH[284] is a company based in Aachen, Germany, which produces and sells products related to nanorobotics. It has been developing Nanomotor technology since 1992 and their first micro-gripper was presented in 1994. Based on an invention of the Research Centre Jülich (IGV, K.H. Besocke) Dr. Klocke and his team developed the Nanomotor including electronics and software. Nowadays their portfolio includes nanorobotics, nanomotors and electronics/89anotool based network electronics. The Company is part of the micro-technology network (IVAM). Klocke Nanotechnik partnerships in different markets and has memberships in four competence centres in microtechnology, nanotechnology and new materials.

Klocke Nanotechnik produces and sells more than 200 nanorobotics components with customer specific configurations with nanometre-precision, like micro-assembly stages, micro-tensile and micro-tribology machines, 3D-Profilometres or the "SEM/FIB-Workbench". Moreover, it manufactures Universal Testing Benches and Micro Production Systems with superior precision and flexible configuration.

MARKET DATA AND FORECASTS[285]

Scanning probe microscopes were the main type of nano-manipulators in commercial use in 2013, with a market globally of USD 250 million (excluding accessories). Other types of nano-manipulators include nano-positioning devices made by firms such as Klocke Nanotechnik, nPoint and Mad City Labs. Sales of nano-positioning devices were estimated at USD 7 million in 2013.

Sales of scanning probe microscopes are projected[286] to grow at a CAGR of 10% from 2014 through 2019. Since most nano-manipulators are used in conjunction with SPMs, they are expected to experience a similar growth rate.

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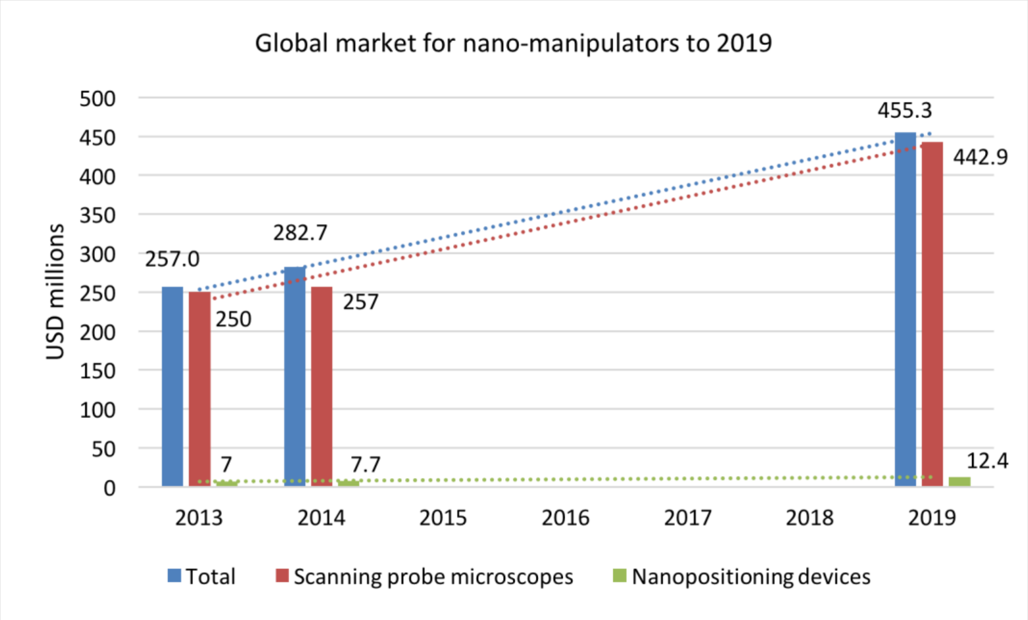
[280] http://nanomotor.de/
[281] http://www.piezosystem.de/nanopositionierung/
[282] http://www.oxford-instruments.com/products/nanomanipulation/nanomanipulator
[283] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.95
[284] http://nanomotor.de/
[285] BCC Reearch (2014), Nanotechnology: A Realistic Market Assessment, p.188-189
[286] Microscopy: The Global Market



Source: BCC Research

Figure 7-10: Global markets for nano-manipulators to 2019

Case study: Oxford Instruments[287] [288] [289] [290]

Oxford Instruments (London Stock Exchange: OXIG) was founded in 1959 and it specialises in the design and manufacturing of tools and systems for the fabrication, analysis and manipulation of matter at the atomic and molecular level. Oxford Instruments has a workforce of over 2000 employees globally. As a result of acquisitions, over 400 employees were added to the workforce in 2014. The company caters to a large spectrum of industries ranging from agriculture, food and beverage, chemicals and oils, electronics, energy/environment, failure analysis, forensics, healthcare, industry and transport, information and communication technology, metals, minerals and mining, nanotechnology, quality control and testing, research/academia, textiles. The company's nanotechnology competency revolves around imaging and analysis software and hardware for microscopes and customised scientific solutions. Some of the offerings in industrial products include analytical scientific instruments for materials and nano-scale analysis (including X-ray and laser technology) and industrial components (such as superconducting wire, X-ray sources).

The ThinFilmID introduced by Oxford Instruments is a cost-competitive software solution that employs the scanning electron microscope energy dispersive X-ray spectrometry (SEM EDS) technique to measure the thickness and determine the composition of thin film with thickness ranging from 2 nanometres to 1000 nanometres. According to company sources, this proprietary technique could enable consumers to perform a complex de-convolution of the spectra of different elements and based on the knowledge of the absorption coefficient of the spectra it is possible to determine at what depth those elements are found in the material [2]. This technique is said to offer lateral resolution down to 200 nm or less and a depth resolution to 1 nm, which is considerably higher than the resolution that can be obtained using the comparable techniques such as ellipsometry and enables precise analysis and thickness measurement of nanomaterials.

The services offering portfolio of Oxford Instruments include equipment spare parts and

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[287] http://www.oxford-instruments.com/oxfordinstruments/media/global/investors/reports/oxford-instruments-report-and-financial-statements-2014.pdf

[288] www.oxford-instruments.com/businesses/nanotechnology/nanoscience

[289] www.oxford-instruments.com › Group Products

[290] Figures have been provided as GBP, and have been translated into USD Equivalents at rates of USD 1 = GBP 0.6812, then into euro at EUR 1 = USD 1.12 for 2015. For 2014 figures, the last figure is EUR 1 = EUR 1.33.

servicing MRI and CT machines.

Some of the latest developments include the introduction of a new ultrasensitive Zyla 4.2 PLUS Scientific CMOS (sCMOS) camera in October 2015 by one of the subsidiaries of Oxford Instruments, Andor Technology. Andor provides scientific imaging and spectroscopy solutions. The camera provides an enhanced signal-to-noise ratio and sensitivity and is very well-suited for live cell imaging, light sheet microscopy, ion signalling, super resolution microscopy, fluorescence correlation spectroscopy.

Oxford Instruments has significant financial muscle. Around the end of 2012, the company acquired Asylum Research, a developer and provider of scanning probe microscopes, for USD 32.0 Million (EUR 24.8 Million), with a deferred payment of up to USD 48.0 Million (EUR 37.2 Million), payable over three years, depending on performance. Atomic force microscopy (AFM) instruments, a type of scanning probe microscopy device, are vital for imaging, measuring, and manipulating matter at the nanoscale.

For the 6 months period which ended 30 September 2015, the company posted revenues of GBP 164.8 Million (EUR 220.70 Million). Over 50% of revenues (amounting to GBP 85.4 million, about EUR 113.2 million) was from nanotechnology. For the 6 months which ended 30 September 2015, operating profit was GBP 20 Million (about USD 30 million at the current exchange rate), a 7% increase from the same period in 2014.

For the mentioned time period, the geographical segmentation of revenues is: Europe: 28%; North America: 33%; Asia: 37%; ROW: 2%.

The Nanotechnology Tools sector of Oxford Instruments produces highest technology products and serves research and industrial customers in public and private sectors. The division generated revenue of GBP 180.6 million (EUR 199.3 million) in 2014 (which is an increment of 8.7% from 2013) and a profit of GBP 21.2 million (EUR 23.4 million), an increment of 2.9% from 2013. The company spent GBP 18.8 million (EUR 20.75 million) on nanotechnology based R&D, out of the overall R&D spending of GBP 27.9 million (EUR 30.8 million).

Though the products introduced as a part of NanoAnalysis and Asylum businesses gained market and were considerably successful, the Omicron NanoScience business (directed towards analytical measurement in high vacuum, at low temperatures and in high magnetic fields) faced difficulties. However, it delivered its highest ever single order (till date) to a customer in Germany to support the fabrication and characterisation of materials for nano electronics.

D NEAR-FIELD OPTICAL MICROSCOPES

TECHNOLOGY AND PRODUCT TRENDS

Scanning near-field optical microscopy (SNOM), also known as near-field scanning optical microscopy (NSOM), is a scanning probe technique developed to surpass the spatial resolution constraints that traditionally limit conventional optical microscopy[291]. SNOM is suitable for studies on the mesoscopic scale (several tens to hundreds of molecular dimensions). It has become an important tool in research and applications of semiconductors, organic layers and membranes, biological materials and optics. The technique exists under two different names: the name scanning near-field optical microscopy (SNOM), used by the IBM group, stresses its focus on the scanning part of the instrument because of IBM's previous invention of the scanning tunnelling microscope (STM)[292] while NSOM results from the focus of the Cornell group on near-field optics.

Near-field scanning optical microscopy is continuing to grow in use, for applications requiring very high optical resolution. SNOM can be used as an imaging/microscopy instrument and also for specimen manipulation, fabrication, and processing on a nanometric scale. The increasing number of non-imaging SNOM applications include precision laser-machining, nanometre-scale optical

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[291] Huckabay H. A. et al. (2013), Near-Field Scanning Optical Microscopy for High-Resolution Membrane Studies, Methods Mol Biol. 2013; 950: 3734.

[292] Kovar M et al. (2015), NSOM: Discovering New Worlds, in: Photonics Handbook®

lithography, and light-activated release of caged biochemical compounds[293] [294].

SNOM is currently still in its infancy, and more research is needed on developing improved probe fabrication techniques and more sensitive feedback mechanisms. The future of the technique may actually rest in refinement of aperture-less near-field methods (including interferometry), some of which have already achieved resolutions on the order of 1 nanometre. However, typical resolutions for most SNOM instruments range around 50 nanometres, which is only 5 or 6 times better than that achieved by scanning confocal microscopy and is costly in terms of time and complexity in achieving good results. One significant advantage of SNOM that remains is its ability to provide optical and spectroscopic data at high spatial resolution and with simultaneous topographic information[295].

Company snapshot: ND-MDT

NT-MDT Co[296] develops equipment for nanotechnology research. The company was founded in 1989 and is based in Moscow (Russian Federation) with more than 20 representative offices and distribution centres in Ireland, the Netherlands, China, and the United States. In the past five years, the number of installed instruments of NT-MDT has grown to over 4000. It is known as a trendsetter in atomic force microscopy (AFM) with state-of-the-art design and a large range of devices. Its microscopes have won many awards including (four times) the prestigious R&D 100 Award.

The NT-MDT portfolio includes the scanning probe microscopes (SPM) for higher education needs; fully automated AFM/STM (scanning tunnelling microscope) instruments for scientific and industrial research centres; probe 'nano-laboratories' integrating the whole spectrum of modern techniques with AFM; modular 'nano-factories' combining the range of equipment and techniques necessary for processing and quality assurance of devices and elements of micro- and nano-electronics; accessories, probes, testing samples and calibration gratings for the probe microscopy.

MARKET DATA AND FORECASTS

The market for near-field optical microscopes was worth USD 61 million in 2013. Sales of SNOMs are expected to grow at a CAGR of 3.8% over the near to mid-term. The growth of the SNOM market is largely driven by a movement away from conventional optical microscopy toward advanced forms of microscopy, partly due to the growing need to image structures on a very small (e.g. nano) scale, as well as the development of instruments and technologies that extend the range of advanced microscopic tools[297].

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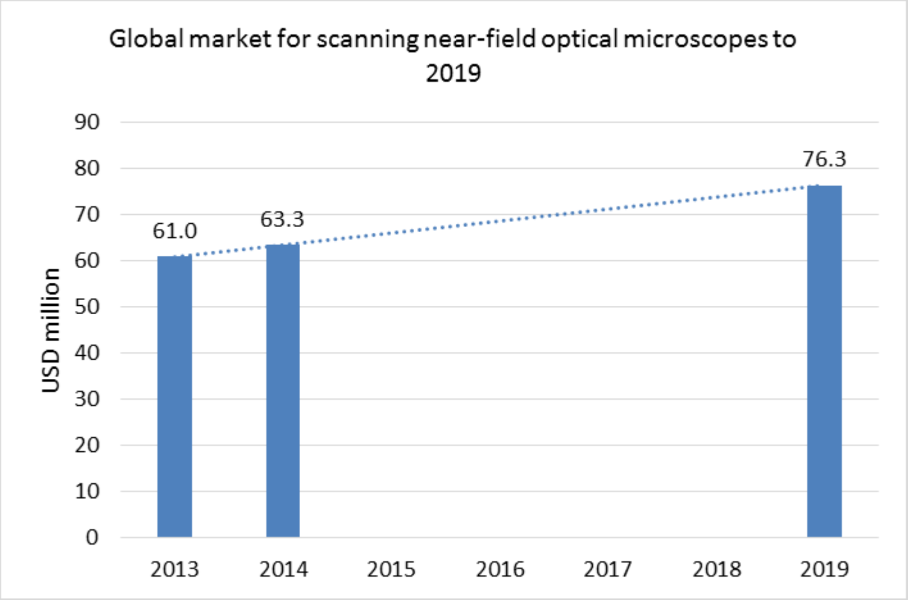
[293] http://www.olympusmicro.com/primer/techniques/nearfield/nearfieldintro.html

[294] "Caged" compounds are biologically active molecules that have a photolabile protecting group attached to a significant functional group so as to render the molecule biologically inert. Their use is derived from the use of light to remove the protecting group and release the biologically active molecule. See http://conway.chem.ox.ac.uk/Caged_compounds.html

[295] http://www.olympusmicro.com/primer/techniques/nearfield/nearfieldintro.html

[296] *www.ntmdt.com*

[297] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.189



Source: BCC Research

Figure 7-11: Global market for scanning near-field microscopes

7.2.3.2 Products by emerging market

NEXT-GENERATION NANOLITHOGRAPHIC TOOLS

TECHNOLOGY AND PRODUCTS

Mainstream optical lithography is ultimately limited by diffraction. Shorter wavelength alternatives have long been sought as a next-generation lithography (NGL) technology, including extreme ultraviolet (EUV), mask-less and nanoimprint lithography[298].

Extreme UV lithography (EUVL) is generally accepted as the leading candidate[299], extending optical lithography by using wavelengths in the range of 11 to 14 nm to shrink the size of features printed[300]. Repeated delays in the commercialisation of EUVL have made companies reluctant to pursue it in the short term.[301] In the meantime, both mask-less lithography and nanoimprint lithography are already entering the commercial arena.

In mask-less lithography, the radiation used to expose a photosensitive is in the form of a narrow beam[302]and no mask is needed. The beam is used write the image into the photoresist, one or more pixels at a time. The forms of mask-less lithography include: scanning electron-beam lithography (SEBL), focused ion-beam (FIB) lithography, multi-axis electron-beam lithography (MAEBL), interference lithography (IL), mask-less optical-projection lithography (MOPL), zone-plate-array lithography (ZPAL), scanning-probe lithography (SPL), and dip-pen lithography (DPL)[303]. At present, several companies, such as Heidelberg Instruments of Germany and Mycronic of Sweden, have mask-less optical lithography systems on the market, but their products are generally used to generate non-nanoscale features on photomasks[304]. Their method is to scan a programmable reflective photomask, which is then imaged onto the photoresist. This has the advantage of higher throughput and flexibility. A key advantage of mask-less lithography is the ability to change

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[298] Semiconductor Engineering: Waiting For Next-Generation Lithography, January 23rd, 2014

[299] Malone C, Smith B (2011), Longer Wavelength EUV Lithography (LW EUVL), mimeo.

[300] SPIE Newsroom: EUV lithography update, 31 June 2002

[301] Intel has continued to use immersion lithography beyond the 22-nm node, but proposes to use EUVL for production at the 10-nm level by 2017. TSMC has also emphasized EUVL in its future plans. See BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.99

[302] http://www.definitions.net/definition/MASKLESS%20LITHOGRAPHY

[303] Menon R et al. (2005), Maskless lithography, Materials Today Volume 8, Issue 2, February 2005, p. 26.

[304] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.98

lithography patterns from one run to the next, without incurring the cost of generating a new photomask. This may prove useful for double patterning[305].

Nanoimprint lithography (NIL) is another novel method of fabricating micro/nanometre scale patterns with low cost, high throughput and high resolution. Unlike traditional optical lithographic approaches, which create patterns through the use of photons or electrons to modify the chemical and physical proper ties of the resist, NIL relies on direct mechanical deformation of the resist and can therefore achieve resolutions beyond the limitations set by light diffraction or beam scattering that are encountered in conventional lithographic techniques. The resolution of NIL mainly depends on the minimum template feature size that can be fabricated. Compare with optical lithography and next generation lithography (NGL), the difference in principles makes NIL capable of producing sub-10 nm features over a large area with a high throughput and low cost. Compared to other lithography processes and next generation lithography with nanoscale resolution, such as e-beam lithography and extreme ultraviolet lithography (EUVL), the most prominent advantage of NIL is its ability to pattern 3D and large-area structures from micron to nanometre scale and its potential to do so at a high throughput and low cost[306]. Canon recently acquired the semiconductor unit of Molecular Imprints (MII), a supplier of nanoimprint tools. That group is called Canon Nanotechnologies (CNT)[307].

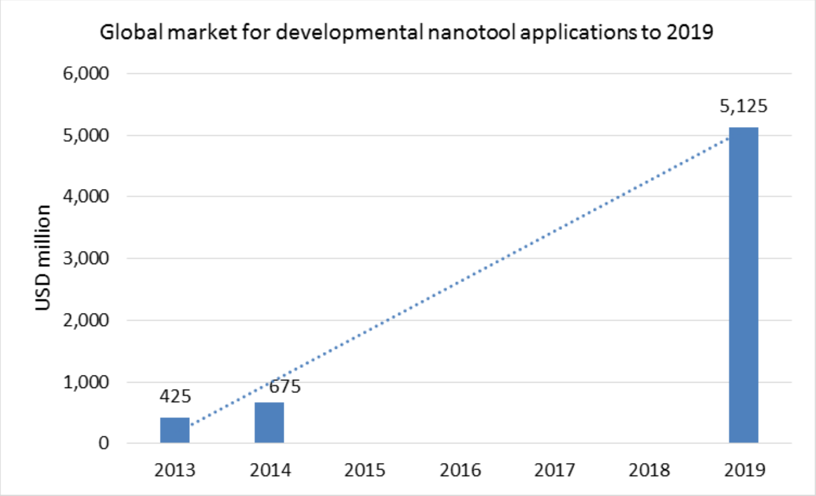
MARKET POTENTIAL

Emerging nanolithographic technologies include a wide range of technologies, of which three (EUVL, mask-less optical lithography and nanoimprint lithography) are most likely to have an impact on the market in the years through 2019. The market for these systems, including those sold for R&D purposes, was USD 425 million in 2013 and should reach USD 675 million in 2014, and more than USD 5.1 billion by 2019[308].

Table 7-4: Global market for developmental 94anotools applications, through 2019

Applications	2013	2014	2019	CAGR% 2014-2019
Extreme ultraviolet lithography	375	625	5,000	51.6
Mask-less optical lithography*	0.0	0.0	75	–
Nanoimprint lithography	50	50	50	0.0

Source: BCC Research



Source: BCC Research

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[305] http://www.definitions.net/definition/MASKLESS%20LITHOGRAPHY
[306] Lan, H, Ding, Y (2010), Nanoimprint Lithography, in: Wang, M. (ed.), Lithography, pp. 656-657
[307] Semiconductor Engineering: What Happened To Next-Gen Lithography?, September 3rd, 2014
[308] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.191

Figure 7-12: Global market for developmental 95anotools applications

Case study: EVGroup E. Thallner GmbH

EVGroup E. Thallner GmbH[309] was established in 1980 as an engineering partner for the semiconductor industry (formally known as Electronic Visions) by the entrepreneurs Erich Thallner and his wife Aya Maria Thallner. EV Group expanded into an international manufacturer of highly innovative precision systems. The company is headquartered in St. Florian am Inn, Austria. It has application labs in the United States and Japan.

EV Group E. Thallner GmbH manufactures wafer-bonding, lithography/nanoimprint lithography, metrology, photoresist coating, cleaning, and inspection equipment. It provides CMOS image sensors, high brightness light emitting diodes, wafer level optics, and photovoltaics solutions. The company also offers technical support, spare parts, training, and preventive maintenance services. It delivers advanced packaging, 3D interconnect, compound semiconductor and silicon-based power devices, microelectromechanical systems, nanotechnology, and SOI and engineered substrates to markets worldwide.

The core products of the company are lithography, bonding and imprint systems. It is one of the key players for all types of wafer bonding equipment, and is one of the market and technology leaders in lithography and nanoimprinting.

Key competencies in lithographic technology lie in the high-throughput contact and proximity exposure capabilities of its mask aligners (EVG600, EVG6000, EVG IQ series) and in its highly integrated coating platform (EVG100 series). All of EVG's lithography equipment platforms are 300mm ready, can be fully integrated into its HERCULES lithography track systems, and are complemented by its metrology tools for top-to-bottom side alignment verification.

With over 15 years' experience in designing and manufacturing precision wafer bonding equipment, EVG wafer bonding systems are well recognised in setting industry standards for the MEMS production industry. Besides supporting wafer level and advanced packaging, 3D interconnects and MEMS fabrication, the EVG500 series wafer bonding systems can be configured for R&D, pilot-line or volume production.

The company's application labs provide equipment demonstrations of its various product portfolios for potential customers looking to leverage EV Group's extensive line up of advanced wafer processing solutions for semiconductor, MEMS and nanotechnology markets. Furthermore, it provides process development support for custom applications to address customer requirements at any stage of the development process. Last but not least, these advanced process development and application labs are designed to accommodate independent research work to explore and develop baseline processes that will open up new market opportunities. This includes working with key partners, like materials suppliers, to develop and optimise new processes and capabilities. EV Group's process development group works with customers needing "demonstrator" parts for their respective customer-specific requirements.

More generally, EV Group E. Thallner GmbH is present across five different markets:

- *Advanced packaging;*
- *Compound semiconductor;*
- *MEMS;*
- *SOI & engineered substrates; and*
- *Nanotechnology.*

Out of these five dynamic markets, nanotechnology seems to be one of the most promising ones for EVG Group.

Nanoimprint Lithography (NIL) is one of the most promising and cost-effective new techniques for generating nanometre-scale-resolution patterns for a variety of commercial applications in

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[309] http://www.evgroup.com/en/

BioMEMS, microfluidics, optics, patterned media and electronics.

Nanotechnology applications include:

- *Hot embossing: Hot embossing technology is a low cost, flexible fabrication method, which has demonstrated polymer high aspect ratio microstructures as well as nanoimprinting patterns. It uses polymer substrates to imprint structures created on a master stamp. This allows the stamp to produce many fully patterned substrates using a wide range of materials. Hot embossing is therefore suited to applications from rapid prototyping to high volume production. Hot embossing can be applied in a wide variety of fields: µTAS, microfluidics (micromixers, micro reactors), micro optics (wave guides, switches), etc.*
- *Micro contact printing: An inked stamp transfers a material to a substrate surface by a soft contact, which forms a self-assembled monolayer (SAM). In this method, soft stamps like PDMS are used. The process occurs at room temperature and under low contact forces.*
- *UV-Nanoimprint Lithography: UV-Nanoimprint Lithography (UV-NIL) uses low viscose materials, which are cross-linked during a UV exposure process forming the hard polymer features. These features can be used as the actual device or can be used as an etching mask for pattern transfer in the substrate.*

The average annual revenue of the company is USD 112 million. It employed 700 staff worldwide in 2013, and up to 750 in 2015[310] *with 600 at headquarters, 80 in the US and 30 in Germany. Approximately 100 work on R&D and 20% of revenue is invested in R&D annually.*

7.2.4 Nanomaterials

GLOBAL MARKET DATA AND FORECASTS[311]

The global market for nanomaterials was worth USD 18.1 billion in 2013 and is expected to grow to USD 52.7 billion in 2019.

Table 7-5: Global market for nanomaterials by type to 2019

Nanomaterial	2013	2014	2019	CAGR% 2014-2019
Nanoscale thin films	12,179.6	14,018.1	37,167.4	21.5
Solid nanoparticles	3,011.4	3,328.2	7,198.2	16.7
Nanostructured monolithics	1,735.9	1,877.6	3,980.3	16.2
Nanocomposites	1,153.3	1,369.8	4,253.5	25.4
Carbon nanotubes	---[312]	158.6	670.6	34.4
Total	18,080.2	20,593.7	52,711.7	20.7

Source: BCC Research, 2014

As seen in the table above, growth in absolute terms is driven by the market for nanoscale thin films, while nanocomposites and carbon nanotubes have the highest compound annual growth rates (CAGR).

Nanoscale thin films dominated the global nanomaterials market in 2013, accounting for 67.4% of total worldwide nanomaterial consumption, reflecting their widespread use in catalytic converters.

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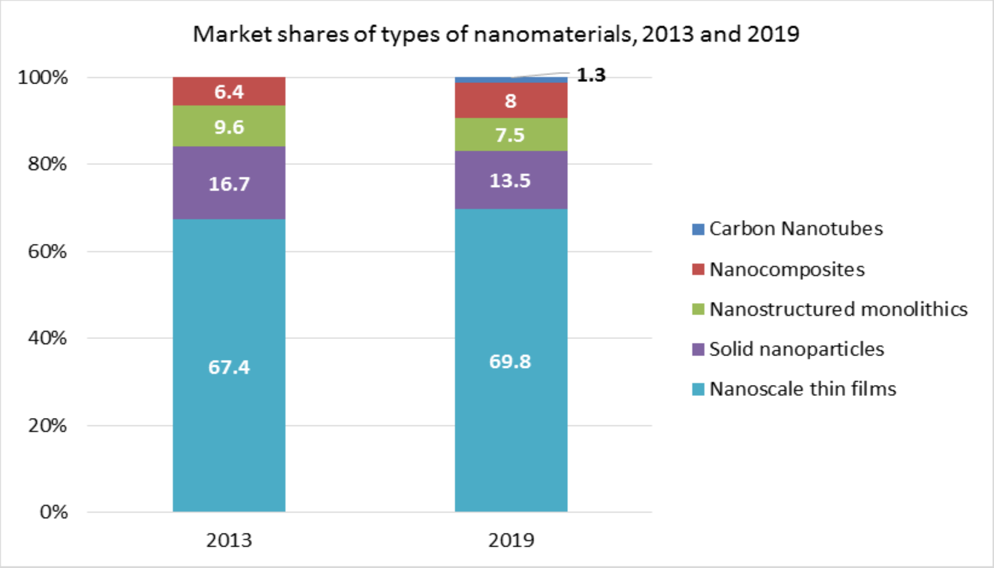
[310] Data from Innodys (French distributor for EVG)

[311] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.9

[312] Not available

Solid nanoparticles accounted for 16.7% of the market and nanostructured monolithics 9.6%, as shown below.



Source: BCC Research, 2014

Figure 7-13: Market share of types of nanomaterials, 2013 and 2019

It is forecast that the market for thin films will grow slightly in percentage terms, to increase to 69.8% by 2019, with the market share of nanostructured monolithics is forecast to fall to 7.5%. Solid nanoparticles are also expected to lose some relative market share, falling to 13.5%. The market for nanocomposites is forecast to grown to 8 % of the total and nanotubes to 1.3%.

7.2.4.1 Products by emerging market

A SOLID NANOPARTICLES

TECHNOLOGY AND PRODUCT TRENDS

A nanoparticle (or nano-powder or nanocluster or nanocrystal) is a microscopic particle with at least one dimension less than 100 nm. There is intense research activity on nanoparticles due to their wide range of potential applications in biomedical, optical, and electronic fields, amongst others. Nanoparticles are of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures. [313].

Solid nanoparticles are solids having at least one external dimension in the nanoscale range. They may be in the form of ultrafine powders, fibres or wires and have one or more nanoscale dimensions (not tubes which are, in effect rolled quasi-two dimensional structures). Their other dimensions may be micrometres or more.

Company snapshot: Baikowski Group

Based in France, Baikowski[314] started its operations in 1904 to grow sapphire crystals using the Verneuil process. This activity was discontinued in 1982 to focus on high purity alumina markets. Since then, it has expanded quickly through successful diversifications of its applications and customer portfolio. Baikowski is now a major player on high quality applications such as technical ceramics, precision polishing, functional additives & coatings, and crystals.

The company focuses on tailoring high purity alumina powders & formulations, as well as other fine oxides & composites such as spinel, ZTA, YAG & ceria for technical ceramics, precision polishing, crystals, and additives/coatings applications. Their market areas are lighting (high intensity discharge lamps, fluorescent tubes, LED), watches & phones (sapphire tops, ceramic

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[313] http://www.sciencedaily.com/terms/nanoparticle.htm

[314] http://www.baikowski.com/

parts), electronics (semiconductors), automotive (car polish, Li batteries), defence (armoured windows, precision optics) and medical (prostheses, imaging, intraocular lenses, and pacemakers).

Baikowski has manufacturing sites in Annecy, France; and Malakoff, Texas, as well as polishing slurries formulation and application lab sites in Charlotte, North Carolina; and Chiba, Japan. Baikowski SAS operates as a subsidiary of PSB Industries SA.

Nano-cellulose crystals are a recent promising development in the area of solid nanoparticles[315]. In 2011, substrate provider Stora Enso took a significant step forward in renewable-materials innovation by building a pre-commercial plant at Imatra, Finland, for the production of micro-fibrillated cellulose. The new nanotechnology material will be used in existing and new fibre-based paper and board products, barrier materials, and other potential future applications. The micro-fibrillated cellulose technology project, including the Imatra pre-commercial plant, is estimated to total approximately EUR 10 million[316].

Company snapshot: Stora Enso

Stora Enso[317] is a leading provider of renewable solutions in packaging, biomaterials, wood and paper on global markets. It was formed by the merger in 1998 of Swedish mining and forestry products company Stora and Finnish forestry products company Enso-Gutzeit Oy. It is headquartered in Helsinki. Customers include packaging, joinery and construction industries as well as publishers, printing houses and paper merchants. The Group has some 27,000 employees in more than 35 countries, and is publicly traded in Helsinki (STEAV, STERV) and Stockholm (STE A, STE R). Their sales in 2014 were EUR 10.2 billion, with an operational EBIT of EUR 810 million and their expenditure on research and development (R&D) was EUR 104 million, equivalent to 1.0% of sales.

The aim of the company is to replace non-renewable materials by innovating and developing new products and services based on wood and other renewable materials. STORA-ENSO's focus is on fibre-based packaging, plantation-based pulp, innovations in biomaterials, and sustainable building solutions.

MARKET DATA AND FORECASTS

The global market for solid nanoparticles was estimated to be over USD 3 billion in 2013, rising to over USD 3.3 billion in 2014, and forecast to approach USD 7 billion in 2019, a CAGR of 15.9% over five years.

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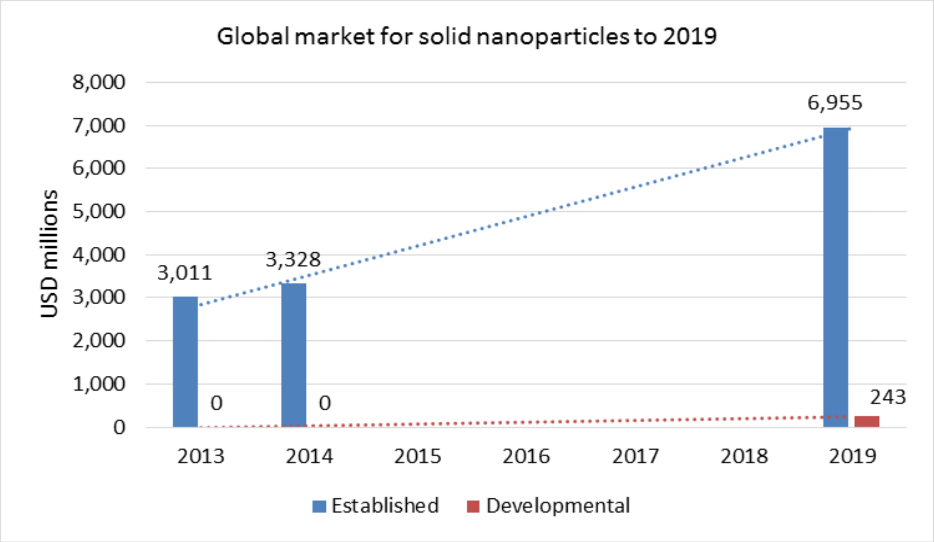
[315] IPW online: Nanocellulose – On the Cusp to Commercialisation? Oct/Nov 2012
[316] Converting Quarterly: Stora Enso to build nano-tech cellulose plant in Finland, May 2011
[317] http://www.storaenso.com/



Source: BCC Research

Figure 7-14: Global market for solid nanoparticles to 2019

Case study: Promethean Particles

PrometheanParticles
Formulating solutions with nanomaterials

Promethean Particles[318] is a SME located in Nottingham, UK. Based on their proprietary technology, the company produces of a range of metal based and ceramic nanoparticles for industry and research. The company was formed around 2008 as a spin out from Professor Ed Lester's research group at the University of Nottingham. The novel technology involved is a reactor design, which enables continuous hydrothermal production of nanoparticles. The central concept arose from his university research, initiated from cross disciplinary conversation leading to a research project. The resultant technology was patented in 2005, supported by the University, before being spun out. The company have retained control of the core patent, with part of the business model being to licence the technology. Manufacturing is also a part of this model, with capacity being expanded from 10 tons a year to 1,000 tons following successful research grants, investment and business development. The company relies on skilled technical individuals, often PhD or Masters graduates, to conduct research and production.

Funding

Funding of the University research work was through Member State research council funding as part of wider research activities. Initial filing of IP was funded by the University of Nottingham, with a small amount provided to develop a proof of concept, pilot scale plant.

The formation of a company in 2008 was driven by investment of £250,000 from The Lachesis Fund and Catapult Venture Managers was obtained to assist with commercialisation of the technology. The Lachesis Fund is a "seed-corn" fund, investing in spin out companies from partner Universities, and part funded through the European Regional Development Fund. Catapult Ventures is an independent Fund Manager, operating on behalf of public and private investors, including the European Investment Fund and European Regional Development Fund. Further funding has been generated through several related FP7 projects, as well a second round of investment in 2012. The further investment amounted to £500,000, and was led by E-Synergy that brought in several new private investors, as well as further funding from Lachesis. A more recent round of funding has also been secured from these and other investors.

FP7 projects have formed a core part of Promethean Particles development funding, allowing them to undertake technical work. To date the company has been involved in three EU

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[318] http://www.prometheanparticles.co.uk/

Framework funded projects; POINTS, SHYMAN, and NanoMILE, with grants totalling around EUR 1.25M. Targets of these projects have included direct research into the production of nanoparticles via hydrothermal routes, understanding the interactions of nanosystems with living systems, and supporting application development for printable circuits. The company considers these projects a success, with the biggest benefits to the business linked to the development and exploitation of the technology. For example, enabling the scale up of the process, development of early stage products into specific markets (e.g. printed electronics, and semiconductors), networking and exposure to potential customers, and moving products up the value chain.

Funding was sought from MS sources, however this has not formed a core part of the business income. This is in part due to the lower attractiveness of this type of funding for this business due to the time resources required, with FP7 funding viewed as more accessible. For example, in some cases FP7 funding was viable due to partner's experience of putting together bids, reducing risk to the business. Smaller amounts of MS support have been secured through mechanisms such as Innovation Vouchers and Knowledge Transfer Partnerships, both supported by Innovate UK (formally the Technology Strategy Board).

Products and Value Chain

Promethean Particles are a manufacturer and supplier of nanoparticles to various markets, where the nanoparticles are used within products to enhance function or properties, with the aim being to licence the proprietary technology. Therefore the business sits at the start of the value chain, providing other industries with a source of materials and technology.

Promethean Particles main physical product are nanoparticles comprised from metal and ceramic, with their approach allowing development and optimisation of approaches to meet customer requirements. The company has supplied into the automotive, electronic, catalysis, biomedical and renewable energy markets. Their client base has expanded in recent years to customers in the US, Japan and Korea, as well as within Europe, in part thanks to FP7 funding.

Staff

The staff count at Promethean Particles has grown over time. Initial staff count was 2, including 1 manager and 1 technical member of staff. An additional technical staff member was then soon added. The staff count has then risen from 6 to 8 between 2012 and 2015, with all being technical staff. The company relies heavily on skilled technical personnel, with staff often possessing a PhD or Masters degrees in related fields.

Regulation and policy

Regulation has both a positive and negative impact on Promethean Particles. Concerns over health and safety aspects of nanoparticles have meant funding is available for this research, which has allowed the company to demonstrate the non-toxic nature of certain products. However, these increased levels of concern have led to regulations, such as the introduction of nano registers within Member states, which are individually managed. This causes some issues as different MS have different approaches.

However, at present, many regulations that influence the business are not nano-specific. For instance, regulations around shipping of their products, and the prospect of REACH compliance as the process is scaled up.

Future

The company looks to continue following a similar business model in the future; seeking to licence the core technology, as well as provide a range of standard products at a larger scale. Investment being used to augment technical staff and facilities to drive this, as well as more targeted business development. Securing technical FP7 funding allowed the company to increase demonstration capacity and focus in on specific products higher up the value chain. They now aim to focus on these higher value products and target specific sectors as a result.

The company are involved in one H2020 project at present, linked to toxicity, but are less positive about other calls. This is due to the overall low success rates of H2020 compared to FP7, combined with the level of effort required to submit a bid, particularly as no staged processes are in place.

B NANOSTRUCTURED MONOLITHS

TECHNOLOGY AND PRODUCT TRENDS

Nanostructured monolithics are bulk solids that have macroscale external dimensions but a nanoscale internal structure e.g. nano-porous solids (e.g. fuel cell membranes), some bulk metals and alloys, and aerogels[319].

Company snapshot: Dais Analytic Corporation

Dais Analytic Corp.[320] 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.

The first commercial product of the company was the energy recovery ventilator ConsERV™. ConsERV™ generally attaches onto existing HVAC systems, typically in commercial buildings, to provide improved ventilation air within the structure. Now the company portfolio includes NanoAir™ HVAC products for heating, ventilation, and air conditioning; NanoClear™ clean water systems for water treatment and desalination; and NanoCap™ ultra-capacitor for energy storage. The Company owns eleven US and one Chinese patent.

The company is located in the Tampa Bay area of Florida, U.S.A and has 25 employees. The sales revenue of the company in 2014 was USD 1.9 million (up by 9% on sales of USD 1.74 million in 2013) and came primarily from the sale of ConsERV™ cores and Aqualyte composite polymer membranes. Despite the strong sales, the company made a loss overall after operating costs (including USD 0.76 million on research and development), a deficit of USD 1.77 million.

In 2015, Dais was awarded a USD 1 million grant from the U.S. Army's Small Business Innovation Research (SBIR) programme to continue developing its NanoClear(TM) water clearing separation application using its Aqualyte(TM) nanomaterials. The U.S. Patent and Trademark Office also notified Dais it has been awarded a second U.S. patent for its NanoCap(TM) energy storage device.

Also in 2015, Dais announced that it has raised USD 75 million for 18,000,000 shares in order to further the commercialisation of its products.

See: http://www.daisanalytic.com

MARKET DATA AND FORECASTS

The global market for nanostructured monolithic materials was estimated to be over USD 1.7 billion in 2013 and almost USD 1.9 billion in 2014, and is forecast to grow to almost USD 4 billion by 2019.

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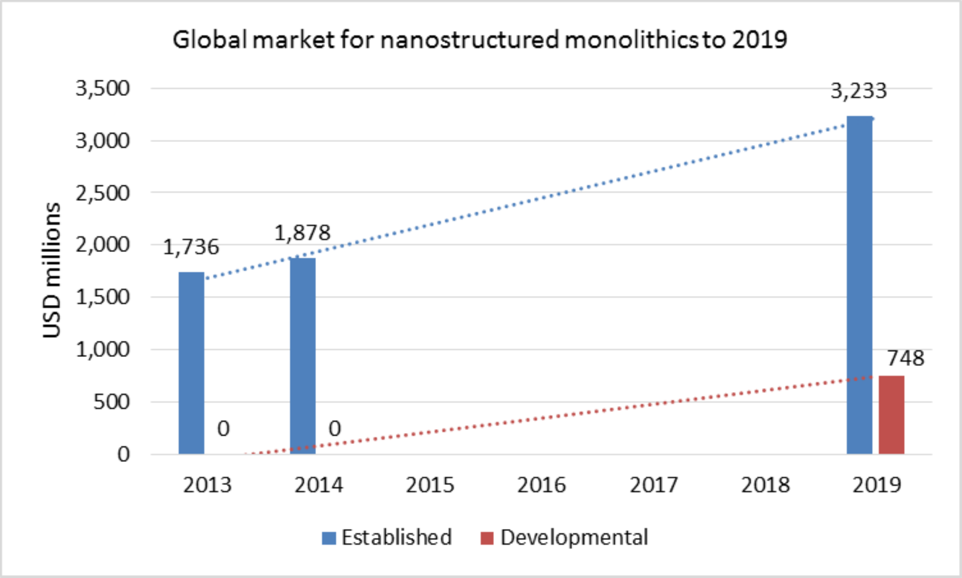
[319] BCC Research (2013), Nanotechnology in Energy Applications, p.10

[320] http://www.daisanalytic.com



Source: BCC Research

Figure 7-15: Global market for nanostructured monolithics to 2019

C CARBON NANOTUBES

TECHNOLOGY AND PRODUCT TRENDS

A carbon nanotube (CNT) is a cylindrical carbon structure that has hexagonal graphite molecules joined at the edges. They are formed from rolled-up sheets of graphene one atom thick. While they have the appearance of black powder or soot, nanotubes have stiffness and strength and typically exhibit good thermal and electrical properties. Carbon nanotubes (CNTs) have the potential to be used as semiconductors, for example, potentially replacing silicon in a wide variety of computing devices. Nanotubes can be characterised by their number of concentric cylinders (called, for example, single-walled, few-walled, multi-walled), their cylinder radius and their cylinder length. Some nanotubes have a property called chirality, an expression of longitudinal twisting[321].

Single-walled (SWCNTs) have only one layer, or wall, like a drinking straw. Multi-walled carbon nanotubes (MWCNTs) are a collection of nested tubes of continuously increasing diameters. They can range from one outer and one inner tube (a double-walled nanotube) to as many as 100 tubes (walls) or more. Each tube is held at a specific distance from neighbouring walls by interatomic forces.

Currently, the most popular use for carbon nanotubes is in structural reinforcement. With their high strength and low weight, combined with their flexibility, they are suitable additives to other materials like concrete. Advances are being made using carbon nanotubes to extract power from sunlight and even as a heat source. Carbon nanotubes are thermally conductive along their length but not across the tube itself making them good thermal insulators as well as conductors. CNTs are also highly electrically-conductive, potentially replacing metal wires. Their semiconducting properties make them candidates for next generation computer chips. Other applications under investigation are their use as chemical carriers for pharmaceutical applications. Specific drugs can be attached to CNTs that can target and attack only certain types of cells, including cancer cells, for example[322]. (See also the NanoData Landscape compilations on ICT, photonics, energy and health).

MARKET DATA AND FORECASTS [323]

The global market for various CNT grades was estimated to be USD 159 million in 2014 and to grow to over USD 670 million in 2019, a growth rate of over 30% (CAGR). The grades include single-

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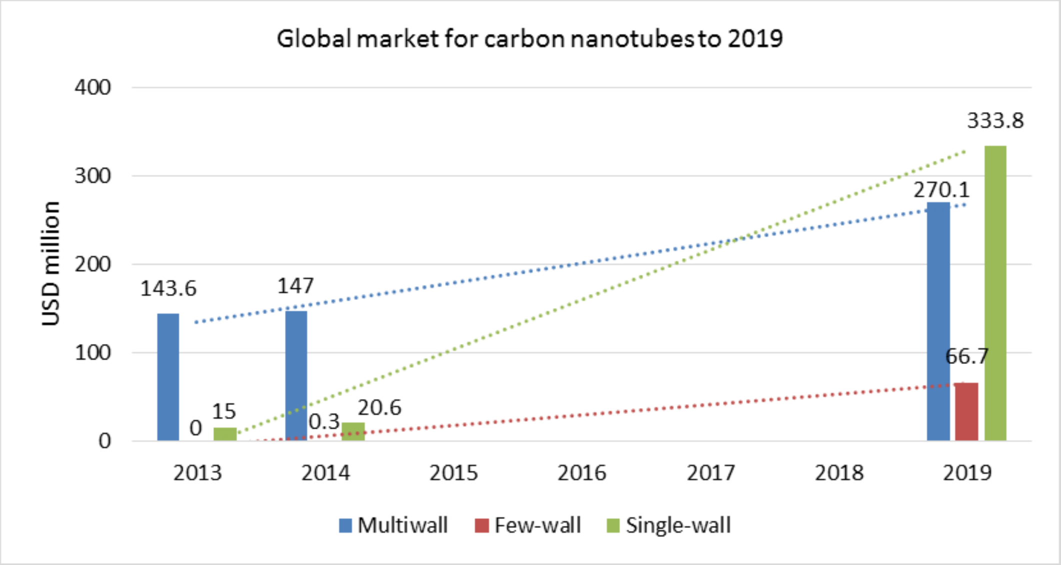
[321] http://whatis.techtarget.com/definition/nanotube-buckytubes

[322] http://www.nanoscience.com/products/carbon-nanotube-synthesis/technology-overview/

[323] BCC Research (2015), Global Markets and Technologies for Carbon Nanotubes, p.6

walled, few-walled and multi-walled CNTs. It is expected that MWCNTs will show lower growth than SWCNTs and FWCNTs as shown in the figure below, and be overtaken in market size by SWCNTs.



Source: BCC Research, 2014

Figure 7-16: Global sales for carbon nanotubes to 2019

Case study: Nanocyl

Nanocyl[324] is headquartered in Belgium since it was founded as a spin-off from the Universities of Namur and Liège in 2002. The company has commercial and technical support wings in the US (Nanocyl Inc.) in Atlanta, Georgia and distributors in various Asia Pacific locations such as Korea (Seoul), Taiwan (Chinese Taipei), China (Shanghai-Guangzhou) and Singapore. Nanocyl specialises in the development and manufacturing of Nanocyl® NC7000™ carbon nanotubes, produced in multi-tons via a chemical vapour deposition (CVD) process.

The company started with an initial funding of USD 3.7 million (EUR 3 Million) in equity backing along with two new loans in 2005. The investors were CNP, SRIW, Compagnie du Bois Sauvage and other unnamed parties. The company also secured a USD 1.9 million loan (EUR 1.5 million) from a regional government and a USD 1.1 million bank loan (EUR 0.9 million). When it started it revealed its plan to invest over USD 6.2 million (EUR 4.9 million) in R&D and equipment (which includes a new synthesis reactor) in 2006.

The product portfolio of Nanocyl includes EPOCYL™ (a range based on liquid bisphenol-A (Bis-A) epoxy resin with a high concentration of carbon nanotubes), THERMOCYL™ (an experimental product range for high quality fire resistance and thermal conductivity), SIZICYL™ (a liquid sizing agent which utilises carbon nanotubes as reinforcement fibres for carbon fibre- or glass fibre- reinforced polymers in composite applications), BIOCYL™ (range of multi-wall carbon nanotubes liquid dispersions based on silicone resins), AQUACYL™ (aqueous dispersion of carbon nanotubes) and ELASTOCYL™ (MWCNT elastomeric dispersions for applications requiring high anti-static performance, high tinting power and functional dispersions in a silicone elastomer matrix). The company also deployed its product ORGACYL™ in the last two years, a type of CNT solvent dispersion for lithium-ion batteries.

At present, the company has a total workforce of 45 to 50 people globally, around 20 people being dedicated to R&D. Nanocyl has a strong commitment to R&D, currently equal to 39% of its total budget.

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[324] http://www.nanocyl.com/

Nanocyl has been involved in a large number of EU projects:

- *RECYTUBE. Reutilisation of scraps containing carbon nanotubes generated during master batch, compounding or injection moulding to produce new plastic nanocomposites with commercial value. (www.recytube.eu, Project Number: 256152);*
- *MULTIPLAT. Novel biomimetic selective ion-conductive thin membranes with highly ordered structure as a multipurpose platform for range of applications.(www.multiplat.net, Project Number: 228943);*
- *MARINA. Risk assessment and management of nanomaterials: Materials, Exposure, Hazard and Risk. (www.marina.eu, Project Number: 263215);*
- *IMS-CPS. Innovative Material Synergies & Composite Processing Strategies (www.imscps.eu, Project Number: 246243);*
- *LASERCELL. Novel competitive performance alkaline fuel cells and stacks that can be economically produced in volume for large scale stationary applications.(http://www.laser-cell.eu, Project Number: 278674);*
- *STORAGE. Structural lightweight composite power storage for hybrid vehicles to perform efficient propulsion and energy needs of future vehicles. (www3.imperial.ac.uk/structuralpowerstorage, Project Number: 234236);*
- *THERMONANO. Low temperature heat exchangers based on thermally conductive polymers nanocomposites. (www.thermonano.org, Project Number: 227407);*
- *SARISTU. Reductions in aircraft weight and operational costs as well as an improvement in the flight profile specific aerodynamic performance. (www.saristu.eu, Project Number: 284562);*
- *DEROCA. Development of safer and more Eco-friendly flame Retardant materials based on CNT co-additives for Commodity Applications. (http://www.deroca.eu, Project Number: 308391);*
- *NANOSOLUTIONS. Biology Approaches to understand interactions of engineered nanomaterials with living organisms and the environment. (http://nanosolutionsfp7.com/, Project Number: 309329);*
- *INSIGHT. In-line characterisation of nanoparticles during nanomaterial manufacturing. The objective is to develop new tools to measure/evaluate the nanoengineered particles in a medium or alone. (http://www.fp7-insight.com, Project Number: 263374); and*
- *PLATFORM. Open access pilot lines development for industrial production of nano-enabled products (buckypapers, CNT treated prepreg and CNT doped non-woven veils) for applications in composite parts for sectors such as Aeronautic and Automotive. The purpose of the project is to efficiently and economically manufacture the components using novel nanomaterials at a scale suitable for industrial uptake. (website under construction, Project Number: 646307).*

The projects revolve around industries such as automotive, energy, electronics, aeronautic, construction, sport and marine in applications such as energy storage, heat exchangers and nanocomposites.

The company made its first sales in structural composites in 2010, lithium-ion batteries in 2013 and rubber goods in 2014. Nanocyl scaled up to industrial production of plastic compounds (3500 metric tons) in 2008. The first commercial use of Nanocyl NC7000™ in the electronics sector was carried out in 2005, in automotive sector in 2007 and in 2010 saw the establishment of an industrial production unit producing 400 metric tons of NC7000™ which clearly indicates its strong market share.

D NANOCOMPOSITES

TECHNOLOGY AND PRODUCTS

Nanocomposites are composites with at least one dimension in the nanometre range. The incorporation of nanomaterials (particles, fibres, CNTs, etc.) into matrices can improve their properties e.g. including nanofibres into can increase the fracture toughness of ceramics and the strength of polymers. Biodegradable and lightweight nanocomposites have specific potential in the aerospace, automotive, electronics and biotechnology industries.[325]

Progress in nanocomposite research and development is varied and covers many industries. Nanocomposites, made using simple and inexpensive techniques, can have a variety of enhanced physical, thermal and other unique properties – low weight, high mechanical strength, unique colour, electrical and thermal conduction and insulation, and high reliability in extreme environments. Their properties can be adapted to specific needs, as biological implant materials, insulators for electronics, and charge conductors for aircraft in case of lightning strikes[326].

Nanocomposites may be organic or, more commonly applied so far, inorganic. Inorganic composites can have a three-dimensional framework (e.g. zeolites), a two-dimensional layered structure (e.g. clays, metal oxides, metal phosphates and chalcogenides) or form chains or clusters. Experimental work has generally shown that virtually all types and classes of nanocomposite materials lead to new and improved properties, when compared to their macrocomposite counterparts. Therefore, nanocomposites promise new applications in many fields such as mechanically-reinforced lightweight components, non-linear optics, battery cathodes and ionics, nanowires, sensors and other systems[327].

Company snapshot: Evonik Industries

Evonik Industries[328] is one of the world's leading specialty chemicals companies. It has a long history based on the German chemical industry and dating back to the nineteenth century. Evonik Industries itself dates back to 1968, when Ruhrkohle AG was founded on November 27 in Essen as a joint venture of Ruhr mining companies on the basis of a federal statute. The current company Evonik Industries AG was formally established in September 2007 from the former RAG Beteiligungs AG.

The central elements of its strategy for sustained value creation are profitable growth, efficiency and values. Around 80% of sales come from market-leading positions. Evonik has several decades of experience in the production and handling of fine-particle substances such as silicas, aluminium oxides, and titanium dioxides. These exist as larger aggregates and agglomerates with diameters of the order of a few micrometres. They are generated in production processes by sintering primary particles smaller than 100 nm that are initially formed in the reactor, and are therefore also included under the generic term nanomaterials. For special applications, Evonik provides formulations (such as dispersions), some of which contain nano-objects in the form of aggregates smaller than 100 nm. The aggregate is the smallest stable unit in which the primary particles are held together by strong chemical bonding. Evonik also refines its technologies for targeted production of customised nanomaterials, participates in basic research on nanoparticle genesis, and continues its research into technologies for producing films in the nanometre range.

In 2014 Evonik employed c. 33,000 employees and generated sales of EUR 12.9 billion with an operating result (adjusted EBITDA) of EUR 1.9 billion. Around 78 percent of sales are generated outside Germany.

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[325] Cury Camargo P, et al. (2009), Nanocomposites: synthesis, structure, properties and new application opportunities, Materials Research, vol.12 no.1, http://dx.doi.org/10.1590/S1516-14392009000100002

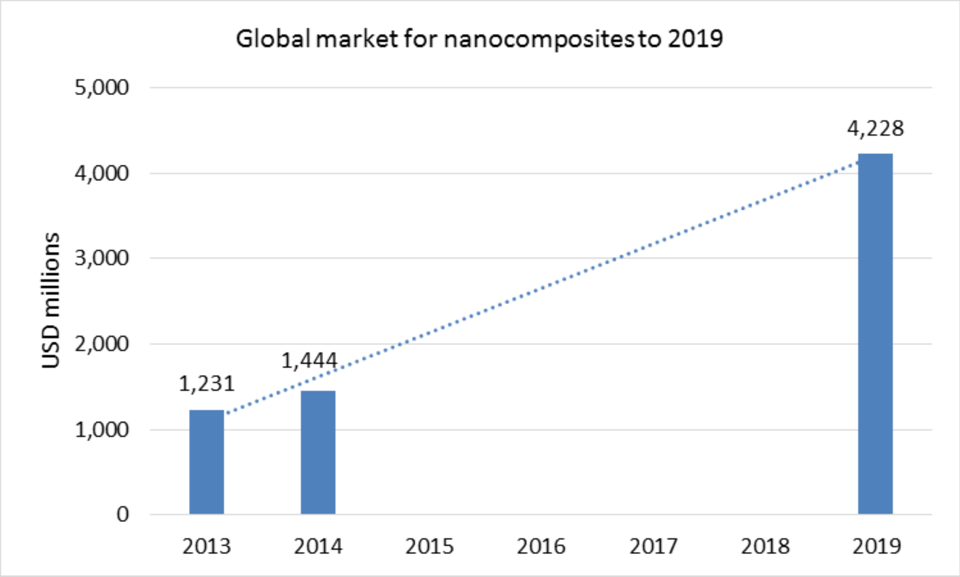
[326] Masia S (2008), Nanocomposite Review. Current Scientific and Technical Advances. Mimeo

[327] Okpala C (2013), Nanocomposites – An Overview, International Journal of Engineering Research and Development, Volume 8, Issue 11 (October 2013): 18

[328] http://corporate.evonik.com/en/Pages/default.aspx

MARKET DATA AND FORECASTS[329]

The global market for nanocomposites was estimated to be over USD 1.2 billion in 2013 and USD 1.4 billion in 2014, forecast to grow to USD 4.2 billion by 2019 (a CAGR of 21% in unit terms and 24% in value terms between 2014 and 2019).



Source: BCC Research, 2014

Figure 7-17: Global market for nanocomposites to 2019

Clay nanocomposites accounted for 59.0% of total nanocomposite consumption by value in 2013, followed by carbon nanotube composites (17.7%) and metal/metal oxide nanocomposites (12.8%). The market share of clay nanocomposites is expected to increase to 60% in 2019, while that of carbon nanotube composites is forecast to fall to 13.5% and metal/metal oxide to 7.7%. The remainder will largely be from new types of nanocomposite, such as fuel cell membrane and photonic band gap nanocomposites.

Table 7-6: Global market and CAGR for individual types of nanocomposites to 2019

	2013	2014	2019	CAGR%
	USD millions			2014-2019
Nanobiocomposites	0	0	69.9	
Ceramic nanocomposites	77	84.9	257.1	24.8
Metal/metal oxide nanocomposites	158.2	181.6	325.8	12.4
Other nanocomposites	51.9	64.2	462	48.4
Carbon nanotube composites	218.1	227.8	568.9	20.1
Clay nanocomposites	726.1	885	2,544.20	23.5

Source: BCC Research, 2014

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[329] BCC Research (2014), Global Markets for Nanocomposites, Nanoparticles, Nanoclays, and Nanotubes, p.7

Case study: Zyvex Corporation

Zyvex Corporation (Richardson, TX, US) was founded in 1997. It has subsequently restructured into Zyvex Technologies (formerly Zyvex Performance Materials), Zyvex Labs and Zyvex Instruments (currently a division of DCG Systems). The restructuring was implemented so that each company could independently focus on its industry-leading technology and products and improve market share.

Zyvex Technologies (Columbus, OH) develops nano-engineered materials and has directed its efforts in achieving excellence in the domain of nano-enabled manufacturing technologies to create products with increased toughness, increased durability and abrasion resistance. The company also engaged itself to create carbon nanotube-enhanced products in a collaboration with Easton Sports.

Products of Zyvex Technologies are strong, light materials based on their molecular chemistry technology and include polymer-modified multi-wall carbon nanotube additives for epoxy composites, reinforcing elastomers, or aqueous-based solutions. The company focuses on industries such as sporting goods/sports (e.g., bicycle wheels), automotive (adhesives for racing), marine (doors), aerospace (nacelle lining), and healthcare (e.g., prosthetics)[330]*.*

Zyvex Labs develops tools to build precise products atom by atom. Products include STM (scanning tunnelling microscope) lithography control systems and tip etchers. One of the achievements of the company is the development of Kentura, which allows nanomaterials to be mixed into resin systems in order to improve their properties.

In 2013, Zyvex received USD 5.7 million (EUR 4.3 million) in Ohio Third Frontier grants for relocation and product commercialisation[331]*. Some of the other recent nano-enabled developments (in May 2015) include a new product called ZNT-boost, which is an epoxy-composite toughening system applicable to carbon and glass fibre composites. This has been claimed to offer the benefits of increased toughness without reducing the strength and mechanical properties of the composite. The first commercial application of ZNT-boost has been for the marine industry. The company partnered with Composites Universal Group (CUG), Scappoose, Oregon for the first commercial adoption of ZNT-boost.*

Though the company initiated the process to be acquired by OcSiAl, the deal did not proceed because Zyvex Technologies decided to remain independent. Zyvex Technologies still maintains a business relation with OcSiAl and works together for certain customers and projects. Zyvex Technologies uses the OcSial materials and OcSial uses Zyvex technology.

The company recorded c. USD 2.5 million (EUR 1.9 million) in revenue in 2014 and in 2015 Zyvex expects to record greater revenue (<USD 5 million, EUR 4.5 million). As a company, it is estimated that around 30% of this amount i.e. USD 0.75 million (EUR 0.56 million) has been used for R&D, which is carried out in Ohio, where Zyvex Technologies has around 17 employees. Zyvex Labs has a workforce of around 30 employees.

Zyvex Technologies being focussed on selling nanomaterials is challenged as these become commodities quickly. As a consequence, Zyvex Technologies plans to integrate its technologies directly into applications and introduce these in the market. At the moment Zyvex Technologies sells intermediate type (composite type) products and is working with companies who are expected to licence the technology. Zyvex Technologies plans to partner with companies who provide integrated products. Zyvex Technologies have representation in other regions such as Taiwan, Singapore and China.

Zyvex Instruments is a part of DCG systems which generated revenue of USD 76 million (EUR 57.1 million) in 2014.

Zyvex Labs collaborated with University College London (UCL) in order to improve its atomically-precise manufacturing processes and develop a new commercial patterning system, which would be used for quantum computing devices[332]*. This collaboration aided a consortium led by Zyvex Labs to secure over USD 14 million (EUR 10.5 million) in funding for research contracts from*

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[330] http://www.zyvextech.com/product-overview/

[331] http://www.zyvextech.com/news/

[332] https://www.ucl.ac.uk/impact/case-study-repository/supporting-commercial-nanotechnology

the US Defence Advanced Research Projects Agency (DARPA) and the State of Texas directed towards enabling the accelerated commercialisation and market adoption of atomically precise devices and manufacturing approaches.

E NANOSCALE THIN FILMS

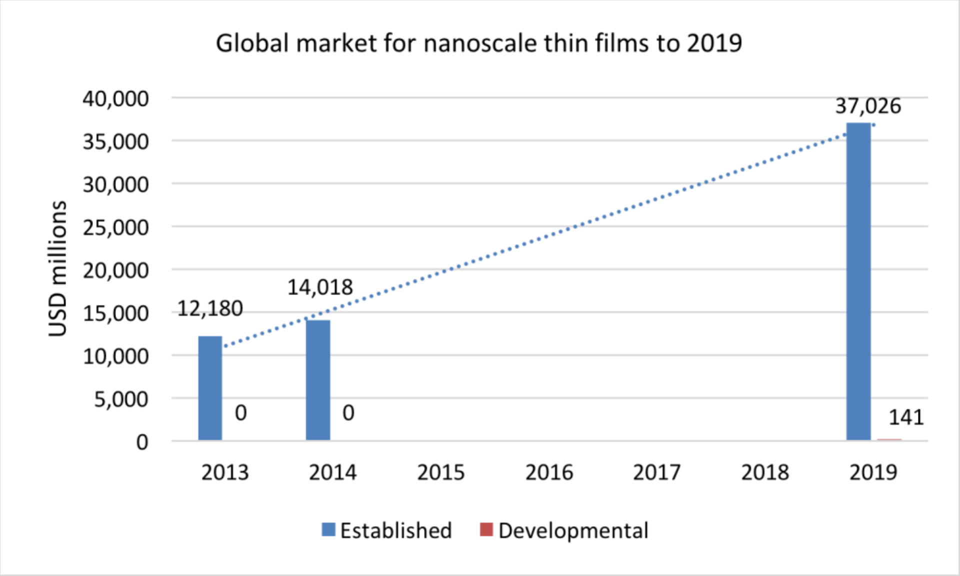
TECHNOLOGY AND PRODUCTS

Nanoscale thin films have thicknesses and/or internal structures measured in units of 100 nm or less. Some thin films are built up from nanoparticles (e.g. thermal sprays or dip coatings from a dispersion of nanoparticles), while others are produced directly via vapour deposition, sputtering or other processes[333].

MARKET DATA AND FORECASTS[334]

The market for nanoscale thin films was estimated to be USD 12.2 billion in 2013 and USD 14 billion in 2014, with a forecast rise to USD 37 billion in 2019, a CAGR of over 20% from 2014 through 2019.

The nanoscale thin film market is dominated by catalytic converters, flat-panel displays and low-k dielectric coatings, which are gaining rapidly in importance.



Source: BCC Research, 2014

Figure 7-18: Global market for nanoscale thin films to 2019

Case study: Aixtron

Aixtron SE[335] is a German-based technology company, which specialises in manufacturing metalorganic chemical vapour deposition (MOCVD) equipment, used for making a range of electronic and opto-electronic products containing compound, organic and silicon-based semiconductors as well as nanotubes and nanofibres.

The company was founded as a spin-off by employees of the Institute for Semiconductor Technology at RWTH Aachen University in 1983. Already from the beginning, research on nanotechnology has been ongoing on semiconductor manufacturing equipment. In the first years, the company specialised in III-V semiconductors, such as gallium arsenide (GaAs) and indium phosphide (InP), while, in the early 1990s, the product range was expanded to gallium

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[333] BCC Research (2013), Nanotechnology in Energy Applications, p.11
[334] BCC Research (2014)
[335] http://www.aixtron.com/en/home/

nitride (GaN) reactors.

Since then, Aixtron has continued to extensively research gallium nitride (GaN) and similar materials and has been involved in several EU and nationally-funded R&D projects such as the German BMBF programme for high bandgap nitride semiconductors and the BMBF project 'PAR-CVD' for the development of high performance parallel calculation processes for analysis and optimisation of CVD processes.

Since 2004, Aixtron has also participated in many FP6 and FP7 projects (FP6: 6 projects, FP7: 9 projects), several of them directly linked to the research of GaN), such as 'RAINBOW' (to improve the quality of indium nitride-based materials), and 'INDOT' (to develop MOCVD technology (equipment, precursors, gas purification and growth processes) for the industrial production of indium nitride (InN) quantum dot based devices. Partners, end users within the projects, were helpful for the company's development and refinement of know-how.

Another successful activity was the acquisition of the long-term exclusive license for Planetary Reactor technology from Philips, which offered Aixtron the world-wide rights to manufacture the system. The entire Aixtron MOVPE equipment range, which is one of the company's biggest product families, is based on this Planetary Reactor technology. One of the last positive occurrences within the story of GaN-research happened in 2013, when Aixtron received the Compound Semiconductor Manufacturing Award for its development, the AIX G5+ reactor for gallium nitride on silicon (GaN-on-Si). In 2015 Aixtron won the China SSL award honouring the achievements in SSL.

Aixtron is investing specifically in research and development projects to not only further pursue the company's leading technology position in MOCVD equipment but also to penetrate growth markets in the fields of power electronics, organic semiconductors and next generation memory and logic applications. The company's R&D department comprises a team of 285 R&D employees (with total number of employees being 789 in 2014). Research and development costs were up 17% from EUR 57.2 million in 2013 to EUR 66.7 million in 2014, whereas 1-2% of their R&D expenses come from European, national and regional funding. Even if the share might be rather low, EU funding has an important role, as several research activities without funding would not have been conducted. Especially high-risk research activities/projects, which could not be conducted by the company itself (due to the lack of competences), would not be pursued. As European funded projects support the collaboration of highly qualified experts, the risk of the research activity and the financial engagement are decreasing. In addition, technology transfer, knowledge production and the possibility to learn from customers, end users, universities was considered positive within EU funded projects.

EU funded projects, were Aixtron participated, had in the case of Specific Targeted Research Projects (STReP), approx. 5 partners, bigger projects, as integrated projects had about 15 partners, coming from academia, research, as well as end users. In terms of non-financial contribution, partners offered in-kind contributions as laboratories and additional human resources.

In terms of intellectual property, Aixtron aims to secure its technology by patenting and protecting inventions. As of December 31, 2014, the company had 196 patent families available (December 31, 2013: 198 patent families). Patent protection for inventions is usually applied for in those sales markets relevant for Aixtron, specifically in Europe, China, Japan, South Korea, Taiwan and the United States. Usually, patents are being applied before the start of the funded project; within the funded project, they focus on the elaboration and development of the product/technology.

In fiscal year 2014, Aixtron recorded total revenues of EUR 193.8 million, an increase of EUR 10.9 million, compared to EUR 182.9 million in 2013 (2012: EUR 227.8 million) mainly due to increased demand from LED chip makers. However, Aixtron's revenues since 2010-2011 have been decreasing: in 2010-2011, the revenue was c. EUR 780 million. For the year, 2015 the company expects to be in the black (after R&D and operating expenditures).

23% of total revenues in 2014 were generated by sales of spare parts and service, which is 2 percentage points lower than in 2013 but higher than in 2012 (2013: 25%, 2012: 22%) and is mainly due to higher equipment revenues. In absolute terms, sales of spare parts and service were at EUR 45.3 million in 2014, largely stable compared to 2013. The sales volume of manufacturing equipment increased slightly (2013: EUR 44.9 million; 2012: EUR 50.9 million).

In 2014, the major part of total revenues, 83%, continued to be generated by sales to customers in Asia, which was 5 percentage points higher than in the previous years (2013: 78%; 2012: 78%). 13% of revenues in 2014 were generated in Europe (2013: 13%, 2012: 9%) and the remaining 4% in the United States (2013: 9%, 2012: 13%).

Concerning the impact of regulation / legislation / codes of conduct, Aixtron could benefit from the CO_2-reduction discussions and the introduction of a ban on conventional light bulbs, as this prohibition would greatly influence the development of LED and hence the activities of Aixtron. In addition, initiatives to phase out the use of mercury are making LED technology more attractive.

F GRAPHENE

TECHNOLOGY AND PRODUCT TRENDS

Graphene is a single, tightly-packed layer of carbon atoms bonded together in a hexagonal honeycomb lattice. It is an allotrope of carbon in the structure of a plane of sp2 bonded atoms with a molecule bond length of 0.142 nanometres. Layers of graphene stacked on top of each other form graphite, with an inter-planar spacing of 0.335 nanometres[336].

In terms of compounds and materials known to man, graphene is

- the thinnest (at one atom thick); the lightest (with 1 square metre weighing c. 0.77 milligrams);
- the strongest (between 100-300 times stronger than steel and with a tensile stiffness of 150,000,000 psi);
- the best conductor of heat at room temperature (at $(4.84\pm0.44) \times 10^3$ to $(5.30\pm0.48) \times 10^3$ $Wm^{-1}K^{-1}$); and
- the best conductor of electricity (studies have shown electron mobility at values of more than 15,000 $cm^2V^{-1}s^{-1}$).

Other notable properties of graphene are its unique levels of light absorption at $\pi\alpha \approx 2.3\%$ of white light, and its potential suitability for use in spin transport[337].

MARKET DATA AND FORECASTS[338]

The commercial market for graphene technologies was essentially zero in 2013. It is expected that the first commercially-significant sales of graphene-based products will be developed by 2018, potentially reaching USD 195 million by 2018 if they develop quickly.

Case study: Graphenea

Graphenea S.A. (www.graphenea.com) is a company which was established in 2010 in Donostia-San Sebastian, Spain, as a joint venture of private investors and the Basque nanoscience co-operative research centre CIC nanoGUNE[339]. Today, Graphenea is specialised in the production of chemical vapour deposition (CVD) graphene films and liquid exfoliated graphene oxides. The company's activities include research, development, manufacturing, and supply of graphene for industrial and research purposes. The products are used in integrated circuits, solar cells, super-capacitors, batteries, airplanes, automobiles, conductive coatings, flexible displays, and touch screens, for example. The company is active in markets throughout the world, including the

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[336] http://www.graphenea.com/pages/graphene#.VnETx79qTgk

[337] Ibid

[338] BCC Research (2013), Graphene: Technologies, Applications and Markets

[339] See http://www.nanogune.eu/graphenea (accessed 24/09/2015). CIC nanoGUNE is a not-for-profit association promoted by the Basque Government in 2006 through its Department of Economic Development and Competitiveness as nanoscience and nanotechnology are seen as instruments which can stimulate the transformation and diversification of the Basque business environment. This Centre for Co-operative Research receives a significant amount of funding through competitive programmes, including EU FP7 and H2020 projects.

United States, Japan, Korea, Taiwan, India and Europe[340].

Graphenea was founded with an initial investment of EUR 100,000 in 2010 to tap into the potential of graphene and its market opportunities. This initial amount came from the founder who remains as CEO and has control over the strategic decisions made within the company[341].

At the same time, Graphenea managed to gather financial support from SPRI, the Basque Business Development Agency, and CIC nanoGUNE. A further investment of EUR 800,000 by Seed Gipuzkoa SCR (a public capital investment organisation in new high-tech companies at the early stage) completed an initial investment of EUR 3 million by 2011. After initial expansion was complete, CIC nanoGUNE ceased to be a partner, in compliance with Graphenea's Foundation Agreement.

In 2013, Repsol, a multinational oil and gas company, and the Centre for Industrial Technology Development (CDTI), a public business entity dependent on the Spanish Ministry of Economy and Competitiveness, signed an agreement to invest EUR one million in Graphenea[342]. This co-investment was to be used to accelerate the company's business plan towards industrial uptake.

Even though the company has still a short history, it is quite a profitable history: with 14 workers and 4 patents[343] in 2015, it has achieved sales higher than EUR 1 million and exports its products to universities, research centres and industries in 53 countries[344]. It is estimated that Graphenea has 10% of the current graphene market.

In February 2015, Graphenea announced that the company had been granted a patent for a method to transfer large-area graphene, grown by chemical vapour deposition (CVD) and transferred from a metal foil to an insulating substrate. According to the company, this could be a key patent in the graphene industry since CVD is the most promising way of growing large, high quality graphene sheets, most often useful only on insulating substrates.

Furthermore, in June 2015, Graphenea was granted EUR 2.5 million from the Horizon 2020 program 'SME Instrument' for the construction, installation and commissioning of a new production plant. The current production capacity will expand by a factor of 200 and is estimated that the current number of employees of Graphenea will double. "It is a very important boost that will accelerate our business plan. It will allow us to grow faster and consolidate our position as the global leader in our industry"[345], said Jesus de la Fuente, Founder and CEO of Graphenea after receiving the news of the SME instrument. The construction of the new plant will take 24 months and the new facility could open in late 2017.

In addition, Graphenea is currently taking part in several FP7 projects under different programmes (NMP, ICT, People), NMP being the most important one[346]. This has provided Graphenea with the opportunity to collaborate and complement its knowledge and expertise with important European universities, research centres and companies working in the field of graphene related nanotechnology, such collaboration being one of the most important objectives when participating in a European project. Regarding the EU funding, Graphenea has received FP7 funds of more than EUR 1.1 million for research activities. Participation in H2020 is also important with two main projects and a funding of more than EUR 1.7 million.

Graphenea is also participant in the Graphene Flagship, the EU's biggest ever research initiative. The flagship was launched in 2013 with a budget of EUR 1 billion, and is a consortium of 74 partners. The Graphene Flagship aims to bring together academic and industrial researchers to take graphene from academic laboratories into European society in the space of 10 years, thus

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[340] See http://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=141389462 (accessed 24/09/2015)

[341] See http://adegi.es/foroemprendedores/blog/tag/graphenea/ (accessed 25/09/2015)

[342] http://www.repsol.com/es_en/corporacion/prensa/notas-de-prensa/ultimas-notas/05122013-repsol-cdti-invierten-un-millon-euros-empresa-graphenea.aspx

[343] See Nanodata Landscape data collection – Patents includes the following patent of Graphenea: 46397070

[344] S http://www.graphenea.com/pages/graphene-manufacturer-producer-supplier (accessed 28/09/2015)

[345] http://www.graphenea.com/blogs/graphene-news/31696897-graphenea-secures-2-5-million-to-install-a-new-production-plant

[346] See Nanodata Landscape data collection – Projects, but also: http://cordis.europa.eu/search/result_en?q=%27graphenea%27&p=1&num=10&srt=Relevance:decreasing

generating economic growth, new jobs and new opportunities[347].

Besides increasing its sales, Graphenea has made a continued effort to popularise the use of graphene by increasing its production capacity and reducing the prices of graphene twice at the beginning of two consecutive years[348].

At the moment, the European regulation of new chemical products is limiting Graphenea's annual production to 1 ton per year as graphene is a new material that has not yet passed the registration process required by the European regulations for new substances. The company has started the process of registration.

In late 2014, Graphenea opened an Applications Laboratory at Cambridge MA, US, in order to meet the needs of the company's North American customers and due to the close relation that the company has with the Massachusetts Institute of Technology (MIT) and Harvard[349]*. In September 2015, Graphenea was selected as one of Europe's top fast growing start-ups to be present at the European Innovation Day (EID) in Silicon Valley*[350].

The next section looks at the wider environment for nanotechnology manufacturing: regulation and standards, and environmental health and safety issues.

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[347] http://graphene-flagship.eu/ (accessed 25/09/2015)

[348] See http://www.graphenea.com/blogs/graphene-news/16716081-graphenea-sales-more-than-double-in-2014 (accessed 28/09/2015)

[349] See http://www.graphene-info.com/graphenea-opens-us-branch-establishes-application-laboratory

[350] See http://sec2sv.com/

8 THE WIDER ENVIRONMENT FOR NANOTECHNOLOGY MANUFACTURING

8.1 Regulation and standards for nanotechnology

There is no specific legislation that addresses manufacturing processes for nanomaterials. There are mandatory reporting schemes, known as nanomaterial registries, which monitor activity on manufacturing of nanomaterials (including their importation and distribution).

8.1.1 European regulations for nanotechnology

In terms of nanotechnology regulation, the European Union is well-advanced but not alone in seeing the need for greater scrutiny on the use of nanotechnologies. To facilitate regulation, *inter alia*, a definition of nanomaterials has been defined by the European Commission in its Recommendation on the Definition of a Nanomaterial - 2011/696/EU. This non-binding document has also been used by other pieces of regulation to define the term 'nanomaterial'. The table below lists some key regulatory documents within the European Union and within Member States.

Table 8-1: 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

The EU is actively developing a set of regulations around nanotechnology. With the first Regulatory Review on Nanomaterials SEC (2008) 2036 and the Second Regulatory Review on Nanomaterials SWD (2012) 288 final, the EC has given Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (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 Communication.

Since the summer of 2013, there has been ongoing work to adapt the Annexes of REACH to specifically address nanomaterials; an impact assessment and a large consultation on this issue have been run by the European Commission: discussions are still ongoing.

One of the milestones of the European Regulatory Framework for nanotechnologies 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 that should have been concluded in December 2014; an outcome of this review could be a revision of the definition.

Other definitions have been developed inside the legal text of several sectorial regulations which address nanomaterials (from biocides to food).

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'; it was followed by a 2012 letter to the European Commission calling for a European Reporting Scheme and signed 10 European Member States, plus Croatia. The European institutions are still weighing the pros and cons of such a reporting scheme; nevertheless, some European Member States have been going forward.

In addition, as part of the electoral promises of the 2007 Presidential Elections, the 'Grenelle de l'Environnement', a large environmental debate was organised in France and resulted in major environmental acts: the Grenelle Acts (Lois Grenelle I & II) which enacted the future creation of a mandatory reporting scheme for nanomaterials. France hence took steps towards setting up the first registration scheme for substances at the nano-scale in Europe; in 2012, the Decree[351] 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 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 stoffen* or *Arrêté royal relatif à la mise sur le marché des substances manufacturées à l'état nanoparticulaire*). The registration of substances will begin from 1 January 2016, while mixtures 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 registering the first products for the year 2014 in the year 2015.

Other EU Member States have been considering options for a registration scheme for nanomaterials; Norway considers such a register under its Pollution Control Authority (SFT). From 2013, the Norwegian Product Register requires information for chemicals containing 'a substance in nano form' with a 'tick box' system. Sweden has given the mandate to its chemical agency (KEMI) to develop a reporting scheme and Italy is also considering setting up a similar system.

With these initiatives, EU Member States have been pushing the European Commission to act; the

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[351] 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

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 a RPA and BiPro;* three reports were published to help the EC decide on an eventual EU-wide registry of nanomaterials. To date, there has been no decision.

8.1.2 Nanotechnology regulation in the rest of the world

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 the Toxic Substances Control Act (TSCA). This proposal would introduce reporting and recordkeeping requirements for nanoscale materials as well as a 135-days pre-notification requirement for the manufacturers of ‘chemical substances as discrete nanoscale materials’.

In Canada, Health Canada and Environment Canada have been looking at similar approaches; in April 2015 they opened a consultation on a Proposed Approach to address Nanoscale Forms of Substances in the Domestic Substances List. The DSL lists substances that are manufactured in or imported into Canada Established under the Canadian Environmental Protection Act (CEPA 1999). With this “proposed approach” the Canadians intend to establish a list of existing nanomaterials in Canada with the use of ‘a mandatory survey under section 71 of the Act […] to obtain the essential data needs to support the development of the list of the existing nanomaterials in Canada and subsequent prioritisation activities for those substances’.

8.1.3 Standardisation and nanotechnology

ISO/TC 229 Nanotechnologies has been developing technical documents on manufacturing at the nanoscale. Nanomanufacturing and nanomanufacturing process are defined in the first part of the joint ISO/IEC 80004 series on nanotechnology vocabulary;

2.11 nanomanufacturing

Intentional synthesis, generation or control of nanomaterials, or fabrication steps in the nanoscale, for commercial purposes

2.12 nanomanufacturing process

Ensemble of activities to intentionally synthesise, generate or control nanomaterials, or fabrication steps in the nanoscale, for commercial purposes

Document ISO/TS 80004-8:2013 Nanotechnologies — Vocabulary — Part 8: Nanomanufacturing processes supports these definitions and gives ‘terms and definitions related to nanomanufacturing processes in the field of nanotechnologies’.

The International Electrotechnical Commission (IEC) is developing series of technical specifications on nanomanufacturing. The 62565 series covers material specifications and the 62607 series covers key control characteristics. Together with the Institute of Electrical and Electronics Engineers (IEEE), IEC is also writing a document dedicated to nanoelectronics: IEC/IEEE 62659 Nanomanufacturing - Large scale manufacturing for nanoelectronics

In Europe, CEN/TC 352 Nanotechnology has not developed standards relevant to manufacturing.

8.2 Environment, health and safety and nanotechnology

Exposure to chemicals during nanotechnology manufacturing processes may be quite diverse. Five categories of manufacturing techniques were identified within the NanoData project. All combinations of nanoparticles and technique categories were evaluated.

The basis for the evaluation was "Stoffenmanager Nano" application[352, 353], 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.

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[354]. 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[355]. However, nanoparticles as such are very unlikely to penetrate the skin[356] 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.

8.2.1 Hazard assessment

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 selected nanoparticles of the manufacturing sector and their hazard bands, either taken from le Feber et al. (2014)[357] or van Duuren et al. (2012)[358] or derived in this project.

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[352] 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.

[353] 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.

[354] 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.

[355] Ibid

[356] 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

[357] 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.

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Table 8-2: Hazard bands for the specified nanoparticles

Nanoparticles	Hazard band	Source
Aluminium oxide (alumina)	C	le Feber et al. (2014)
C60 (fullerenes)	D	van Duuren et al. (2012)
Calcium carbonate	A	This report
Carbon	Needs specification, may be carbon black, carbon nanotubes, fullerenes or graphene	
Carbon black	D	van Duuren et al. (2012)
Cerium oxide	C	le Feber et al. (2014)
Copper indium gallium selenide (CIGS)	E	This report
Copper oxide	E	This report
Dendrimer	D	This report
Gold	D	van Duuren et al. (2012)
Graphene	E	This report
Iron	D	van Duuren et al. (2012)
Manganese dioxide	C	This report
Multi-walled carbon nanotube (MWCNT)	E	This report
Nanoclay	D	van Duuren et al. (2012)
Nickel monoxide (nickel oxide)	E	This report
Silicon dioxide (silica), synthetic amorphous	C	le Feber et al. (2014)
Silicon dioxide (silica), crystalline	E	van Duuren et al. (2012)
Silver	D	le Feber et al. (2014)
Single-walled carbon nanotube (SWCNT)	E	This report
Strontium titanate (strontium titanium trioxide)	n/a	This report, no data
Titanium dioxide (titania, rutile, anatase)	B	le Feber et al. (2014)
Titanium nitride	D	van Duuren et al. (2012)
Vanadium pentoxide (divanadium pentoxide)	E	This report
Zinc oxide	B	le Feber et al. (2014)
Zirconium dioxide (zirconia)	A	This report

8.2.2 Exposure assessment

Five categories of techniques to manufacture nanomaterials and nanostructures were identified, namely:

- Set A: Chemical vapour deposition, EBPVD, electrodeposition, electroplating, MBE, MOCVD, molecular beam epitaxy, physical vapour deposition, Sputter deposition, pyrolysis, atomic layer deposition (vapour/aerosol synthesis);
- Set B: Self-assembly;
- Set C: Lithography, Nanocontact printing, Laser ablation, Reactive ion etching, RIE (nano-etching);
- Set D: Sol-gel, solution phase synthesis, wet chemical synthesis (liquid phase synthesis);
- Set E: Ball milling (solid phase synthesis).

The likelihood of exposure to nanoparticles during synthesis, production and manufacturing processes is highly dependent upon the type of process and the type of equipment involved in the process. In some cases, due to physico-chemical or technical reasons, the process needs to be enclosed (e.g. during gas phase synthesis when an extremely low pressure or an inert atmosphere is required). Thus, the presence of an intrinsic barrier being part of the equipment might lead to lower observed exposures.

The predominant route of exposure is inhalation as the production processes are automatic and do not require a personal influence. Dermal and oral exposure become relevant during the collection and further use of produced nanoparticles. Consequently, the exposure which is described below for manufacturing is focusing on inhalation.

In “Stoffenmanager Nano” sets of exposure scenarios are assigned to exposure bands labelled 1 to 4 (1=low exposure, 4= highest exposure).

8.2.3 Risk assessment

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table below. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures ort to establish the risk involved with more precision. It should be emphasised that, because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 8-3: 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 nanotechnology manufacturing are listed the table below.

Table 8-4: Priority bands for nanotechnology manufacturing

		Exposure Band				
		Set A Gas vapour	Set B Self-assembly	Set C Top-down	Set D Liquid-phase	Set E Ball mill
Nanoparticle	**Hazard Band**					
Aluminium oxide (alumina)	C	1	2	2	3	1
C60 (fullerenes)	D	1	2	2	2	1
Calcium carbonate	A	2	3	3	3	2
Carbon	n/a	n/a	n/a	n/a	n/a	n/a
Carbon black	D	1	2	2	2	1
Cerium oxide	C	1	2	2	3	1
Copper indium gallium selenide (CIGS)	E	1	1	1	1	1
Copper oxide	E	1	1	1	1	1
Dendrimer	D	1	2	2	2	1
Gold	D	1	2	2	2	1
Graphene	E	1	1	1	1	1
Iron	D	1	2	2	2	1
Manganese dioxide	C	1	2	2	3	1
Multi-walled carbon nanotube (MWCNT)	E	1	1	1	1	1
Nanoclay	D	1	2	2	2	1
Nickel monoxide	E	1	1	1	1	1
Silicon dioxide (silica), synthetic amorphous	C	1	2	2	3	1
Silicon dioxide (silica), crystalline	E	1	1	1	1	1
Silver	D	1	2	2	2	1
Single-walled carbon nanotube (SWCNT)	E	1	1	1	1	1
Strontium titanate	n/a	n/a	n/a	n/a	n/a	n/a
Titanium dioxide (titania, rutile, anatase)	B	1	3	3	3	1
Titanium nitride	D	1	2	2	2	1
Vanadium pentoxide	E	1	1	1	1	1
Zinc oxide	B	1	3	3	3	1
Zirconium dioxide	A	2	3	3	3	2

The majority of the materials have a high priority (1), indicating the need to apply exposure control methods or to assess the risks more precisely. Copper indium gallium arsenide, copper oxide, graphene, multi-walled and single-walled carbon nanotubes, nickel monoxide, crystalline silicon dioxide and vanadium pentoxide are high priority across all production methods considered here.

Calcium carbonate, titanium dioxide, zinc oxide and zirconium dioxide showed the lowest priority profiles of the materials considered, although for some production methods most are still ranked as high priority (1)

This section on hazard, exposure and risk is presented in much greater detail in the Annex.

9 CONCLUDING SUMMARY

Nanotechnology manufacturing is defined in this project as the processes and products that relate to the manufacture and use of nanomaterials. It provides the building blocks for high performance products associated with a wide range of industries such as aerospace and defence, automotive and transportation, information and communication technologies, energy and healthcare.

Nanotechnology manufacturing is being supported through measures at national and European levels to enable researchers to produce publications and engage in projects that increase knowledge that is being patented and commercialised into products. At European level, there are specific actions that are aiming to support this – ERA-NETs, ETPs and JTIs.

Researchers from Germany and France generated the largest number of publications in 2014, followed by the United Kingdom (UK), Italy, Spain and Poland. EU28 and EFTA higher education and research organisations were led by the University of Cambridge (UK) and the Polish Academy of Sciences (each with over 100 publications in 2014). Four of the top fifteen higher education and research organisations were based in Germany, two each the United Kingdom, Belgium and Sweden.

Publishing also takes place in companies (mostly at a much lower level in terms of numbers of publications annually), those with the most nanotechnology manufacturing publications globally in 2014 being IBM and Samsung, both with around 40 publications in 2014, twice the number of the company with the next highest number of publications, NTT[359].

The products identified as being on the market at this time, over 200 in number, were approximately one third nanotools (for nanolithography, microscopy and nano-manipulation) and two thirds nanomaterials (solid nanoparticles (powders, wires, fibres, rods and dots), carbon nanotubes, nanoscale thin films, graphene, etc.). In total, 89 companies were identified as manufacturing products, 22 of them producing nanotools and 69 producing nanomaterials[360]. The largest number of companies (18) in any category was for producers of graphene.

The global market value of nanotechnology tools is forecast to be USD 11 billion in 2019, largely based on nanolithography products. The global market for nanomaterials is forecast to grow to USD 52.7 billion in 2019, with thin films having the largest market value and nanocomposites and carbon nanotubes the highest growth rates.

There is no specific legislation that addresses manufacturing processes for nanomaterials, only mandatory reporting schemes (nanomaterial registries), monitoring nanomaterial activities (including importation and distribution). The EU is actively developing a set of regulations. Some Member States have introduced additional ways to regulate nanotechnologies including databases and reporting schemes.

The majority of the nanomaterials considered in the review of nanotechnology manufacturing have a high priority (combined ranking of exposure and hazard), indicating the need to apply exposure control methods or to assess the risks more precisely. The respiratory route is the main one for exposure for many occupational scenarios.

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[359] Nippon Telegraph and Telephone Corporation

[360] Two are in both categories

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[361] (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'.

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[361] 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.

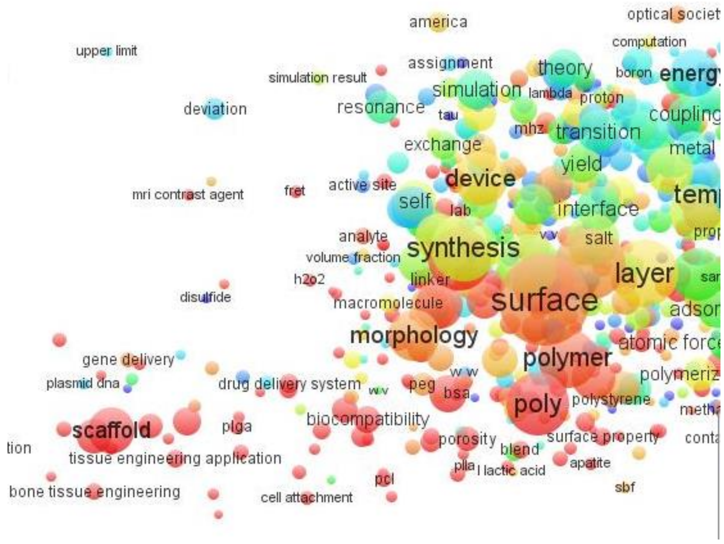

Figure A: Partial VOSViewer map for nanotechnology and health

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[362]	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[363]	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.

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[362] In FP6 these were called Priorities and in FP7 Work Programmes.

[363] 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'[364] in the title or abstract of the project. 3,544 projects were selected in this way[365], 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.

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[364] 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".

[365] Unlike the other sectors considered by the project (HT, EN, PH, MF), for ICT additional projects were identified by use of keywords such as graphene. These were judged to be too important in ICT to be omitted. This did, however, result in the total number of nanotechnology projects being different for ICT (4,143) and the other sectors (3,544).

Table C: Number and share of nanotechnology projects in FP6 and FP7

		Total	FP7	FP6
FP total	Number of FP projects	35,265	25,238	10,027
	Share of FP (total)	100%	71.6%	28.4%
Nanotechnology	Number of FP projects	3,544	2,636	908
	Share of FP	100%	74.4%	25.6%
Share of nanotechnology of total FP		10.0%	10.4%	9.1%

C1.2 Classification of projects by sector and sub-sector

The 3,544 projects relevant to nanotechnology were subjected to a search using the sector keywords to identify projects relevant to each sector. This search was undertaken using the keywords identified for each sector. The project details for the selected projects were reviewed manually, where possible, as a further check of the quality of the outputs of the keyword search process.

For example, using the method described above, 944 projects were categorised as being related to nanotechnology and health, approximately 27% of total nanotechnology projects. Using the keywords identified for each of the five health sub-sectors[366], 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.

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[366] 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)[367].

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.

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[367] 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+[368].

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**[369]	United Kingdom
EL[370]	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[371].

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

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[368] Data was also analysed from countries outside of the EU28 namely Iceland (IS), Israel (IL), Norway (NO), Switzerland (CH) and Turkey (TR).

[369] GB is also used

[370] GR is also used

[371] 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[372]. 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[373] 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[374] as well as existing market reports[375]. 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[376], Nanowerk[377],

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[372] 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.

[373] http://www.iso.org/iso/country_codes

[374] E.g. Nanomedicine: Nanotechnology, Biology, and Medicine 9 (2013) 1–14, Hessen Nanotech (2008) Applications of Nanotechnologies in the Energy Sector.

[375] See BCC Research www.bbcresearch.com

[376] http://www.azonano.com/

[377] http://www.nanowerk.com/

the consumer products inventory of the Project on Emerging Nanotechnologies[378], the product database of understandingnano.com[379], the Nanoinformationsportal of the Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH[380], the Danish Inventory of Nanoproducts[381] and the nanowatch.de database[382]. 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[383], 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[384], the Nano-Map of the German Federal Ministry of Research[385], the database on photonic companies compiled by EPIC, the members directory of SEMI[386], and the Nano-Bio Manufacturing Consortium (USA)[387], 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,

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[378] http://www.nanotechproject.org/cpi/
[379] http://www.understandingnano.com/nanotechnology-product-suppliers.html
[380] http://nanoinformation.at/produkte.html
[381] http://nanodb.dk/
[382] http://www.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank/
[383] http://www.ema.europa.eu/
[384] http://www.nanora.eu/
[385] http://www.werkstofftechnologien.de/en/
[386] http://www.semi.org/en/Membership/MemberDirectory/
[387] http://www.nbmc.org/members-only/

and public database. European Patent Office[388], PRODCOM[389] and patentlens[390] 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[391]. 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

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[388] https://www.epo.org/searching.html

[389] http://ec.europa.eu/eurostat/web/prodcom

[390] https://www.lens.org/lens/search?n=10&q=nanotechnology&p=0

[391] 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: MANUFACTURING KEYWORDS

Below is the list of keywords used in the extraction of data and the subsequent analyses.
Each keyword is associated with either the overall sector or one of the five method groups as follows:

Sector MF: Nanotechnology manufacturing

Method groups:
BM: Ball milling
GV: Gas - vapour
LP: Liquid phase
SA: Self-assembly
TD: Top-down

In the analysis, where data falls into the nanotechnology manufacturing sector (MF) but not into one of the method groups, it may be characterised in the report as Other (OTH).

Asterisks are used to indicate that part of a word is missing. For example, the search for "ball mill*" would identify data related to "ball mill", "ball mills" and "ball milling". Thus one search term was used to cover each of the words with multiple possible endings. Abbreviations are also included (e.g. CVD.

ALD	GV
Atomic layer deposition	GV
Ball mill*	BM
Chemical vapor deposition	GV
Chemical vapour deposition	GV
CVD	GV
EBPVD	GV
Electrodeposition	GV
Electro-deposition	GV
Electroplating	GV
Electro-plating	GV
Laser ablation	TD
Lithography	TD
MBE	GV
MOCVD	GV
Molecular beam epitaxy	GV
Nanocontact printing	TD
Physical vapor deposition	GV
Physical vapour deposition	GV
PVD	GV
Pyrolysis	GV
Reactive ion etching	TD
RIE	TD
Self assembly	SA
Self-assembly	SA
Sol gel	LP
Sol-gel	LP
Solution phase synthesis	LP
Sputter deposition	GV
Sputtering	GV
Wet chemical synthesis	LP

ANNEX 3: ABBREVIATIONS

Abbreviation	Definition
AFM	Atomic force microscope
ALD	Atomic layer deposition
BEUC	Bureau Européen des Unions de Consommateurs
BM	Ball mill/ ball milling (for NanoData project)
bn	Billion
CAGR	Compound annual growth rate
CBRNE	Chemical, biological, radiological, nuclear and explosive
CDE	Centre for Drug Evaluation and Research
CEN	European Standardisation Committee
CMC	Chemistry, manufacturing and controls
CNT	Carbon nanotubes
COD	Co-decision procedure
CVD	Chemical vapour deposition
DFG	Deutsche Forschungsgemeinschaft
d-MRI	Diffusion magnetic resonance imaging
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
ETUC	European Trade Union Confederation
EU	European Union
Eurofound	European Foundation for the Improvement of Living and Working Conditions
f-MRI	Functional magnetic resonance
FP7	Seventh European Framework Programme
GV	Gas- or liquid-phase (for NanoData project)
IPC	International Patent Classification
IPR	Intellectual property rights
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
MAPP	Manual of policies and procedures
MBE	Molecular beam epitaxy
MEMS	Micro electro-mechanical system
MF	Nanotechnology manufacturing (for NanoData project)
MNBS	Micro- and Nano-Bio Systems
MOCVD	Metal-oxide chemical vapour deposition
MR	Magnetic resonance
MRI	Magnetic resonance imaging
MRS	Magnetic resonance spectroscopy

Abbreviation	Definition
MRSI	Magnetic resonance spectroscopic imaging
MWCNT	Multi-walled carbon nanotubes
NACE	Nomenclature statistique des activités economiques dans la communauté européenne
NGO	Non-governmental organisation
NIR	Near infrared
NIR-II	Near-infrared-ii imaging
NANOPHOTONICS	Nanoparticles
NST	Nanoscience and nanotechnology
NT	Nanotechnology
OSHA	European Agency for Safety and Health at Work
OSH-professional	Occupational safety and health professional
PATSTAT	European Patent Office worldwide patent statistical database
PECVD	Plasma-enhanced chemical vapour deposition
P-NIL	Photo nanoimprint lithography
ppm	Parts per million
PVD	Physical vapour deposition
QD	Quantum dot
R&D	Research and development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RIE	Reactive ion etching
SA	Self-assembly (for NanoData project)
SME	Small or medium-sized enterprise
SNAP	Strategic Nanotechnology Action Plan
STOA	Science and technology options assessment
SWCNT	Single walled carbon nanotubes
TD	Top-down (for NanoData project)
T-NIL	Thermoplastic nanoimprint lithography
TT	Technology transfer
US/ USA	United States of America
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 (~10^-9m).
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 stabilized 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: Nanotechnology manufacturing processes

A recent article by Charitidis *et al* (2014) discusses recent developments and the implementation of several methods for the production of nanomaterials, as summarised in the table below.

Table: Overview of manufacturing methods and their application for nanomaterials and structures

	Manufacturing method	Nanomaterial / applications	Review summary
Gas Vapour	Aerosol based processes	Nanocoatings, fibres, metal nanoparticles, semiconductors, iron chlorides for growing carbon nanotubes, fullerenes	Common method for production of nanoparticles. Relatively simple, cost-effective and can be applied on large surfaces.
	Atomic or molecular condensation (gas condensation)	Metal nanoparticles	
	Arc discharge generation	Metal nanoparticles, metal oxides, fullerenes	Produces very small amounts of metal nanoparticles, relative reproducibility. European project aims to develop large scale production (1kg/day)
	Laser ablation process	Metal oxides, high crystalline minerals, fullerenes	Not often applied in large scale, due to low yield and high operation costs
	Plasma process		High production rates possible, relatively simple, low cost, but particle collection is demanding
	Chemical vapour deposition	Carbon nanotubes and carbon nanofibres	Widely used due to low set-up costs, high production yield and ease of scale-up. Applied in semiconductor and ceramic industries. Only promising method for scale-up.
Liquid Phase	Sol-gel	Colloidal nanoparticles, advanced coatings, oxides	Long established industrial process
	Solvothermal method	Crystalline oxide- and non-oxide materials, semiconductors, carbon nanotubes, diamonds, carbides, chalcogenides, nitrides, phosphides or borides. Fine powders and oxides	Hydrothermal synthesis is ready for industrial scale because of breakthroughs in reactor design, could be scaled to 100 tons per annum. Current system's yield is 1 ton/annum.
	Sonochemical method	Metallic nanoparticles	Extensively used to produce nanomaterials with unusual properties. Very inexpensive method.

Ball Mill	Mechanical attrition	Nanocrystalline powders	Can support large quantity production of nanocrystalline powders. Cost effective.
Top-down – nanolithography		1D nanostructures, nanocatalysts, semi-conductors etc.	Large quantities are possible
	Template fabrication	Nanowires, carbon nanotubes	One of the most popular and cheapest methods, in combination with electrodeposition, sol-gel or vapour-phase.
	Scanning probe microscopy	Patterns at nanometre level, for nanoelectronic devices	

Source: Charitidis et al (2014) Manufacturing of nanomaterials: from research to industry, Manufacturing Review, 2014, 1.11

ANNEX 6: 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[392]), 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)[393] and the Federal Ministry for Transport, Innovation and Technology (BMVIT)[394]. The largest share of direct support for R&D is channelled through three funding agencies: The Austrian Science Fund (FWF)[395] that focuses on funding academic research; the Austrian Research Promotion Agency (FFG)[396] specialising in funding applied industrial research and the co-operation between the higher educational sector and industry; and the Austria Economic Service (AWS)[397] 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**"[398] 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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[392] https://rio.jrc.ec.europa.eu/
[393] http://www.en.bmwfw.gv.at/
[394] https://www.bmvit.gv.at/en/
[395] https://www.fwf.ac.at/en/
[396] https://www.ffg.at/en
[397] http://www.awsg.at/
[398] 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[399], 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)[400] 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**[401]**,** 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**[402], 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)[403]**:** Styria's Economic Strategy 2020 is a successor to the State Government's previous economic strategy 2006. The 2006 strategy identified so-called economic and technological strong-points ("Stärkefelder") of the region, on which innovation policy activities were focused: material sciences; mechanical engineering/automotive and transport technologies; chemical and process engineering; human technology; information and communication technologies; environmental technologies; energy; building services engineering (including timber construction); nanotechnology; computer simulation and mathematical modelling. The 2011 strategy bundles activities in these fields under three major leading themes: i) mobility, ii) eco-technology, and iii) health technology. The central aim is to focus on future activities and to establish Styria as a "European benchmark for the structural change towards a knowledge based production-society".

BELGIUM

Since its two regions play a central role in Belgian policy making, the main nanotechnology activity in the country is carried by the regional government of Flanders, with a number of institutions working in the area of nanotechnology.

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[399] http://www.sozialministerium.at/cms/site/attachments/6/1/7/CH2120/CMS1371046721712/umsetzungsbericht_2012_en.pdf

[400] https://www.ffg.at/en

[401] http://www.bionanonet.at/about-bionanonet

[402] http://www.bionanonet.at/about-nanotoxicology?lang=english

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

Strategische onderzoekscentra[404] (SOC's) is a strategy of the Region of Flanders which gives institutional funding to four Strategic Research Centres that collaborate with the academic and business worlds. Each of the institutes have their own specific focus.

- Imec[405] is a leading European independent research centre in micro- and nano-electronics, *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[406], 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[407], 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[408] 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 program in order to support research projects in that field which led to the creation of **NanoWal**[409], 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[410]. It included four different sub-programmes in the areas of: nanoparticles, nano-fibres and nanocomposite materials; nano-biology and nanomedicine; 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[411], nanotechnology is addressed under the **Materials Research** priority, where it is set as an area to be supported by national budget to increase the global competitiveness of the Czech economy through products with high added-value.

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[404] http://www.ewi-vlaanderen.be/wat-doet-ewi/excellerend-onderzoek/strategische-onderzoekscentra
[405] http://www2.imec.be/be_en/home.html
[406] http://www.vib.be/en/Pages/default.aspx
[407] https://vito.be/en
[408] https://www.iminds.be/en
[409] www.nano.be/
[410] http://www.csnmt.cz/getfile.php?type=file&IDfile=24
[411] http://www.vyzkum.cz/FrontClanek.aspx?idsekce=1020

DENMARK

In Denmark, the Ministry of Higher Education and Science[412] has the main responsibility for research and innovation policy.

In the period from 2001 to 2004, steering groups set up by the Danish government carried out a Technology Foresight pilot programme. The aim of the programme was to carry out eight foresight studies in the three-year period, and to identify issues of strategic importance for science, technology, education, regulation and innovation policy in these areas. The foresight studies included bio- and health care technologies, and ICT (pervasive computing, future green technologies, hygiene and nanotechnology, especially nanomedicine[413]). The last phase of the foresight programme was closely linked to the establishment of the Danish National Advanced Technology Foundation[414] 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[415]** 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[416].

Since 2009, the Danish National Advanced Technology Foundation has channelled funding for projects in high-tech sectors, such as nanotechnology, biotechnology and ICT.

Support for nanotechnology research has been managed through a number of sources. The Danish Council for Strategic Research, part of the Danish Agency for Science, Technology and Innovation is one of these, although the council itself did not authorise funds for research, dependent instead on the Programme Commission, which covers Nanoscience, Biotechnology and IT (NABIIT). The Strategic Research Programme for the Interdisciplinary Applications of NABIIT technologies supported the establishment of networks and research initiatives. Research support also came from the Danish National Research Foundation, the Danish Ministry of the Interior and Health's inter-ministerial working group on Nanotechnology and Human Health, and the Danish National Advanced Technology Foundation. Latterly, also under the Danish Council for Strategic Research, the Programme Commission on Strategic Growth Technologies has had annual calls of total annual value approximately EUR 10 million for research projects on nanotechnology, biotechnology and information- and communication technology. In 2013, The Danish government and five political parties decided to revise the research and innovation system, agreeing to merge the Danish National Advanced Technology Foundation, the Danish Council for Strategic Research and the Danish Council for Technology and Innovation into a new innovation foundation. Thus, the new organisation

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[412] http://ufm.dk/en

[413] Danish Nano-science and Nano-technology for 2025, Foresight Brief No. 032

[414] http://www.tekno.dk/about-dbt-foundation/?lang=en

[415] http://ufm.dk/en/publications/2004/technology-foresight-on-danish-nanoscience-and-nanotechnology

[416] http://www.nano-vaccine.org/

Innovation Fund Denmark[417] (IFD), has been the responsible body since 2014.

FINLAND

The main focus areas of public research and development (R&D) funding in Finland are energy and the environment, health and well-being, the information and communications industry, the forest cluster, and metal products and mechanical engineering. Nanotechnology is treated as a technology to be applied across all these focus areas. Finland spends approximately 3.5 % of its gross national product on (R&D). Exploitation of research results being seen as even more important than the amount of investment, the Finnish innovation environment seeks to promote the exploitation of scientific and technological results in Finnish companies.

The main research policy decisions are drawn up in the Science and Technology Policy Council of Finland chaired by the Prime Minister. The principle instruments in the implementation of the policy are the funding organisations working under the ministries. Tekes, the Finnish Funding Agency for Technology and Innovation operates under the remit of the Ministry of Trade and Industry while the Academy of Finland is governed by the Ministry of Education. Nearly 80% of all public research funding is channelled through these two organisations.

The **first Finnish nanotechnology programme** was financed jointly by Tekes and the Academy of Finland in 1997–1999[418]. Its objective was to build know-how, multi-disciplinary infrastructure and linkages between fundamental and applied research. The programme also established a new form of co-operation using joint funding between Tekes and the Academy of Finland. The total value of the programme was EUR 7 million (Tekes EUR 4m, the Academy of Finland EUR 3 m).

FinNano, the Finnish nanoscience and nanotechnology programme, was established in 2005. The programme was co-ordinated jointly by Tekes and the Academy of Finland and covered the whole innovation chain from basic research to commercial products. The aim of the programme was to strengthen Finnish nanotechnology research in selected focus areas and to accelerate the commercial development of nanotechnology in Finland. The key objective was to boost internationally recognised high-level research and competitive business based on nanotechnology.

In addition to FinNano, the Ministry of Education provided funding to develop nanoscience education and infrastructure in Finnish universities and the Nanotechnology Cluster Programme was initiated in 2007 with the Centre of Expertise Programme. In total, Finnish public funding for nanotechnology during 2005–2010 was approximately EUR 235m.

In practice, the FinNano programme was executed in two parts: Tekes' FinNano – Nanotechnology Programme (2005–2009) and the Academy of Finland's FinNano – Nanoscience Programme (2006–2010). The Programme had a total value of approximately EUR 70m, including EUR 25m in research funding and EUR 20m in corporate financing from Tekes. The original programme plan defined three main focus areas:

1) Innovative nanostructure materials;
2) Nanosensors and nanoactuators; and
3) New nanoelectronics solutions.

In 2007, the aims of the programme were redefined as being for:

- Society: Renewal of industry clusters and production, environment and safety;
- Applications: Electronics, forest cluster, chemical sector, health and well-being; and
- Technologies: Nanostructured and functional materials, coatings and devices;
- Measurement methods, production and scalability.

According to a programme's interim evaluation in 2008, the main successes of FinNano were to activate companies in research and product development, to map all the existing nanotechnology infrastructure and to create cross-cutting networks of nanotechnology professionals.

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[417] 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

[418] http://www.tekes.fi/globalassets/julkaisut/research_and_technology.pdf

In 2011, the final report on FinNano was published, showing the results of the Programme[419]. According to that report and an independent evaluation by Gaia Consulting Ltd., all the Finnish nanotechnology programmes succeeded and fulfilled their objectives, which ranged from capturing knowledge in nanoscience and technology to boosting Finnish nano research and business. The next steps in the development of nanotechnology for industry in Finland were recommended to be achieved by other means. These included measures to enhance technology transfer, encouragement of entrepreneurship, and seed funding and basic research funding based on problems and not in disciplines.

In more recent years, Finland has therefore stopped identifying nanotechnology as a separate area for funding, opting to fund it under general R&D funding programmes and actions to enhance technology transfer and commercialisation by industry in Finland.

FRANCE

In 1999, the "**French Research Network in Micro and Nano Technologies**" (RMNT) was created for the purpose of strengthening and reorganising micro- and nano research and aligning it with the private sector.

In 2003, a **network of major technology centres** was created, linking together the facilities at the following organisations:

- *CEA-LETI*[420] in Grenoble (centred in Minatec);
- The *Laboratoire d'Analyses et d'Architectures des Systemes*[421] (LAAS) in Toulouse ;
- The *Laboratoire de Photonique et de Nanostructures*[422] (LPN) in Marcoussis ;
- *The Institut d'Électronique Fondamentale*[423] *(IEF) Orsay,* in Minerve; and
- The *L'Institut d'Electronique, de Microélectronique et de Nanotechnologie* [424] (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**[425]) 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**[426] (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

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[419] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf
[420] http://www-leti.cea.fr/en/
[421] https://www.laas.fr/public/
[422] http://www.lpn.cnrs.fr/fr/Commun/
[423] http://www.ief.u-psud.fr/
[424] http://exploit.iemn.univ-lille1.fr/
[425] http://www.agence-nationale-recherche.fr/suivi-bilan/historique-des-appels-a-projets/appel-detail1/programme-national-en-nanosciences-et-nanotechnologies-pnano-2005/
[426] http://www.gouvernement.fr/investissements-d-avenir-cgi

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 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**[427]" 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**[428] in 2006. This was done through the **Nano Initiative—Action Plan 2010**[429], 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**[430], 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

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[427] http://d-nb.info/97392179x/34

[428] http://www.research-in-germany.org/en/research-landscape/r-and-d-policy-framework/high-tech-strategy.html

[429] http://www.cleaner-production.de/fileadmin/assets/pdfs/Nano_initiative_action_plan_2010.pdf

[430] http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf

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 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)[431]: 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

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[431] https://www.cluster-bayern.de/en/

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.

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)[432]**. 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[433] 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

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[432] http://www.crann.tcd.ie/

[433] Forfás ceased to exist in 2015 and was, in part, subsumed under the Department of Jobs, Enterprise and Innovation.

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)[434],** a consortium of all Irish third level institutions with international leading research capability in nanoscience and nanotechnology. Furthermore, CRANN is also part of the Molecular Medicine Institute which is a not for profit company established by an extended network of Irish Universities and their associated academic hospitals. The BioNano Laboratory aims to facilitate and accelerate the translation of biomedical nanotechnology research into improved nanoscale diagnostics and nanomedicine.

In October 2013, a new Science Foundation Ireland funded research centre, **Advanced Materials and BioEngineering Research (AMBER)[435]** 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[436]), Delft University of Technology (with the **Else Kooi Laboratory**[437], previously called Dimes research centre on nanoelectronics) and the University of Groningen (with **BioMaDe[438]** focused on bio-nanotechnology). The early 2000s, these formed the core of **NanoNed** - the Nanotechnology R&D initiative in the Netherlands[439]. 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[440]**. The plan, prepared by the Interdepartmental Working Group 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

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[434] http://www.crann.tcd.ie/Research/Academic-Partners/testt.aspx
[435] http://ambercentre.ie/
[436] https://www.utwente.nl/mesaplus/
[437] http://ekl.tudelft.nl/EKL/Home.php
[438] http://www.biomade.nl/
[439] However, four other universities, and TNO, the Netherlands Organisation for Applied Scientific Research, are also represented.
[440] http://www.rritrends.res-agora.eu/uploads/27/8079721-bijlage%281%29.pdf

"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**[441] formed a consortium that built, maintained and provided a coherent and accessible infrastructure for nanotechnology research. NanoLab drew on government funding, which was first spent on upgrading existing infrastructure. Only when the existing infrastructure was fully used and a well-characterised additional need was identified and additional investment made. As a consequence, the Dutch nanotechnology research infrastructure was heavily used by research groups and the local industry. The partners in this enterprise considered themselves often as competitors but co-operate and co-ordinate their actions because of the substantial government funding.

In 2011, the **NanoNextNL**[442] 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**[443], 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**"[444]. 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

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[441] http://www.nanolabnl.nl/

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

[443] http://topsectoren.nl/english

[444] www.bioin.or.kr/fileDown.do?seq=5186

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 specialisation area in Poland.

PORTUGAL

In 2005, the Portuguese and Spanish Governments decided to jointly create the **International Nanotechnology Laboratory (INL)[445]** 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,

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[445] http://inl.int/

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**[446] to align Spain with the strategy of the European Union to reach a 3% of the GDP invested in R&D by year 2010, thereby reducing the gap between Spain and other countries. Its general objective was to achieve a gradual focus of Spanish resources on strategic actions to meet the challenges faced by the Spanish Science and Technology System. This was to be achieved by continuing the existing policies, agendas and successful programmes, as well as by implementing new actions needed to finish meeting the challenges identified for the national science, technology and engineering system.

In order to enhance critical mass and research excellence, the goals of the INGENIO 2010 Programme, within the **CONSOLIDER programme** (launched by the Ministry of Education and Science, through the General Secretariat of Scientific Policy, to promote high quality research and to reach critical mass and research excellence), included creating Centros de Investigación Biomédica en Red (Biomedical Research Networking Centres, CIBER) by setting up consortia, with their own legal personality, without physical proximity, which were designed to conduct single-topic research on a specific broadly-defined disease or health problem. CIBER were formed through the association of research groups linked to the national health system to help form the scientific basis of the programmes and policies of the national health system in the priorities areas of the National R+D+I Plan. Among the centres that have been created within this programme is the Biomedical Research Networking centre in Bioengineering, Biomaterials and ***Nanomedicine*** (CIBER-BBN), founded in 2006. The ***Nanobiomed consortium***, which researches the use of nanoparticles for drug delivery, was also founded with CONSOLIDER funds.

Between 2008 and 2011 the **National Strategy of Nanoscience and nanotechnology, new materials and new industrial products**[447] was implemented by the Ministry of Economy and Competitiveness. This policy measure was part of the National Plan for R+D+I 2008-2011[448] 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[449] and in the State Plan of Scientific and Technical Research and Innovation 2013-2016[450] (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)[451]: 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

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[446] http://www.ingenio2010.es/
[447] http://www.idi.mineco.gob.es
[448] Ibid
[449] http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_Strategy_Science_Technology.pdf
[450] http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_RDTI_Plan_2013-2016.pdf
[451] http://www.nanobasque.eu/aNBW/web/en/strategy/index.jsp

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 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[452]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[453] 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**[454] 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

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[452] https://www.gov.uk/government/organisations/innovate-uk

[453] https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative

[454] http://webarchive.nationalarchives.gov.uk/20130221185318/http://www.innovateuk.org/_assets/pdf/taylor%20report.pdf

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)[455]** was created with the objective of supporting the exploitation and commercialisation of MNT through informing, linking and facilitating innovation and collaborations between users and suppliers of nanotechnology in order to build a strong MNT community in the UK. The centres were grouped into four main themes: nano-metrology; nanomaterials (including health and safety); nanomedicine; and nanofabrication. Between its creation and 2014 the NanoKTN secured about £82million for UK industry, mainly focussed on SMEs, providing a good return investment on the initial input of £3million. In 2014, NanoKTN was merged with another 15 KTN in the new organisation KTN Ltd.

In 2006, the Engineering and Physical Sciences Research Council issued its **Report of the Nanotechnology Strategy Group[456]** 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[457]**”, 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[458]** 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[459]**. 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

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[455] https://connect.innovateuk.org/web/nanoktn

[456] https://www.epsrc.ac.uk/newsevents/pubs/report-of-the-nanotechnology-strategy-group/

[457] https://www.epsrc.ac.uk/newsevents/pubs/nanotechnology-programme/

[458] http://www.nibec.ulster.ac.uk/uploads/documents/nanoscaletechnologiesstrategy.pdf

[459] http://www.steptoe.com/assets/htmldocuments/UK_Nanotechnologies%20Strategy_Small%20Technologies%20Great%20Opportunities_March%202010.pdf

Nanotechnology Strategy Forum (NSF)[460] 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**[461] also addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.

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[460] https://www.gov.uk/government/groups/nanotechnology-strategy-forum

[461] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015

ANNEX 7: NANOMATERIALS COMPANIES – ADDITIONAL INFORMATION

There are no complete overviews of the size of the nanomaterials industry in terms of numbers of enterprises and employees. Data on the number of enterprises differ substantially between the various sources. Databases may contain companies that supply nanomaterials, but do not manufacture them. They may also contain organisations that produce nanomaterials but do not sell them commercially as products e.g. research organisations. Some databases are not quality controlled but rely on organisations to identify themselves, this being sufficient for them to be added to the database. In the NanoData project, only companies that manufacture and sell nano-related products were identified, via searches of published information including company websites. The information was checked against additional sources whenever there was any uncertainty.

A short summary of data available on the Nanora and Nanowerk databases follows.

The Nanora database contains companies identified by the NANORA partners in Belgium (Wallonia), France (Nord-Pas-de-Calais), Germany (Hessen and Saarland), The Netherlands (Southern Netherlands), Ireland and United Kingdom (North West England). Searching the database for companies supplying raw nanomaterials, the NANORA database generates 310 organisations, of which 123 are research organisations, 106 SMEs and 59 large firms. The others (145) are service providers and associations.

From the Nanora database, the 310 organisations supplying raw nanomaterials were found to be distributed as shown in the table below. In addition to the above caveat about the nature of the manufacturing organisation, the figures may include double counting as a producer can be listed in more than one category. Some organisations may also be producers that do not sell their products commercially.

Table: Number of actors active in nanomaterials in seven European regions[462]

Nanomaterial	# of actors in Nanora database
Raw nanomaterials	310
- Nanocoatings (incl. polymers)	123 (43 SMEs, 31 large firms)
- Nano dispersion	122 (42 SMEs, 24 large firms)
- Nanoparticles	176 (57 SMEs, 35 large firms)
○ Carbon (incl. graphene, fullerenes, diamond, carbon nanotubes)	39
○ Ceramic (incl. carbides, nitrides, oxides	80
○ Metals (incl. alloys, pure metals)	87
- Nanorods (incl. nanofibres, nanotubes, nanowires)	47 (10 SMEs, 4 large firms)
- Nanosheets and nanoplates	80 (22 SMEs, 16 large firms)
- Nanofluids	63 (11 SMEs, 7 large firms)
- Nanostructured materials	127 (33 SMEs, 24 large firms)

Source: http://www.nanora.eu/tinca/?field_tags_tid%5B%5D=1648
Note: Large firms = more than 250 employees in the Nanora database

The Nanowerk database of suppliers of nanomaterials includes 307 companies worldwide supplying nanomaterials. The table below presents an overview. Most companies are based in the USA. Within Europe, Germany has the largest number of companies supplying nanomaterials. It should be noted that these are suppliers of nanomaterials, not necessarily manufacturers of nanomaterials. Some are also producers but they do not sell their products.

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[462] http://www.nanora.eu/tinca/?field_tags_tid%5B%5D=1648

Table: Number of companies active in nanomaterials worldwide, by country and material type[463]

	Carbon nanotubes	Fullerenes	Graphene	Fibres / Wires	Particles	Quantum dots	Nanotubes
Argentina					1		
Australia	1				4		
Austria				1			
Belgium	2	1			1		
Brazil					1		
Canada	3	1	2		6	3	
Cyprus	1						
Czech Republic				1	1		
Estonia				1			
Finland	1				1		
France	1				4	1	
Germany	4	2		1	18	1	
Greece	1						
India	8	1	6	1	10	1	
Iran				1	1		
Ireland					1		
Israel						1	
Italy			1		1		
Japan	1	2	1	1	2		
Malaysia			1				
Netherlands			1		1		
New Zealand				1			
Norway	1		2				
Poland			1				
Portugal					2		
China	8		9		14		
Russia	1	1			1		
South Africa					1		
KR	1		2	3	9		
Spain	1	1	7	4	2	1	
Sweden			1		2		
Switzerland					3		
Taiwan	3						
Thailand					1		
Turkey	1	1	2	1	3		
United Kingdom	3	2	5		9	1	
Ukraine					1	1	
USA	35	11	19	16	72	10	2

Source: http://www.nanowerk.com/nanotechnology/nanomaterial/nanomatmatrix.php

Notes: The database contains double-counting – for instance, a producer of CNT and Fullerene would be listed in both categories. The category "nanotubes" contains non-carbon nanotubes such as boron or titania.

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[463] http://www.nanowerk.com/nanotechnology/nanomaterial/nanomatmatrix.php

ANNEX 8: PRODUCTS FOR NANOTECHNOLOGY MANUFACTURING

This Annex is divided largely into the same categories as used in the main body of the report:

1. Nanotools
    A. Nanomanipulators;
    B. Nanomachining tools;
    C. Microscopy; and
    D. Nanolithography
2. Nanomaterials
    A. Solid nanoparticles;
    B. Graphene;
    C. Carbon nanotubes;
    D. Nanostructured monolithics;
    E. Nanocomposites; and
    F. Thin films.

1 NANOTOOLS

A NANOMANIPULATORS

Product Name	Description	Producer
QFOCUS QF1 Single-Axis, Microscope Objective, Piezo Nanopositioning Stage	Aerotech's QNP™-series of piezo nano-positioning stages offer sub-nanometre-level performance in a compact, high-stiffness package. A variety of travel (100 µm to 600 µm) and feedback options make this suitable for applications ranging from microscopy to optics alignment. The QNP piezo stages are guided by precision flexures that are optimised using finite element analysis to ensure high-stiffness and long device life. The resulting design offers outstanding stiffness and resonant frequency enabling high process throughput and fast closed-loop response. Furthermore, these stages have been designed to provide excellent geometric performance (straightness and angular errors) while at the same time minimising the overall stage package size.	Aerotech
QNPHD Series Single-Axis, High-Dynamic Piezo Nanopositioning Stages		
QNP-L Series Single-Axis Linear Piezo Nanopositioning Stages		
QNP-XY Series Two-Axis, XY, Piezo Nanopositioning Stages		
QNP-Z Series Single-Axis, Z Piezo Nanopositioning Stages		
Micromanipulator miBot™	The miBot™ is the smallest nanometre resolution manipulator of the market. The use of piezo actuators in a revolutionary mobile motion technology makes the miBot™ both extremely precise and very easy to control. Diverse micro-tools can be mounted on the miBot™ tool holder, which makes it particularly well-suited for R&D applications in material science, microelectronics and photonics,	Imina technologies SA

	whenever *in situ* physical interactions with the sample are sought.	
3D-Nanofinger®	The 3d-Nanofinger used for Profilometres and Coordinate Measuring Machines	Klocke Nanotechnik GmbH
Nanorobotics	In the last years Klocke Nanotechnik and partners developed a new Nanorobotics system that builds a bridge between nanotechnology and the classical mechanical engineering. These products combine the advantages of both technologies: the backlash free movement with resolution of down to 2 nm and the capability of up to two kilogrammes of load at up to 70 mm stroke.	Klocke Nanotechnik GmbH
Bare Ring Actuators Without Preload - Series HPSt	Low temperature application; thermostable modification; laser adjustment; shock wave generation; sensor testing; test and acceleration damping; active vibration cancellation; fuel injection; active engine mounting; as well as all kinds of positioning tasks, which require high loads and/or extreme accelerations.	Piezosystem Jena GmbH
Piezoelectric PIA Impulse Generators	"PIA impulse generators provide fast accelerations to test objects, structures and materials. A special dielectrical piezoceramic is used for highly-effective piezo impulse generators with a high power density.	
Piezoelectric PiSha Shaker	Piezo shaker translates an electrical excitation signal directly into a motion. Due to the operating voltage of the shaker, the amplitude of the deflection is determined by the charging current and the speed of the shaker movement (in the sub-resonant mode). The internal structure of the shaker is adapted to the occurring high forces, pressures and accelerations. So the shaker achieves a reliable operation under oscillation at a continuous load.	
Ring Actuators with Preload - series HPSt VS	Low temperature application; thermostable modification; laser adjustment; shock wave generation; sensor testing; test and acceleration damping; active vibration cancellation; fuel injection; active engine mounting; as well as all kinds of positioning tasks, which require high loads and/or extreme accelerations.	
Stack Actuators without Preload - Series PSt		
Stack Type Actuators with Preload - Series PSt VS		

B NANOMACHINING TOOLS

Product Name	Description	Producer
RAVE Merlin® mask repair system	A precision production tool for subtractive removal of opaque mask defects, repairing defects on binary chrome on glass masks, alternating phase shift masks and both 248nm and 193nm halftone phase shift masks, carbon patch trimming, sequential defect removal as well as repair of “non-removable” particles and irregularly shaped quartz bump defects.	RAVE LLC

Femtosecond Laser Micro-nanomachining system	Femtosecond laser micro-nanomachining system for any material.	Tokyo Instruments

C MICROSCOPY

Product Name	**Description**	**Producer**
Cypher S AFM	With the Cypher™ atomic force microscope there are a range of critical benefits e.g. the third generation NanoPositioning System (NPS™) sensors are the quietest in the world today. With positioning accuracies better than 60 picometres in X, Y and Z, the AFM is used for measurements, positioning and nanomanipulation.	Asylum Research
MFP-3D Infinity	The Asylum Research MFP-3D Infinity™ atomic force microscope is the latest, most advanced AFM in the MFP-3DTM family. It combines higher performance, powerful new capabilities, and a new system architecture designed for future expansion.	
MFP-3D Origin	The MFP-3D Origin™ atomic force microscope marks the intersection of performance and affordability in the Asylum Research MFP-3D™ AFM family. Leading closed-loop AFM resolution and performance. Diverse applications, powerful results, such as polymers (morphology and nano-mechanics), electronic devices and other advanced materials (e.g. nanoscale failure analysis).	
MFP-3D-Bio	The Asylum Research MFP-3D-BIO™ integrates atomic force microscope and optical microscopy for bioscience research.	
Dimension FastScan	The Dimension FastScan atomic force microscope benefits from enhanced Nanoscale Automation. Dimension FastScan uses Bruker's new AutoMET™ software for the combination of high-resolution AFM imaging with fast, automated metrology.	Bruker Nano Surfaces
Dimension FastScan Bio AFM	The Dimension FastScan Bio™ atomic force microscope (AFM) breaks long-standing barriers to provide routine high-resolution research of biological dynamics, with temporal resolution up to three frames per second for live sample observations.	
Dimension Icon-Raman	High Performance AFM with co-localised micro-Raman Capability. The Dimension Icon AFM-Raman system, consisting of the Icon AFM and a research-grade confocal Raman microscope (Horiba, LabRam, etc.), is on a single, rigid, anti-vibration platform. This configuration allows the system to maintain each individual instrument's full functionality, providing optimum combined performance.	
MultiMode 8	Atomic force microscope for highest resolution imaging. Providing highest resolution imaging and quantitative material property mapping. Delivering MultiMode versatility. World's most published AFM. Powered by PeakForce Tapping technology to provide new information, faster results, and greatly improved ease of use. New quantitative material	

	property mapping is made possible using PeakForce QNM®, which analyses each tip-sample interaction to extract nano mechanical properties including modulus, adhesion, deformation, and dissipation.	
Flex-ANA — AFM for force mapping	Atomic force microscope for fully automated nano mechanical data acquisition and analysis. Key features and benefits include real-time, automated data collection and analysis, proprietary algorithm to cope with large variations in sample height, and is ideal for nano mechanical testing and force mapping of hard or soft, sticky or stiff, uneven or smooth, transparent or opaque samples.	Nanosurf AG
Flex-Axiom — AFM for materials research	Flex-Axiom is an atomic force microscope for materials research. It has measurement capabilities in air and liquid, versatility in applications and modes, compatibility with inverted microscopes and high precision scanning and data acquisition capability.	
Flex-Bio — AFM for life science	Flex-Bio is an atomic force microscope for life science, which offers seamless integration with inverted microscopes, advanced force spectroscopy investigations and correlate fluorescence, topology and biomechanical properties in a single package.	
FluidFM — Nano and cell manipulation	FluidFM is a Nanofluidic tool for single-cell biology and next-level nanomanipulation. It combines an Atomic Force Microscope with Cytosurge FluidFM® technology. Uses include: cell adhesion and spectroscopy mapping, single-cell manipulation and analysis, deposition and lithography even in liquid, injection and extraction, etc.	
LensAFM — AFM for optical microscopes	Atomic force microscope, extends the resolution of upright microscopes or 3D profilometres.	
NaioAFM — AFM for small samples	All-in-one atomic force microscope for small samples and education uses.	
NaniteAFM — AFM for large samples	Compact and mountable atomic force microscope for large-sample measurements. Easy and quick cantilever exchange and alignment reduces downtime. Automated batch measurements and scripting interface for system integration.	
Park HDM Series	The task of identifying nanoscale defects is a very time consuming process for engineers working with media and flat substrates. Park NX-HDM is an atomic force microscopy system that speeds up the defect review process by an order of magnitude through automated defect identification, scanning and analysis. Park NX-HDM links directly with a wide range of optical inspection tools, significantly increasing throughput.	Park Systems Corp.
Park NX-Bio	Life scientists want to see how biological materials look like at nanoscale resolution and how soft they are in liquid and buffer conditions. Park NX-Bio enables that with its innovative in-liquid imaging Scanning Ion Conductance Microscopy (SICM) and its highly acclaimed atomic force microscopy (AFM) technology.	

Park NX-Hivac	Park NX-Hivac allows failure analysis engineers to improve the sensitivity of their measurements through high vacuum Scanning Spreading Resistance Microscopy (SSRM). Because high vacuum scanning offers greater accuracy, better repeatability, and less tip and sample damage than ambient or dry N2 conditions, users can measure a wide range of dope concentration and signal response in failure analysis applications.	

D NANOLITHOGRAPHY

Product Name	Description	Producer
FleXform-ADC™	Complete development kit for flexible hybrid electronics. The FleXform-ADC is designed for developing and prototyping printed and/or flexible sensors integrated with physically-flexible ICs.	American Semiconductor Inc. (US)
FleX™	FleX™ Silicon-on-Polymer is a process for creating high-performance, single-crystalline CMOS with multi-layer metal interconnect on a flexible substrate.	
AMONIL®: nanoimprint resist	UV-curable nanoimprint resist (AMONIL®) and a matching adhesion promoter (AMOPRIME).	AMO GmbH Gesellschaft für Angewandte Mikro- und Optoelektronik mbH
Large Area Nanogratings	AMO offers gratings fabricated by in-house interference lithography (IL). The IL technology allows producing large, coherent and periodic gratings with nearly constant pitch. Pattern transfer and further processing can be carried out according to customer requirements.	
OptiStack® lithography system	Enabling the progression of Moore’s law beyond 20 nm, Brewer Science® OptiStack® systems are used for advanced lithography.	Brewer Science, Inc. (US)
Elionix ELS-F125 (125 kV)	The Elionix ELS-F125 Electron Beam Lithography system for fabrication of 5 nanometre linewidths. Offering an accelerating voltage of 125 kV, the ELS-F125 has dramatically increased throughput, reduced distortion in large write fields, and reduced footprint from previous generation models.	Elionix Inc
Elionix ELS-G100 (100 kV)	The Elionix ELS-G100 can generate patterns with a line width of 6nm. The system provides a stable 1.8nm electron beam using high beam currents at 100kV accelerating voltage. The system’s WindowsTM based Graphical User Interface (GUI) provides for ease of use in a diverse, multi-user environment.	
PhableR 100	Photolithographic Tool	Eulitha AG (CH)
EVG®510HE	Semi-automated hot embossing system	EV Group GmbH (AT)
EVG®520HE	Semi-automated hot embossing system	
EVG®620	Automated mask alignment system	
EVG®6200	Automated bond alignment system. Wafer-to-wafer alignment for subsequent wafer bonding applications.	

EVG®720	Automated UV nano-imprint lithography system	
EVG®7200	Automated UV nano-imprint lithography system	
EVG®750	Automated hot embossing system	
EVG®750R2R	Automated hot embossing system	
EVG®770	Automated NIL Stepper is designed for step and repeat large area UV-Nano-imprint Lithography (UV-NIL) processes compatible for 100 mm up to 300 mm wafers.	
HERCULES®NIL	UV-NIL Track System	
IQ Aligner®	The IQ Aligner µ-CP System allows for micro-moulding and nano-imprinting processes with stamps and wafers from 150 mm to 300mm diametre.	
Fountain Pen Nanolithography (FPN) MultiProbe system	The Fountain Pen Nanolithography (FPN) MultiProbe system is an SPM platform capable of both chemical nanolithography and online imaging with multiple probes.	Nanonics Imaging Ltd.
MultiView 4000	Providing up to four AFM systems in one, the MultiView 4000 system is a novel platform for the most advanced experiments in nanoscale transport, optical pump-probe, and read-write lithography. Access to multiple probes enables non-destructive characterisation, manipulation, and measurement of electrical, thermal, and optical properties of materials and electronic devices. With up to four probes that can be operated simultaneously and independently, the MV 4000 is a nanoscale probe station with feedback and scanning capabilities.	NANONICS IMAGING Ltd.
Photonic Professional GT	3D laser lithography system, Photonic Professional GT for 3D microprinting and maskless lithography. It combines two writing modes in one device: an ultra-precise piezo mode for arbitrary 3D trajectories (FBMS) and the high-speed galvo mode (MBFS) for fastest structuring in a layer-by-layer fashion. It allows for the fabrication of high-resolution photo masks and other direct write applications.	Nanoscribe GmbH
EZImprinting (EZI)	EZImprinting (EZI) is a super-high yield (> 99 %) nanoimprint lithography platform with sub-10nm resolution and one-step Auto Release™ function. EZI provides a bench-top, stand-alone nanoimprint platform: the AR-NTP-400/600.	NIL Technology
Nanoimprint Lithography	NIL Technology is engaged in the fabrication of stamps for nanoimprint lithography (NIL), performing nanoimprint services, nanoimprint pre- and post-processing and nanoimprint consultancy. NIL Technology's stamps are based on patent pending MEMS technology which generically ensures large are homogeneous imprints.	
Canion FIB	Focused ion beam system	Orsay Physics TESCAN ORSAY HOLDING
COBRA-FIB	Focused ion beam system	
ExB FIB	Focused ion beam system	

i-FIB	Focused ion beam system	
Ionfab 300Plus	Flexible ion beam (FIB) etch and deposition	Oxford Instruments
PlasmaPro Estrelas100	Deep silicon etch technology for MEMS applications	
Vistec SB250 electron beam lithography system	The Vistec SB250 electron beam lithography system has been designed as a universal and cost-effective tool for both direct write and mask making applications to allow the customers to react quickly to market demands. With its 210 x 210mm stage travel range, suitable for exposing masks up to 7 inch and wa nanoimprint fers up to 200 mm diametre.	Vistec Electron Beam GmbH
Vistec SB254	The Vistec SB254 is a high performance, universal and cost effective electron-beam lithography system (variable shaped beam/cell projection optionally), enabling the usage for both direct write and mask making for a large variety of applications in industry and applied research.	Vistec Electron Beam GmbH
Vistec SB3050 series	The Vistec SB3050 series - now with a cell projection option - is our commitment to semiconductor manufacturing professionals. Designed to meet the challenges of direct patterning down to the 32nm technology node, it features variable shape beam (VSB) technology with vector scan and continuously moving stage principles for throughput optimisation.	
Vistec SB351 system	The Vistec SB351 system has been developed for the 90nm node and features the 65nm R&D capability node. Thanks to its modular system architecture the SB351 variable shaped beam system is used for both mask making (incl. nanoimprint) and direct write. Fully automatic substrate handling and network-supported operation software allow production, prototyping and R&D work. Further highlights of the Vistec SB351 are the full 300mm wafer exposure capability and the fast data preparation software including proximity effect correction.	

2 NANOMATERIALS

A SOLID NANOPARTICLES

Product Name	Description	Producer
Alumina (Al2O3) nanofibres	Alumina nanofibres	ANF Technology
Nano alumina particles	Alumina particles	
NANOFIBRES	Carbon nanofibres	Goodfellow Cambridge Ltd.
AL606021	Alumina powder	
AU006022	Gold powder	
NC006010	Carbon - nano-materials – powder condition: nanoclusters, size : 50-100 nm	
SI516022	Silicon carbide - powder	

TI546005	Titanium carbide - powder	
DIA-HNP	High-quality diamond nanoparticles	Grafen
DIA-MNP	Diamond nanoparticles	
NRD-AU	Gold nanorods	
NW-AG	Silver nanowires	
NW-AU	Gold nanowires	
NW-CU	Copper nanowires	
NW-NI	Nickel nanowires	
NW-TIO	Titanium oxide nanowires	
CFQD® quantum dots	Cadmium and heavy-metal free quantum dots, called CFQD® quantum dots, are fluorescent semiconductor nanoparticles typically between 10 to 100 atoms in diameter.	Nanoco Technologies Ltd
CIGS and CIS nanoparticles	Nanoco has developed a range of CIGS and CIS (copper indium gallium di-selenide/sulphide, copper indium di-selenide/sulphide) materials that can be deposited much more economically using conventional printing techniques.	
GP01-10-100	Gold Nanoparticles, 10 nm, 0.01% Au, 100 mL	Nanocs Inc.
GP01-10-20	Gold Nanoparticles, 10 nm, 0.01% Au, 20 mL	
GP01-15-20	Gold Nanoparticles, 15 nm, 0.01% Au, 20 mL	
GP01-2-100	Gold Nanoparticles, 2 nm, 0.01% Au, 100 mL	
GP01-2-20	Gold Nanoparticles, 2 nm, 0.01% Au, 20 mL	
GP01-3-100	Gold Nanoparticles, 3 nm, 0.01% Au, 100 mL	
GP01-3-20	Gold Nanoparticles, 3 nm, 0.01% Au, 20 mL	
GP01-5-100	Gold Nanoparticles, 5 nm, 0.01% Au, 100 mL	
GP01-5-20	Gold Nanoparticles, 5 nm, 0.01% Au, 20 mL	
Aluminium Nanopowder	Elemental form	Nanoshel
Diamond Nanopowder	Elemental form	
Gold Nanopowder	Elemental form	
Graphite Nanopowder	Elemental form	
Nickel Nano Powder	Elemental form	
Tin Nanopowder	Elemental form	
Zinc Nano Powder	Elemental form	
Ceramic nanoparticles	Ceramic nanoparticles from Particular® offer more than conventional mass products: Using the laser process, nanoparticles can be produced from hard	Particular GmbH (DE)

	ceramics such as yttria-stabilized zirconia or alpha-corundum and are dispersed directly in water or solvents like acetone.	
XSnano fuel additive	NANO fuel additive, info on nano particles not disclosed	XSNANO LTD

B GRAPHENE

Product Name	Description	Producer
Epitaxial Graphene	Graphene specialists focusing on three key application areas – composites, energy generation and sensors. Provides a graphene testing, device prototyping and characterisation service.	2-Dtech
HSMG™ (High Strength Metallurgical Graphene™)	HSMG™ (High Strength Metallurgical Graphene™) shows very high mechanical strength and durability, up to double the tensile strain resistance of CVD (chemical vapour deposition). The company transfers graphene onto any desired substrate for industrial and laboratorial use.	Advanced Graphene Products
Graphene flakes, graphene transistors, catalytically-produced graphene and custom-made graphene substrates.	Material nanofabrication of graphene flakes, - graphene transistors, catalytically-produced graphene and custom-made graphene substrates.	AMO GmbH
Graphene powder	Graphene powder manufactured using a sustainable and proprietary ‘bottom-up’ process.	Applied Graphene Materials plc (UK)
Graphene materials	Graphene: annual capacity of 1.5 tons (expanding to 300 tons p.a.)	Deyang Carbonene
Super-expanded graphite, pristine GNPs, water-dispersed GNPs and fine nanographite powder	The company developed their own exfoliation process (which they call G+)	Directa Plus
Graphene materials	Graphene for the European market (five tonnes of graphene a year), produced at its first plant in Cambridge, UK with a patented process that is still limited to using methane gas. Now, the company is working towards setting up a Malaysian plant (with aims of finishing it by 2017) to serve Asia's graphene needs and produce nine tonnes a year.	Felda Global Ventures
Graphene flakes	Graphene flakes to be used in Li-Ion battery anodes. Aims to mass produce.	Grafentek
Graphene and Graphenstone	Graphene oxide, reduced graphene oxide, graphene sheets, graphene nanofibres.	Graphenano
Graphene: Bulk high quality graphene oxide,	Bulk high quality graphene oxide, reduced graphene oxide, pristine graphene. Mainly selling to academia	Graphene Leaders Canada

reduced graphene oxide, pristine graphene	and research companies. The company developed their own graphite-exfoliation method to produce graphene.	
"Silver Decorated Graphene	Graphene custom made to various specifications and on different substrates	Graphene Platform Corp
CVD-grown graphene products and related products	Graphene Square also markets a low-cost thermal CVD system enabling users to synthesize their own large-area, high-quality graphene samples in a lab environment.	Graphene Square
CVD grown graphene on foils and wafers, Q-Graphene, graphene nanopowder, graphene oxide, graphene in solution, and reduced graphene oxide.	CVD grown graphene on foils and wafers, Q-Graphene, graphene nanopowder, graphene oxide, graphene in solution, and reduced graphene oxide. Graphene Supermarket is operated by Graphene Laboratories.	Graphene Supermarket
SIC-S1-10-1	production of high quality graphene for industrial applications	Graphenea
Split Plasma treated carbon materials - graphene flakes/GNPs, graphene-based inks and CNTs	Surface engineering: Functionalisation via plasma gives the ability to add desired chemical groups, providing greater dispersion and compatibility between different matrices and nanomaterials resulting in enhanced product properties.	Haydale
Graphenol	Graphenol can be supplied with amine, amide, ester, carboxylic, or hydroxyl functional groups. The product Is delivered as a dispersion in surfactant free water or Organic solvent as predominately single or double sheets.	National Nanomaterials
Graphene materials	Ningbo Morsh Technology are supplying graphene to Chongqing Morsh Technology, who's using the graphene to produce 15" single-layer graphene films that will be used to produce graphene transparent touch panel conductive films.	Ningbo Morsh Technology
Graphene materials and surface modified graphene materials, tailed to customer specifications	Operates a functionalised nanomaterial manufacturing facility, with production with a capacity of 100 tons.	Perpetuus Carbon

C CARBON NANOTUBES

Product Name	Description	Producer
Multi-walled carbon Nanotubes.	The carefully selected catalysts and the precise control of reaction conditions used for the manufacture of nanotubes result in an ultra-high purity product (>99.5 %) containing no nanoparticles or other common impurities. MWNT	Catalytic Materials LLC

	have average widths of 6 nm can be dispersed in a variety of solvents.	
Baytubes®	Carbon nanotubes for increased power yields and ability to withstand hurricane-strength wind speeds –basis of the wind power systems Hybtonite® manufactured by Eagle Wind Power, Finland.	Covestro
M2701	High purity multi-wall nanotubes 99+% < 8 nm	HeJi Inc
M2702	High purity multi-wall nanotubes 99+% 8-15 nm	
M2703	High purity multi-wall nanotubes 99+% 10-20 nm	
M2704	High purity multi-wall nanotubes 99+% 20-30 nm	
M2705	High purity multi-wall nanotubes 99+% 30-50 nm	
M2706	High purity multi-wall nanotubes 99+% >50 nm	
M4901	Multi-wall nanotubes 95+% < 8 nm	
LitwWire	LiteWire is a carbon nano-tube conductor in wire form. LiteWire is a direct replacement for copper wire. It also replaces any other metallic conductor used today.	LitwWire
Multi Walled Carbon Nano Tubes(OD)	Sample purity of NANOSHEL MWCNT is 80-98 Vol%, as determined by Raman Spectrophotometer and SEM Analysis. Nanoshel Nano material contains no residual catalyst impurities. Tubes occur in bundles of length ~1 - 20µm. (±1.5µm) Individual tube length has not been determined	Nanoshel
Single Wall Carbon Nanotubes High Purity	These products are widely used in manufacturing of a mass of rather unorganised fragments of nanotubes. The products are formulated from high quality nanotubes, procured from well-known vendors. In addition to this, these products can be used for controlling nanoscale structures.	
Single Walled Carbon Nano Tubes (Amine Surface Modified)	Single walled carbon nano tubes (amine surface modified)	
Single Walled Carbon Nanotubes	Single walled carbon nanotubes	
SWCNT (fluorinated carbon nanotubes)	SWCNT (fluorinated carbon nanotubes)	
SWCNT (ultra pure)	SWCNT (ultra pure)	
SWCNT (boron nitide modified)	SWCNT (boron nitride modified)	

SWCNT (nickel modified high purity)	SWCNT (nickel modified high purity)	
Carbon Nanotube Dispersions	Tailor made to request	Nanostructured & Amorphous Materials, Inc. (Nanoamor)
Carbon Nanotubes and Nanofibres	Tailor made to request	
As produced Multiwall Carbon Nanotubes	ca. 55 wt% carbon nanotubes ca. 45 wt% graphite nanoparticles and graphitic impurities; Diameter distribution ca. 2 - 50 nm; Typical Length ca. 2 microns	n-Tec AS
Purified Multiwall Carbon Nanotube	ca. 80 wt% carbon nanotubes ca. 20 wt% graphite nanoparticles and graphitic impurities; Diameter distribution:	Purified Multiwall Carbon Nanotube
Carbon nanotube	Long carbon nanotubes	Q-Flo Ltd
Ros1	Short multi-walled carbon nanotubes	Rosseter Holdings Ltd
Ros2	Multi-walled carbon nanotubes	
Ros3	Multi-walled carbon nanotubes	
Ros4	Multi-walled carbon nanotubes	
Carbon Nanotube Fibres	CNT fibres have a thermal conductivity approaching that of the best graphite fibres but with 10 times greater electrical conductivity	Teijin Limited
Carbon Nanotube Fibres	Carbon nanotube fibres applied to a technique that uses carbon nanotubes to detect light in the terahertz frequency range without cooling, Improvements in MRIs, passenger screening, other image-detection applications on the horizon.	

D NANOSTRUCTURED MONOLITHICS

Product Name	Description	Producer
Airglass	Silica based aerogel	Airglass
Cryogel	Foam-like hydrophobic aerogel	Aspen Aerogels Inc.
Pyrogel	Foam-like hydrophobic aerogel	
Spaceloft	Foam-like hydrophobic aerogel	
Nanogel Thermal Wrap	Silica based aerogel	Cabot Corporation
Nafion	Nanoporous fuel cell membranes	E. I. Dupont De Nemours and Co.
Fixit 222 Aerogel High-Performance Insulating Plaster	Silica based aerogel	Fixit AG
NANOGEL	Is a new material, it is in solid state; between 90 to 99.8% of its composition is air. NANOGEL properties: Low refractive index. Low density,	Graphendis

	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.	
NANOPERM Softmagnetic Alloy	NANOPERM® is a rapidly quenched iron based alloy with a fine crystalline microstructure. The typical grain size is only 10 nanometres - this is why the material is called 'nanocrystalline'. This fine material structure is the reason for soft magnetic properties that can be controlled in a wide range by an annealing process under the presence of external magnetic fields.	Magnetec GmbH
Aerogel	Silica based aerogel	MarkeTech International Inc.
HP-150	VIP-based areogel	NanoPore
HT-170	VIP-based areogel	
Aerogel	Silica based aerogel	SEPAREX S.A.
Quartzene®	Silica based aerogel	Svenska Aerogel AB
VITROPERM Nanomagentic Alloy	Nanocrystalline alloys VITROPERM are materials based on Fe, Si and B with additions of Nb and Cu. They are produced via Rapid Solidification Technology as a thin ribbon, initially in the amorphous state and then crystallized in a subsequent heat treatment around 500 - 600°C. This gives rise to an extremely fine-grained microstructure with grain sizes of 10 nanometres - hence the name nanocrystalline.	VAC Vacuumschmelze
Thermoskin	Silica based aerogel	Vinzenz Harrer GmbH

E NANOCOMPOSITES

Product Name	Description	Producer
Hybtonite®	A system of low viscosity, solvent-free carbon nano-epoxy resins.	Amroy Europe Oy
Cerablak coating	Coating for a broad range of applications: corrosion protection, hydrophobic/non-wetting/non-stick surfaces, high temperature oxidation protection, high emissivity coatings, protection for molten metal processing equipment, and protective coatings for bio-ceramic materials. A new family of nanocomposite films and materials can be produced with encapsulated nano-inclusions, within a Cerablak™ matrix, of varying chemistries to induce/enhance desirable optical, mechanical, electrical, and chemical properties.	Applied Thin Films
Altuglas ShieldUp	50% lighter than traditional glass, the nanostructured acrylic glass combines PMMA and a nanostructured elastomer. Shock-resistant and excellent chemical resistance.	Arkema

Ultradur High Speed	Ultradur High Speed PBT (polybutylene terephthalate) has significantly improved flow properties delivering measurable benefits over standard PBT grades in a variety of applications. Depending on the glass-fibre content, it flows nearly twice as far as comparable standard Ultradur PBT grades. The key to this flow improvement lies in the nano-structured additive developed specifically for PBT. The good flowability of Ultradur High Speed makes the production of injection-moulded plastic components less expensive and helps to save energy. These factors qualified the material to receive an eco-efficiency label from BASF, awarded to products that perform better from an environmental and financial standpoint than comparable products.	BASF
NANOBYK-3650 Additives	The silica nanoparticles of the NANOBYK®-3650 product family are uniformly distributed within the coating and work like a shock absorber system. Their interaction absorbs impact energy, preventing any damage to the coating. In addition to elasticity, the coating has a consistent hardness, with both qualities together providing optimum long-term protection.	BYK
CETOSIL Acrylate Nanocomposite Coatings	A series of acrylate nanocomposite coatings that contain up to 30 % of nano-sized silica. The use of special surface grafted silica nanoparticles ensures the transparency and low viscosity of the coatings. Based on a new, worldwide patented technology for surface grafting of silica nanoparticles, acrylates can be filled with up to 50% silica. The resulting formulation shows no undesired increase in viscosity or abrasiveness. Radiation-cured acrylate nanocomposite coatings show excellent mechanical and viscoelastic properties.	Cetelon
Pleximer	The nanocomposite market is limited by the small number of manufacturers that have invested in the know-how and the specialised equipment necessary to run platy nanoclays. Pleximer technology enables manufacturers to produce nanocomposites with existing equipment. NaturalNano is currently focused on leveraging this new drop-in, turnkey product to a select number of industrial compounders who supply major industries such as automotive, performance sporting goods and aerospace. It is expected that a substantial number of manufacturers who cannot currently produce a nanoclay composite will enter the nanocomposite market by adopting Pleximer as their nanomaterial of choice.	NaturalNano
Nanomyte	Nanomyte coating additives are designed for use in urethane, epoxy, and silicone formulations. PC-10 nanomaterials are specially designed additives for thermoset coatings (e.g., polyurethane, nitrocellulose and epoxy). The addition of PC-10 leads to dramatic improvement in desirable mechanical properties without affecting the	NEI Corporation

	intrinsic properties of the thermoset polymer, such as gloss and transparency. Specially formulated for aqueous fluoropolymer coatings, Nanomyte PC-20 is easily incorporated into commercial coating formulations. Wear resistance is dramatically improved with only a small additive loading. Ideal for demanding applications and severe environments. PC-20 nanomaterials are specially designed as additives for thermoplastic resins, such as PVC, PTFE, and others. Small additions of PC-20, supplied as a dispersion in a solvent, can lead to dramatic improvements in the mechanical properties of our customers' thermoplastic coatings.	
Teslan CNT	Teslan carbon nanotube formulation is a major advancement in the battle to conquer corrosion in oil and gas, military, transportation and other critical applications e.g. on offshore platforms, storage tanks, water-control structures, bridges, over-the-highway trucks and trailers, off-highway equipment and other steel structures. Teslan is formulated to exceed current levels of performance from conventional three-coat primer and paint jobs and reduce rust-fighting costs.	Tesla Nanocoatings

F THIN FILMS

Product Name	Description	Producer
Sun Control Window Films	3M Ceramic Series films bring low reflectivity, high clarity and outstanding heat reduction, to save energy while keeping the interior cool. Using nanotechnology, ceramics have been developed and used to create a film that is tough, does not corrode and is clear.	3M
SAMP Technology	Aculon's proprietary "Self-Assembled Monolayer of Phosphonates" (SAMP) methodology can coat surfaces to impart hydrophobicity, adhesion or corrosion inhibition.	Aculon, Inc. (US)
UNCD®	UNCD is ADT's brand name for a family of thin film diamond products. ADT's standard UNCD Wafers are wafer-scale diamond products, used for MEMS development, tribological testing, and unique nano-scale processing applications.	Advanced Diamond Technologies, Inc. (US)
nAERO	Beneq aerosol A-R coatings for solar PV and CSP applications.	Beneq Oy
DuraSeal Nanocoatings	Applied to pipes, tubing, couplings, valves and other specialty items, DuraSeal's specialty coatings provide customized solutions to abrasion and corrosion problems that have plagued the oil and gas industry for decades.	Duraseal
DIA-CVD	Nanocrystalline CVD diamond on silicon	Grafen
Clarity Defender® Plus	Water-repellent, non-stick transportation glass coating increases all-weather visibility, cleanability.	Nanofilm

Clarity PermaSEAL®	Ideal for protecting clear lenses of different materials while preserving optical qualities. Optically clear, this nanofilm provides an invisible protective shield that won't affect surface light transmission, performance or function. It resists scratching and abrasion and is both hydrophobic and oleophobic to block soiling and ease cleaning.	
Clarity PermaSEAL® SC47V	Soil resistant to preserve the optical qualities of lenses of different materials. This protective nanofilm offers the highest level of hydrophobic and oleophobic properties for soil resistance and easy cleaning. This UV resistant formula also shields surfaces from abrasion and marring.	
Clarity UltraSEAL® AB5	This optically clear, self-assembling nano-dimensional film protects bare and coated glass and ceramics from abrasion and scratching, marring, staining and chemical erosion. It also helps prevent build-up of soils and imparts easy-clean properties for efficient removal of fingerprints, oily smudges and soils.	
Clarity UltraSEAL® ABW	This optically clear, self-assembling nanofilm shields bare and anti-reflective coated glass against damaging contaminants, chemical erosion, abrasion and scratching with the highest level of hydrophobic and oleophobic performance. Formulated for outdoor use, it withstands extended UV exposure, acid rain and other environmental attack.	
Clarity UltraSEAL® OHC	When applied to either bare glass or anti-reflective coated glass, this optically clear, self-assembling nanofilm chemically bonds to the surface for long-lasting durability in high-use application. It protects surfaces from scratches, mar marks, stains and chemical erosion from environmental contaminants.	
Relisse® 2520	Relisse forms a durable, quick-release nanofilm on glass moulds used in casting plastic and composite products, such as plastic lenses, aircraft windows and composite components so articles release quickly and cleanly. Relisse chemically bonds to the surface, so it does not transfer to the moulded part, ensuring smooth, defect-free results. The hydrophobic formula also seals the mould's surface against contaminants and facilitates easy cleaning.	
TuffTek®	TuffTek® is the internationally recognized surface engineering platform innovation incorporating NanoMech's patented and patent pending nano-manufactured coatings	Nanomech (US)
Graphene Film	Tailor made to request	Nanostructured & Amorphous Materials, Inc. (Nanoamor)
Pilkington Activ	The Pilkington Active self-cleaning glass range is based on a 15nm thick thin-film coating of titanium dioxide. Other varieties of Pilkington Active offer additional features like solar control and low-emissivity energy-saving glass.	Pilkington Glass

Chromium sputtering targets	The hard material coatings chromium (Cr) and chromium nitride (CrN) optimally protect engine components such as piston rings against premature wear and consequently extend the useful life of important engine parts. Chromium is used as a bonding layer for DLC coatings (Diamond-Like Carbon), for example on bucket tappets.	Plansee SE
CuGa sputtering targets	Many CIGS manufacturers use copper-gallium (CuGa) or copper-indium-gallium (CuInGa) sputtering targets for the deposition of the absorber layer. Compared to the co-evaporation method, the sputtering process is more stable, achieves improved material utilisation and makes it possible to produce uniform layers more easily.	
CuInGa sputtering targets	Sputtering targets	
Molybdenum sputtering targets	Molybdenum coatings are the crucial components of the thin-film transistors used in TFT-LCD screens. Molybdenum layers are also used as back contacts in CIGS solar cells.	
Molybdenum-Sodium sputtering targets	The range includes MoNa sputtering targets with a sodium content of 5 % and 10 %. This corresponds to 1.3 and 2.6 % by weight.	
Molybdenum-Tantalum sputtering targets	Both during the production process and as a component in the future displays, these layers are exposed to atmospheric humidity and perspiration from the user's hand. The answer to corrosion: PLANSEE's molybdenum-tantalum solutions.	
Titanium and zirconium coatings sputtering targets	Titanium and zirconium coatings are applied using the reactive magnetron sputtering or the arc evaporation process. We supply both materials as sputtering targets and arc cathodes in all common sizes and formats.	
SGG Nano	SGG NANO is a high performance coated glass with advanced energy efficient solar control and thermal insulation (low e) properties.	Saint-Gobain Glass
TitanCoat™	Multi-layer, defect-free, ultra-smooth, hard coatings	UES, Inc. (US)

ANNEX 9: HUMAN HEALTH AND SAFETY

INTRODUCTION

Exposure to chemicals during nanotechnology manufacturing processes may be quite diverse. In this report, the safety evaluation will be limited to the engineered nanoparticles intentionally produced.

The nanoparticles that are used or produced in nanotechnology manufacturing processes are listed in the Table: *Hazard bands for selected nanoparticles*. Furthermore, five categories of manufacturing techniques were identified. Since no information was available on which nanoparticles are produced in which category of techniques, all combinations of nanoparticles and technique categories will be evaluated.

The basis for the evaluation will be the "Stoffenmanager Nano" application developed by TNO (Van Duuren-Stuurman, et al. 2012). In short, Stoffenmanager Nano is a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios. This tool combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. "Stoffenmanager Nano" does not contemplate the dermal and oral routes of exposure. The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in production facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries (ECHA 2012). 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 safety are covered.

Currently version 1 of Stoffenmanager Nano is being updated with recent data and insights. The hazard of six metal oxide nanoparticles has been reassessed and their hazard bands have been updated. This revision, which follows the hazard assessment methods established by van Duuren-Stuurman et al. (2012), but makes use of more recent toxicity data, has been published in a TNO-report (Le Feber, et al. 2014). Hazard bands for the nanoparticles, as listed in the table *Hazard bands for selected nanoparticles,* are taken by preference from this report and, if not available in that report, from van Duuren-Stuurman et al. (2012). If a nanoparticle in the list has not been evaluated in either publication, data were collected from public literature to derive its hazard band.

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 manufacturing 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.

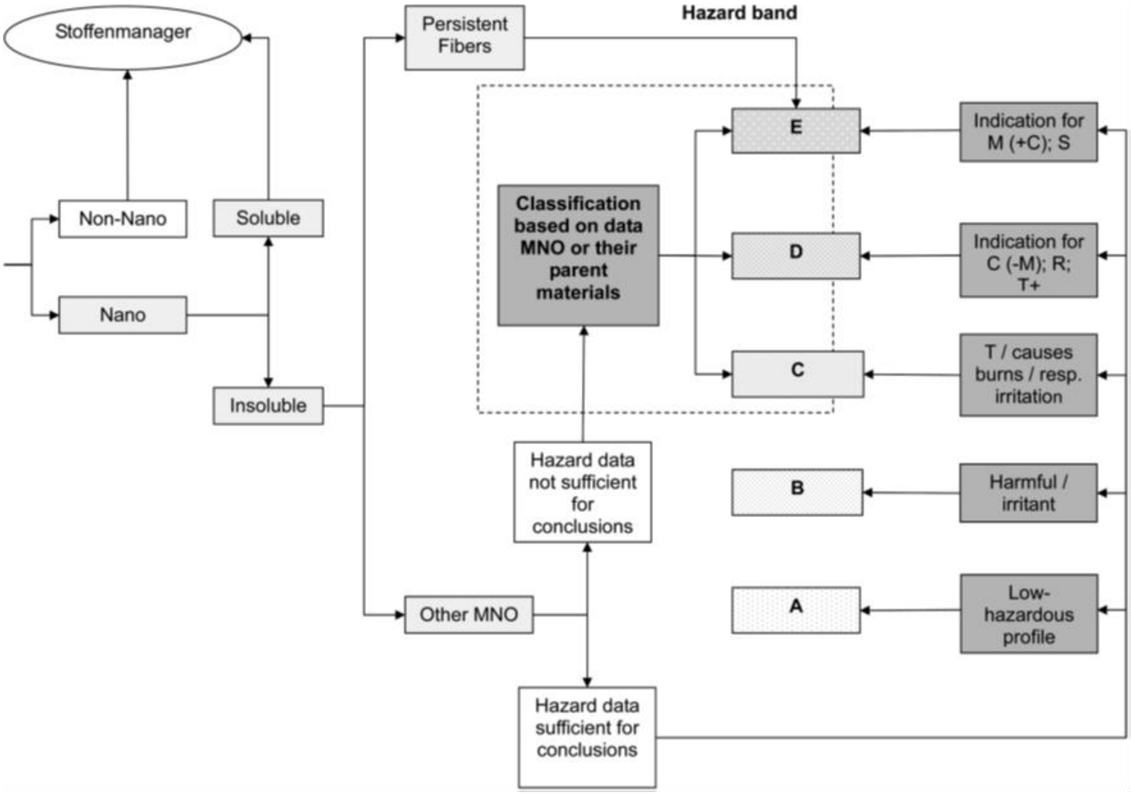

Figure 1: The stepwise approach of hazard banding of Stoffenmanager Nano (Van Duuren-Stuurman, et al. 2012)

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).

SINGLE- AND MULTI-WALLED CARBON NANOTUBES

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). Multi-walled carbon nanotubes (MWCNTs) have shown systemic immunological and inflammatory responses after short-term inhalation exposure (El-Ansary, et al. 2013, Yildirimer, et al. 2011). In the case of short to medium term pulmonary exposures to SWCNTs or MWCNTs in rodents, no tumours were reported. Cellular responses and gene expressions in these studies showed significant effects associated with lung cancer (Zhao and Castranova 2011).

Several studies have shown the potential for MWCNTs to act like the persistent fibres of asbestos, causing thoracic inflammation and fibrosis (NIOSH 2013, USEPA 2013). Additionally, MWCNT have been shown to penetrate into the alveolar region of the lung and to cause inflammation due to accumulation of alveolar macrophages. These biological events have been shown to lead to mesothelioma, although MWCNT have not been demonstrated to *de facto* cause mesotheliomas. Still the weight-of-evidence for certain types of MWCNT (e.g., those with high aspect ratios) is increasing:

mice injected with long (> 15 µm) MWCNT or asbestos showed significantly increased granulocytes in the pleural lavage, compared with the vehicle control at 24 hours post exposure. 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/cm^2) MWCNT caused a higher fold increase in cell migration and invasion than crocidolite asbestos (c. 3- and 2-fold, respectively). Also asbestos and rigid, high-aspect-ratio CNT activated the NLRP3 inflammasome to the same extent (Palomäki, et al. 2011). The NLRP3 believed to play a central role in inflammatory diseases (Abderrazak, et al. 2015). Frustrated phagocytosis is believed to be the trigger for the chain of events leading to mesotheliomas; in order to be able to cause this phenomenon fibres need to be biopersistent and longer than 5 µm (Donaldson, et al. 2013). Concluding, flexible, rigid, high-aspect-ratio MWCNT may cause cancer in a similar fashion as asbestos and may be as potent in this respect.

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

CALCIUM CARBONATE

The substance calcium carbonate has been registered under REACH. The registrant has indicated that the substance has a nanoform and has provided separate information on the nanoform. Calcium carbonate, including its nanoform, has not been classified as hazardous by any route of exposure. EFSA has recently given a scientific opinion on re-evaluation of calcium carbonate (E 170) as a food additive. This opinion, concluded that "*the available data are sufficient to conclude that the current levels of adventitious nanoscale material within macroscale calcium carbonate would not be an additional toxicological concern*" (Sadiq, et al. 2012)*.* In view of this lack of toxicity, nanocalcium carbonate is not classified and therefore assigned hazard band A.

DENDRIMERS

The most successful early dendrimeric constructs were synthesised using classical linear, random coil polymers, such as polyethylene glycol (PEG), N-(2-hydroxypropyl)methacrylamide (HPMA) copolymers, poly(glutamic acid) (PGA), poly(ethyleneimine) (PEI) and dextrin (a-1,4 polyglucose), while more recently polyamidoamine (PAMAM;Starburstk) dendrimers and poly(propylenemine) (also called PPI, DAB; AstramolR) dendrimers have gained commercial success (Surekha, et al. 2012).

Many in vitro studies have shown toxic effects for almost all of dendrimeric nanopolymers, depending on particle size, shape, coating and many other factors (Duncan and Izzo 2005, Jain, et al. 2010). When they display clear toxicity, it is mostly associated with cationic dendrimers disrupting the cell membrane, e.g. the 5.0G PPI dendrimer has a 24h-EC_{50} for HEPG2 cells between appr. 10 and 1 µg/mL and a 72h-EC_{50} < 1 µg/mL (Jain, et al. 2010). At concentrations around 1 mg/mL, also clear haemolytic effects were observed in vitro (4 h incubation) with uncoated dendrimers, but not with coated ones (Jain, et al. 2010). Via the i.p route LD_{50} of 7.0 G PAMAM dendrimers is between 40 and 160 mg/kg in mice, while subchronic administration of 2.5 and 10 mg/kg bw did not result in mortality nor in renal damage. Based on the available data, no clear conclusion can be drawn with respect to dendrimer toxicity, but based on their membrane disruptive effects, it cannot be excluded they may cause serious health effects, especially after respiratory exposure. Since there is no indication of mutagenic effects, and they also do not seem probably as these polymers appear to destroy the cell membrane before they can reach the nucleus, this nanoparticle is assigned the one but highest hazard band, D.

COPPER INDIUM GALLIUM SELENIDE (CIGS)

Indium compounds are used in the semiconductor industry, in manufacturing flat panel displays and optoelectronics (including photovoltaics). Also in the recycling industry exposure to these compounds may occur, when reclaiming indium from spent indium-containing materials. Before 2006 mainly indium phosphide alone was used (Fowler, et al. 2010). Since then, the use of other indium compounds, amongst others copper indium gallium selenide (CIGS) has greatly increased (Fowler, et al. 2010). No toxicity data on copper indium gallium selenide are available from public literature or regulatory authorities. IARC has classified indium phosphide as probably carcinogenic to humans (Group 2A), based on sufficient evidence in experimental animals, but inadequate evidence in humans (IARC 2006). In view of the classification of another indium compound as carcinogenic, CIGS is assigned hazard band E, based on the precautionary principle.

COPPER OXIDE

CuO nanoparticles are positive in an in vitro Comet assay with human skin epidermal (HaCaT) cells, causing a dose dependent increase of tail DNA (Alarifi, et al. 2013). In vivo they induce micronucleated reticulocyte formation in mouse peripheral blood after an i.p. injection of nanoparticles (0, 1 and 3 mg/mouse) (Song, et al. 2012). Soluble copper salts have comparable effects, e.g. copper sulphate induces chromosome aberrations in chick (Bhunya and Jena 1996) and mouse (Agarwal, et al. 1990) bone marrow cells and in mouse spermatocytes (Fahmy 2000).

In public literature, there is still a lively discussion on whether the root cause of CuO nanoparticle cytoxicity is the release of cupric ions (Bondarenko, et al. 2013, Horie and Fujita 2011, Piret, et al. 2012, Privalova, et al. 2014) or a direct effect of the particle (Karlsson, et al. 2008, Midander, et al. 2009). However, cytotoxicity is in vitro firmly established. Bondarenko et al. (2013) made, amongst others, an inventory of CuO cytotoxicity to mammalian cells and derived a median EC_{50} of 25 mg Cu eq./L for CuO nanoparticles, based on 21 tests, while the median value of soluble copper salts is 53 mg Cu eq./L, based on 10 tests.

Comparative *in vitro* testing with mammalian cells showed that CuO nanoparticles are a more potent toxicant than many other metal oxides such as Al_2O_3 (Lanone, et al. 2009), CeO_2 (Lanone, et al. 2009, Rotoli, et al. 2012), $CuZnFe_2O_4$ (Karlsson, et al. 2008), Fe_2O_3 (Fahmy and Cormier 2009, Karlsson, et al. 2008, Sun, et al. 2012), Fe_3O_4 (Karlsson, et al. 2008, Sun, et al. 2012), TiO_2 (Karlsson, et al. 2008, Lanone, et al. 2009, Sun, et al. 2012) and ZrO_2 (Lanone, et al. 2009)), than SiO_2 (Fahmy and Cormier 2009, Sun, et al. 2012), than carbon nanoparticles and multiwalled carbon nanotubes (Karlsson, et al. 2008), and than microsized CuO particles (Cohen, et al. 2013).

All these cytotoxicity tests were executed with particles suspended in the test medium. However, Aufderheide et al. (2013) simulated in vivo respiratory exposure with A549 cells using the CULTEX system, in which the cells are exposed to air-borne particles. The authors tested a.o. copper(II) sulphate, copper(II) oxide, and micro- and nanoparticles. All copper compounds induced cytotoxic effects, most pronounced for soluble copper(II) sulphate. Micro- and nanosized copper(II) oxide also showed a dose-dependent decrease in the cell viability, whereby the nanosized particles decreased the metabolic activity of the cells more severely.

Concluding, in vitro CuO nanoparticles are a more potent cytotoxicant than many other metal oxide nanoparticles and than microsized CuO particles.

Only a few in vivo tests with CuO nanoparticles were available from public literature and none with the occupationally most important route: inhalation.

Sandhya Rani et al. (2013) intratracheally instilled the lungs of rats with phosphate-buffered saline (PBS) or CuO nanoparticles (50 nm, SA 29 m^2/g, crystalline shape, diametre and length <50 nm), or quartz silica particles at a dose of 1 and 5 mg kg^{-1} body weight. CuO produced a transient dose dependant increase of ALP, LDH, and total leucocytes count in BAL fluid. A dose dependant decrease in SOD and catalase values in exposed rats was observed compared to control at all post exposure periods. Histopathological examination of the lungs revealed a dose-dependent degeneration, fibrosis and granuloma formation in the nanoparticles exposed rats, 1 day after instillation. The effects had worsened 1 week after instillation. On all investigated parametres, the effect of quartz nanoparticles (no characterisation provided) was less pronounced than that of copper nanoparticles.

Cho et al. (2010) instilled CuO and other nanoparticles (CeO_2, TiO_2, carbon black, SiO_2, NiO, ZnO) into lungs of rats. All exposures were carried out at equal-surface-area doses. Only CeO_2, NiO, ZnO, and CuO were inflammogenic to the lungs of rats at the doses used (50 and 150 cm^2/rat, equivalent, respectively, to 172 and 515 µg for CuO). Both acute and more chronic effects were observed. The chronic inflammatory responses CuO treatment caused after 4 weeks were fibrotic/granulomatous inflammation.

Based on the available evidence, CuO nanoparticles are genotoxic in vivo, potently in vitro cytotoxic in comparison to many other metal oxide nanoparticles and are able to cause chronic inflammatory responses in in vivo instillation tests, a property they share with other metal oxide nanoparticles. The importance and severity of these effects when animals or humans are exposed via relevant routes (e.g. inhalation) cannot be assessed due to lack of data. Since there clear indications of mutagenicity, it is assigned to hazard band E.

GRAPHENE

Graphene is composed of sp^2-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).

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 (Fe_30_4), titanium dioxide ($Ti0_2$), silicon dioxide ($Si0_2$), zinc oxide (ZnO), indium (In), tin (Sn), core—shell zinc sulphate-coated cadmium selenide (CdSe (3) ZnS), and carbon nanotubes.

Intratracheal instillation of 50 µg GO in mice caused severe pulmonary distress 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, cell type, administration route (for in vivo experiments), dose, time of exposure, 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 safer 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.

MANGANESE DIOXIDE

No relevant toxicity studies on nano-manganese dioxide were encountered in public literature. It is insoluble in water and therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent material are used. Manganese dioxide is only classified for acute toxicity by the EU[464]. It is considered harmful if swallowed or inhaled. Based on this classification, the nanoforms should be assigned hazard band C, the lowest category a nanoparticle can be assigned just based on toxicity data for is non-nano parent compound (Van Duuren-Stuurman, et al. 2012).

NICKEL MONOXIDE (NICKEL OXIDE)

Horie et al. (2009) investigated the influences of ultrafine NiO particles on cell viability. Ultrafine NiO particles showed higher cytotoxicities toward human keratinocyte HaCaT cells and human lung

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[464] See http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/cl-inventory/view-notification-summary/67644

carcinoma A549 cells than fine NiO particles and also showed higher solubilities in culture medium.

Cellular responses induced by black NiO nanoparticles with a primary particle size of 20 nm, were examined in human lung carcinoma A549 cells. In vivo responses were examined by instillation of NiO nanoparticles into rat trachea. In vivo and in vitro oxidative stress was induced resulting in activation of antioxidant systems (Horie, et al. 2011).

No clear data on genotoxicity of nanoNiO was encountered in public literature, but the on-line REACH dossier on NiO[465] (presumably non-nano) contains quite a number of positive *in vitro* tests on cell transformation, mammalian cell gene mutation and DNA damage.

Cho et al. (2010) instilled NiO and other nanoparticles (CeO_2, TiO_2, carbon black, SiO_2, CuO, ZnO) into lungs of rats. All exposures were carried out at equal-surface-area doses. Only CeO_2, NiO, ZnO, and CuO were inflammogenic to the lungs of rats at the doses used (50 and 150 cm^2/rat, equivalent, respectively, to 55 and 164 µg for NiO). Both acute and more chronic effects were observed. The chronic inflammatory responses NiO treatment caused after 4 weeks were neutrophilic/lymphocytic inflammation.

Fujita et al. (2009) investigated the pulmonary effects of the inhalation of fullerenes compared with ultrafine nickel oxide particles. Rats were exposed whole-body to ultrafine nickel oxide (Uf-NiO) particles (0.2mg/m^3; 9.2×10^4 particles/cm^3, 59 nm diametre) during 6 h a day for 4 weeks (5 days a week).Pulmonary response in rats at 3 days, 1 month, and 3 months post-exposure was examined. Ultrafine nickel oxide particles induced high expression of genes associated with chemokines, oxidative stress, and matrix metalloproteinase 12, as well as mild infiltration of inflammatory cells, mainly neutrophils and alveolar macrophages, in alveoli and interstitial tissue at 3 days and 1 month after exposure. No granuloma, emphysematous change, or fibrosis was observed during the observation period. There were no significant differences in body, lung, liver, or brain weight Nodule-like lesions were observed in animals that were exposed to Uf-NiO particles at both 3 days (n = 2/5) and 1month (n = 1/5) post-exposure, but not in the fullerene exposed group. No histopathological abnormalities were observed in the liver, kidney, spleen, cerebrum, cerebellum, testis, or nasal cavity tissues in the exposed or control groups.

Morimoto et al. (2010) conducted a similar experiment on NiO and fullerene nanoparticles in which rats were exposed via installation and compared them to the inhalation study reported by Fujita et al. (2009). The effects observed in both study types were similar to each other. These data from the intratracheal instillation and inhalation studies also suggested that well-dispersed fullerenes do not have a strong potential for neutrophil inflammation (Morimoto, et al. 2010). Micron-sized nickel oxide nanoparticle agglomerates also induced a persistent inflammatory response in an instillation study with rats (Morimoto, et al. 2011).

Carcinogenicity studies reported for conventional NiO in the REACH dossier**Error! Bookmark not defined.** were clearly positive when administered i.p. or i.m. to mice and rats, while whole body inhalation carcinogenicity studies were equivocal in their results (mice) or slightly positive (rats)

Based on the available evidence NiO nanoparticles may be both mutagenic as well as carcinogenic. Therefore, this metal oxide nanoparticle is assigned to hazard band E.

STRONTIUM TITANATE (STRONTIUM TITANIUM TRIOXIDE)

No toxicity studies on nanostrontium titanate were encountered in public literature nor on its bulk parent compound. Therefore, no hazard banding can be derived.

VANADIUM PENTOXIDE (DIVANADIUM PENTAOXIDE)

No toxicity studies on nanovanadium pentoxide 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.

ZIRCONIUM DIOXIDE (ZIRCONIA)

In a cytotoxicity assay with MTT in THP-I cells exposed for 24 hours copper oxide nanoparticles

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[465] http://apps.echa.europa.eu/registered/data/dossiers/DISS-a21aae14-ff8a-0613-e044-00144f67d031/AGGR-680c9c02-81e3-4b19-bda5-a664834dee8b_DISS-a21aae14-ff8a-0613-e044-00144f67d031.html#GEN_MAT_ME_HD

appeared to be more toxic than zirconia nanoparticles (IC_{50} = 4-31 and 172-571 µg/mL, respectively) (Lanone, et al. 2009). No correlation between cytotoxicity and equivalent spherical diametre or specific surface area was found.

Slight dose dependent cytotoxicity was observed (80% viability at the highest concentration tested of 200 mg/L)) for micro- and nanoZrO_2 and nanoTiO_2 in NIH 3T3 cells (Karunakaran, et al. 2013). It should be noted that in this test microTiO_2 was more potent: 60 % viability at 200 mg/L.

Landsiedel et al. investigated the effects of 13 nanomaterials or micron-scale ZnO upon inhalation exposure to rats at aerosol concentrations of typically 0.5 to 50 mg/m^3 for five consecutive days (6 h/day) and observed the following :

- Eight nanomaterials ($BaSO_4$, SiO_2.acrylate, SiO_2.PEG, SiO_2.phosphate, SiO_2.amino, nano-ZrO_2, ZrO_2.TODA and ZrO_2.acrylate) did not elicit effects on the rat lung, and their (local pulmonary) NOAECs were at least 50 mg/m^3 (or at least 10 mg/m^3 if this was the highest concentration tested).
- SiO_2 without a surface layer, induced multifocal macrophage aggregates in the respiratory tract immediately after the exposure period that exacerbated towards a slight multifocal inflammation during the 3-week post-exposure period. Its NOAEC was 2.5 mg/m^3.
- Four nanomaterials (coated nano-TiO_2, coated nano- ZnO, nano-CeO_2 , Al-doped nano-CeO_2) evoked transient and concentration-dependent pulmonary inflammatory reactions that were only partially reversible during the two- or three-week post-exposure period. Their NOAEC was 0.5 mg/m^3 or below. The same applies to micron-scale ZnO, for which, however, no NOAEC was laid down since it was only tested at one (high) test substance concentration.
- SiO_2.acrylate induced splenetic alterations as extra-pulmonary effects, immediately after the final exposure, (for which, therefore, a systemic NOEC was set at 0.5 mg/m^3) and micron-scale ZnO and coated nano-ZnO moderate to severe necrosis of the olfactory epithelium. The splenetic effects were fully reversible within the post-exposure period, and the nasal cavity alterations partially reversible.

Based on this limited evidence, it appears zirconia nanoparticles are less potent inflammatory agents than e.g. ZnO and CeO_2, if they are at all capable of eliciting such effects. ZnO and CeO_2 are assigned hazard band B and C, respectively, therefore zirconia nanoparticles are assigned to hazard band A.

The table below presents an overview of selected nanoparticles in the manufacturing sector and their hazard bands, either taken from le Feber et al. (2014) or van Duuren et al. (2012), or derived in this report (see above).

Table 1: Hazard bands for selected nanoparticles

Nanoparticles	Hazard Band	Hazard Band Source
Aluminum oxide (alumina)	C	le Feber et al. (2014)
C60 (fullerenes)	D	van Duuren et al. (2012)
Calcium carbonate	A	This report
Carbon	Needs specification, may be carbon black, carbon nanotubes, fullerenes or graphene	
Carbon black	D	van Duuren et al. (2012)
Cerium oxide	C	le Feber et al. (2014)
Copper indium gallium selenide (CIGS)	E	This report
Copper oxide	E	This report
Dendrimer	D	This report
Gold	D	van Duuren et al. (2012)
Graphene	E	This report
Iron	D	van Duuren et al. (2012)
Manganese dioxide	C	This report
Multi-walled carbon nanotube (MWCNT)	E	This report
Nanoclay	D	van Duuren et al. (2012)
Nickel monoxide (nickel oxide)	E	This report
Silicon dioxide (silica), synthetic amorphous	C	le Feber et al. (2014)
Silicon dioxide (silica), crystalline	E	van Duuren et al. (2012)
Silver	D	le Feber et al. (2014)
Single-walled carbon nanotube (SWCNT)	E	This report
Strontium titanate (strontium titanium trioxide)	n/a	This report, no data
Titanium dioxide (titania, rutile, anatase)	B	le Feber et al. (2014)
Titanium nitride	D	van Duuren et al. (2012)
Vanadium pentoxide (divanadium pentaoxide)	E	This report
Zinc oxide	B	le Feber et al. (2014)
Zirconium dioxide (zirconia)	A	This report

EXPOSURE ASSESSMENT

IDENTIFIED CATEGORIES OF MANUFACTURING TECHNIQUES

Five categories of techniques to manufacture nanomaterials and nanostructures were identified, namely:

- Set A: Chemical vapour deposition, EBPVD, electrodeposition, electroplating, MBE, MOCVD, molecular beam epitaxy, physical vapour deposition, Sputter deposition, pyrolysis, atomic layer deposition (vapour/aerosol synthesis);
- Set B: Self-assembly;
- Set C: Lithography, Nanocontact printing, Laser ablation, Reactive ion etching, RIE (nano-etching);

- Set D: Sol-gel, solution phase synthesis, wet chemical synthesis (liquid phase synthesis);
- Set E: Ball milling (solid phase synthesis).

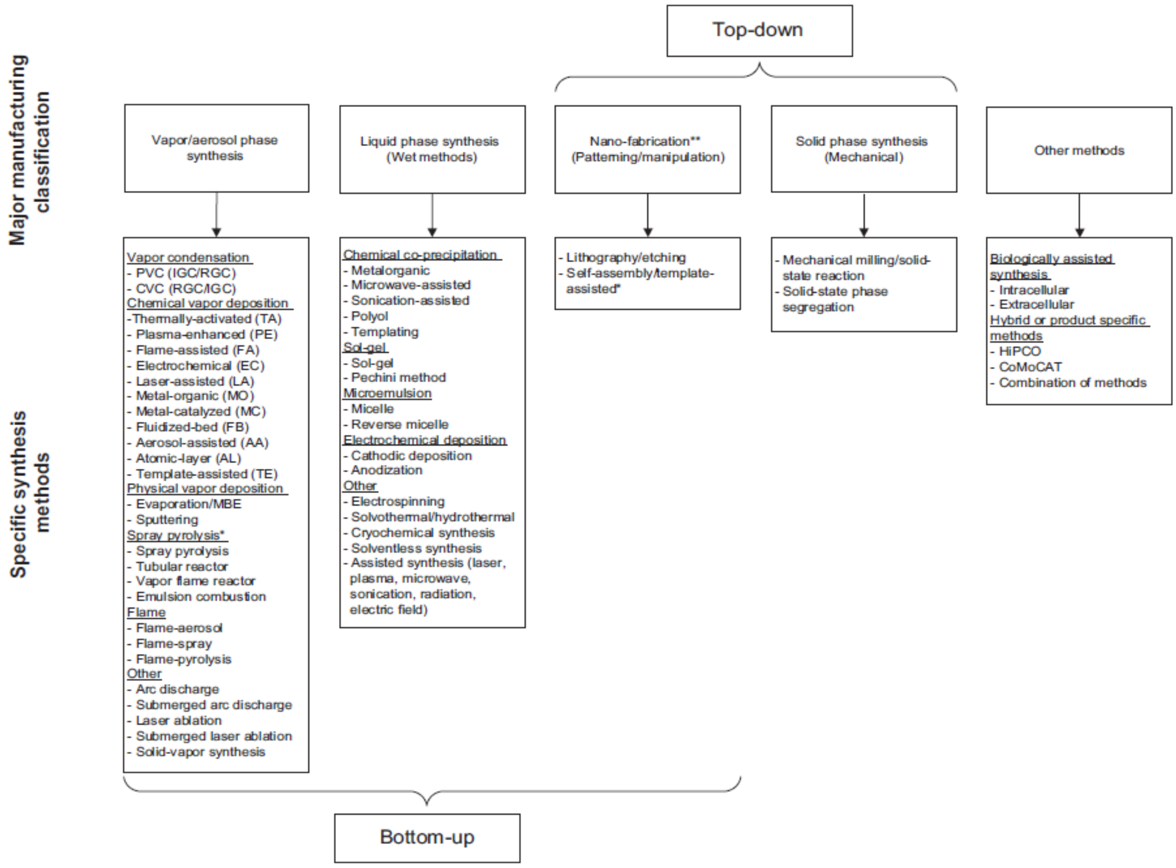
The likelihood of exposure to nanoparticles during synthesis, production and manufacturing processes is highly dependent upon the type of process and the type of equipment involved in the process. In some cases, due to physico-chemical or technical reasons, the process needs to be enclosed (e.g. during gas phase synthesis when an extremely low pressure or an inert atmosphere is required). Thus, the presence of an intrinsic barrier being part of the equipment might lead to lower observed exposures.

The predominant route of exposure is inhalation as the production processes are automatic and do not require a personal influence. Dermal and oral exposure become relevant during the collection and further use of produced nanoparticles. Consequently, the exposure which is described below for manufacturing is focusing on inhalation.

In “Stoffenmanager Nano” sets of exposure scenarios are assigned to exposure bands labeled 1 to 4 (1=low exposure, 4= highest exposure). In version 2 of Stoffenmanager Nano, the exposure bands 1 to 4 will be attributed according to the methodology described in ISO/TS 12901-1:2012 and 12901-2:2014 (ISO 2012, ISO 2014). This methodology has been applied to the manufacturing sets identified. The results are described in the sections below.

SET A (VAPOUR/AEROSOL SYNTHESIS)

According to Virji et al. (2014), in a review of engineered nanomaterial manufacturing processes and associated exposures, vapour/aerosol synthesis corresponds with Set A.



* Spray pyrolysis is technically a liquid phase method; ** Nano-fabrication include both top-down and bottom-up processes; PVC (physical vapor condensation); IGC (inert gas condensation); RGC (reactive gas condensation); CVC (chemical vapor condensation); MBE (molecular beam epitaxy); HiPCO (high pressure carbon monoxide reaction); CoMoCAT (cobalt molybdenum catalyst process)

Figure: A review of engineered nanomaterial manufacturing processes (From: Virji and Stefaniak 2014)

Furthermore, ISO (2012, 2014) published guidelines for occupational risk management applied to engineered nanomaterials with the use of the control banding approach. In the figure above, different manufacturing techniques were presented, including the expected level of workers exposure which is designated as an exposure band (EB, ranging from EB 1 the lowest exposure to EB 4 the highest exposure).

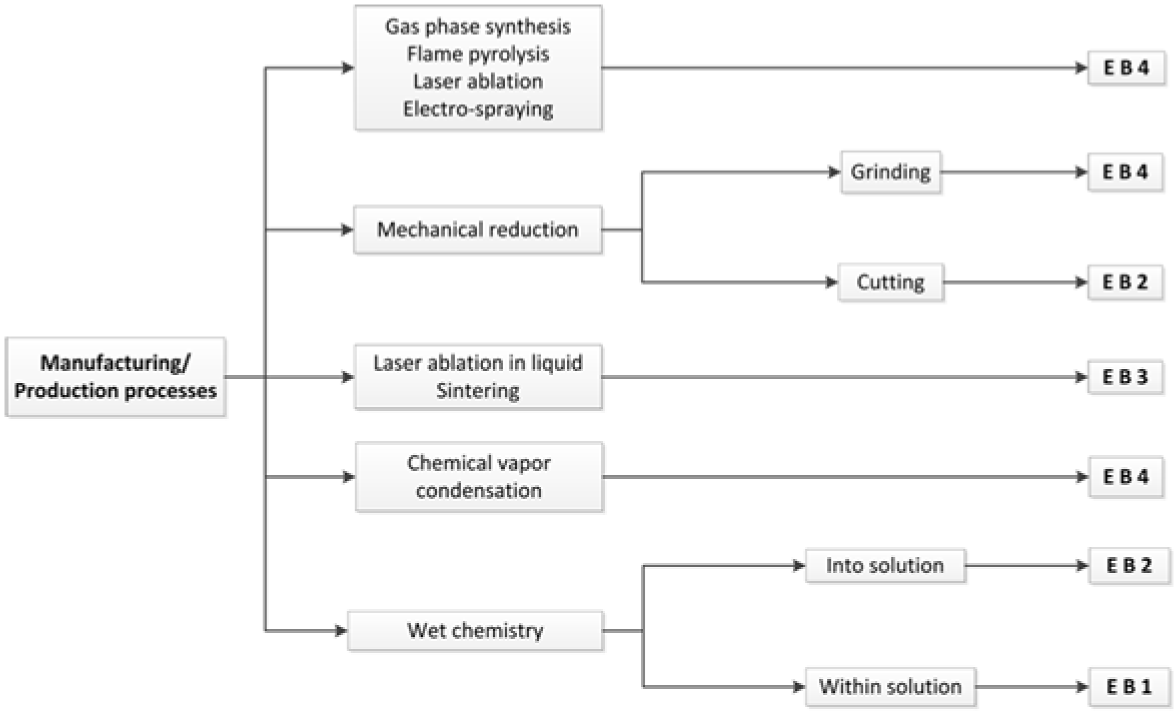


Figure: Exposure banding process – synthesis, production, manufacturing (From: ISO 2012, ISO 2014)

In the figure, gas phase synthesis, flame pyrolysis, laser ablation, electro-spraying and chemical vapour condensation are comparable to set A and have the highest exposure band (4). Several factors may affect the substances, structures and levels of exposure generated during vapour/aerosol-based processes. The type of chemical exposure is influenced by the various precursor materials, reactants, catalysts, stabilisers, purifying solvents, other additives as well as inert and reactive gases, fuels, and oxidisers. Exposure levels are influenced by a host of process factors such as energy source, temperature, pressure/vacuum, reaction vessel, gas flow rates, reaction times, physical states of input and output materials, post-processing such as grinding or size separation, chemical reaction, and substrate composition and characteristics.

The following conclusions can be drawn from peer-reviewed articles (reviewed in Virji and Stefaniak 2014) that performed an exposure assessment for vapour/aerosol phase synthesis:

- Starting a reactor/furnace warm-up results in an increase in particle number concentration;
- Increasing reactor temperature results in an increase in particle number concentration;
- Increasing distance from a reactor yields a decrease in particle number concentration;
- Particle number and/or mass concentrations increase during recovery tasks;
- Particle mass concentration increases during transfer from the reactor;
- Particle number and mass concentrations increase while manually dumping nanoparticles into containers;
- Specific activities associated with increases in particle levels include opening a reaction chamber, cleaning a torch or reaction chamber walls with a brush, and sweeping;
- Use of engineering controls such as fume hoods and enclosures reduces particle number concentration.

In general, the exposure potential for techniques to manufacture nanomaterials and nanostructures related to set A is affected by several factors, but is believed to be relatively high (Exposure band 4) (ISO 2012, ISO 2014, Virji and Stefaniak 2014).

SET B (SELF-ASSEMBLY)

Both ISO (2012, 2014) and Virji and Stefaniak (2014) focused on the evaluation of the production of purified nanoparticles and therefore, nanotechnology processes including self-assembly (set B) were not included. Self-assembly of nanoscale structures from functional nanoparticles has proven to be a powerful path to developing small and versatile electronic components. However, no peer-reviewed articles were identified, describing an exposure assessment regarding the techniques used to manufacture nanomaterials and nanostructures related to set B. Therefore, conclusions regarding the exposure potential based on references are not possible and consequently conclusions were based on expert knowledge. Self-assembly processes can be performed both on a solid and a liquid interface. Especially self-assembly on a solid interface only occurs with high external forces (magnetic, electric, or flow), which may result to a high exposure potential. However, as most self-assembly processes are using an liquid interface and the handled amount of product are very low, in general it is believed the exposure is relatively low (Exposure band 2).

SET C (NANO-ETCHING)

Both ISO (2012, 2014) and Virji and Stefaniak (2014) on the evaluation of the production of purified nanoparticles and therefore, nanotechnology processes including lithography (set C) were not included. Set C manufacturing techniques are nanotechnology processes, producing at a nanoscale with low quantities of nanoparticles, not per se resulting in products containing nanoparticles or even exposure to nanoparticles. Although no data was obtained from peer reviewed articles describing exposure assessments for these processes (and consequently conclusions were based on expert knowledge), the exposure potential to manufacture nanomaterials and nanostructures is believed to be low (Exposure band 2).

SET D (LIQUID PHASE SYNTHESIS)

Wet chemistry is similar to manufacturing processes in set D and are ranked within the lowest exposure bands (1 and 2). Compared to vapour phase synthesis methods, considerably less attention has been given to understanding factors that affect exposure during liquid phase synthesis (set D). This disparity may be partly because historical industrial hygiene experience with dusts has shown that exposures tend to be lower for wet processes compared to dry processes. The process-related factors that may affect exposure to these chemicals as well as to the ENM product, include the characteristics of the solutions and solvents used, energy added, chemical reactions, reaction vessel, drying temperature, substrate characteristics and composition, and post-processing treatment such as annealing, sintering, grinding, or size separation. In addition, the wide variety of chemicals used in the liquid phase methods as precursors, solvents, reactants (reductants, precipitants, gelling agents, etc.), catalysts, surfactants, stabilisers, washing solutions, and purifying solvents may result in worker exposure to a range hazardous substances. In general, the exposure potential for liquid phase synthesis is believed to be relatively low (Exposure band 1) (ISO 2012, ISO 2014, Virji and Stefaniak 2014).

SET E (SOLID PHASE SYNTHESIS)

Mechanical reduction and more specific is comparable to set E with ball milling and is ranked with the highest exposure band (4). No data is available on process factors that influence exposures to Nanoparticles among workers engaged in solid phase synthesis processes (set E). Some process factors that may be relevant include milling method, power, milling medium and whether it is performed wet or dry, milling speed, and time. Material factors that may be relevant include the structure of the ENM, dustiness, and chemical composition. For example, activities like ball-milling can generate high levels of dust if performed without a liquid solvent. Therefore, the exposure potential for techniques to manufacture nanomaterials and nanostructures related to set E is believed to be relatively high, but straightforward process changes reduce the exposure potential to a great extent (Exposure band 4) (ISO 2012, ISO 2014, Virji and Stefaniak 2014).

RISK ASSESSMENT

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table *Priority bands in the Stoffenmanager*. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures or to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 2: Priority bands in the Stoffenmanager

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Risks based on the hazard and exposure banding applied to the manufacturing sector are listed in the table below.

Table: Priority bands in the nanotechnology manufacturing sector

		Exposure band				
		Set A	**Set B**	**Set C**	**Set D**	**Set E**
Nanoparticle	**Hazard band**	**4**	**2**	**2**	**1**	**4**
Aluminium oxide (alumina)	C	1	2	2	3	1
C60 (fullerenes)	D	1	2	2	2	1
Calcium carbonate	A	2	3	3	3	2
Carbon	n/a	n/a	n/a	n/a	n/a	n/a
Carbon black	D	1	2	2	2	1
Cerium oxide	C	1	2	2	3	1
Copper indium gallium selenide (CIGS)	E	1	1	1	1	1
Copper oxide	E	1	1	1	1	1
Dendrimer	D	1	2	2	2	1
Gold	D	1	2	2	2	1
Graphene	E	1	1	1	1	1
Iron	D	1	2	2	2	1
Manganese dioxide	C	1	2	2	3	1
Multi-walled carbon nanotube (MWCNT)	E	1	1	1	1	1
Nanoclay	D	1	2	2	2	1
Nickel monoxide	E	1	1	1	1	1
Silicon dioxide (silica), synthetic amorphous	C	1	2	2	3	1
Silicon dioxide (silica), crystalline	E	1	1	1	1	1
Silver	D	1	2	2	2	1
Single-walled carbon nanotube (SWCNT)	E	1	1	1	1	1
Strontium titanate	n/a	n/a	n/a	n/a	n/a	n/a
Titanium dioxide (titania, rutile, anatase)	B	1	3	3	3	1
Titanium nitride	D	1	2	2	2	1
Vanadium pentoxide	E	1	1	1	1	1
Zinc oxide	B	1	3	3	3	1

The high hazard materials are towards the E end of the ranking while the high exposure materials are towards the 4 end of that ranking. Thus, the materials with the lowest risk will have hazard A and exposure 1 and those with the highest risk will have hazard E and exposure 4. There are, however, materials of moderate risk and low exposure that are less risk potentially that lower risk materials with high exposure.

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