NanoData Landscape Compilation

Update Report 2017

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EUROPEAN COMMISSION

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Update Report 2017

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EXECUTIVE SUMMARY

Background

This report is an update on the data in the NanoData Landscape Compilation reports published in June 2017. Those reports were based on data from 2015 (for the reports on energy, health, ICT, manufacturing and photonics) and 2016 (for the reports on construction, environment and transport).

EU R&D policy and projects

The move from the EU Seventh Framework Programme (FP7) to the EU Horizon 2020 Framework Programme (H2020) has seen both an increase in budget (from EUR 50 billion for FP7 to over EUR 70 billion for Horizon 2020) and strategic changes, including a widening of the knowledge base and increased emphasis on societal impacts, collaboration with industry and the market-related application of research results. Greater financial support is being provided for SMEs (with a target of 20% of total budget).

As a horizontal and enabling technology, nanotechnology is seen as relevant to many areas under the pillars for Excellent Science (e.g. future and emerging technologies (FET)) and Societal Challenge (e.g. secure, clean and efficient energy), but it also gets specific attention under the Industrial Leadership pillar in Leadership in Enabling and Industrial Technologies (LEIT), which covers (i) nanotechnologies, advanced materials, advanced manufacturing and processing, and biotechnology; (ii) ICT; and (iii) space.

Nanotechnology projects formed 8.8% of H2020 projects to July 2017[1], 1,201 projects out of 13,643 being found to be related to nanotechnology in that they contained the term "nano" in their 'Title' or 'Objective'.

In terms of the distribution of funding for nanotechnology between the different H2020 pillars, Excellent Science has received over half (57%) and Industrial Leadership over a third (34%). These compare with the H2020 budget allocations to the pillars to date of 37.8% for Excellent Science and 22.8% for Industrial Leadership, showing that nanotechnology-related projects are strongly represented in these two pillars. 34% of the H2020 budget is going to Societal Challenges but only 6.8% to nanotechnology projects so far.

Looking at the distribution of funding for nanotechnology within the pillars, almost a third (30.7%) of funding under Excellent Science was for the European Research Council and almost 15% for Marie Skłodowska-Curie Actions (MSCA). Within Industrial Leadership, all but 2.8% of the funding for nanotechnology is allocated to Leadership in Enabling and Industrial Technologies (LEIT), the bulk being allocated to LEIT-NMBP (21%, of which 16.7% is in the nanotechnologies sub-category).

Under the SME Initiative, nanotechnology has received a smaller share of funding than for H2020 overall (4.5% for H2020 and 2.8% for H2020 nanotechnology).

Higher education institutions (HEIs) dominate in terms of H2020 nanotechnology funding (with 44%), followed by public research organisations (PROs 30%) and companies (23%) although companies have a higher number of participations (1,224) than PROs (906) but less than HEIs (1,491). However, HEIs have received a smaller share of funding to date in H2020 than in FP6 and FP7 relative to the other participant types.

Publications

[1] Data from July 2017, EC open access data website https://data.europa.eu/euodp/en/data/dataset/cordisH2020projects

About 2.3 million publications globally related to nanoscience and nanotechnology (NST) between 2000 and 2016. The largest proportion by sector was in ICT (35%), almost three times any other sector (manufacturing 13%, health 12%, energy 9%, photonics 5%). Construction and transport each represented less than 1% of the total.

The global numbers of publications are growing year on year, most strongly for photonics and energy (at a rate of about 20% each) and least strongly for transport (no growth) and construction (3%) between 2000 and 2016.

The number of nanoscience and nanotechnology publications in the EU&EFTA countries has also increased year on year, doubling from over 27,000 in 2000 to nearly 55,000 in 2016. However, global publication output has grown at a higher rate, so the percentage of EU&EFTA publications has dropped from 40% of total output to 26%.

The strongest publishing region is Asia and the countries in 2016 were China and the US, followed by India, South Korea, Germany, Japan, the United Kingdom and France. Of the EU28, the strongest in publications in 2016 (in addition to Germany, the United Kingdom and France) were Spain and Italy.

Higher education institutions lead the organisations publishing on nanotechnology in 2016, with strong performances from the Chinese Academy of Sciences, the Russian Academy of Sciences and several Chinese universities. The highest placed EU&EFTA organisations are the CNRS (FR). Within HEIs, CNRS is joined by the Max Planck Gesellschaft (DE), CNR (IT), CSIC (ES), and the University

In all sectors other than health, the company contributing to the most nanotechnology publications globally in 2016 was Samsung, with strong performances also from IBM, Toyota, Intel, NTT, BASF, STMicroelectronics, Sinopec and LG Chem, although publication numbers are low relative to those of HEIs. In health, the leaders were Genea Biocells, Merck, Bristol Meyers Squibb and Genentech. Publication activity by companies was particularly low in environment, construction and transport.

Patenting

The top five patenting offices through which nanotechnology patents were files between 1993 and 2013 were the USPTO (in the top five for all eight sectors), EPO (all sectors), the Japanese Patent Office (JPO) (all sectors), WIPO (six sectors) and the Korean Patent Office (five sectors). The leading EU patent offices were in the United Kingdom (in the top five for health and photonics), France (manufacturing and environment) and Sweden (for transport). The greatest number of patent applications by sector is in ICT, both globally and for the EU and EFTA countries.

The US leads in country of applicant for all sectors, with Japan in second place except in health (Germany). Korea is in third place for ICT, manufacturing, energy and environment, Germany being in third for photonics, transport and construction. EU countries in the top five for one or more sectors are Germany (all sectors), France and the Netherlands (3) and the United Kingdom (2).

The leading EU organisation for patent applications on nanotechnology was the CNRS in France, other strong performers being the CEA (FR), Fraunhofer Gesellschaft (DE) and IMEC (BE). Globally, there were strong performances in patent applications from the US Institutions of the University of California, Massachusetts Institute Technology, the University of Texas, the University of Michigan, Caltech, Northwestern University and Princeton. The strongest non-US non-EU&EFTA performers include organisations from Korea, Japan, China and Taiwan (Chinese Taipei).

The leading EU&EFTA companies for patent applications are ASML Netherland BV (NL), Infineon Technology AG (DE), Hitachi Global Storage Technology Netherlands BV (NL) and Mapper Lithography (NL).

Applicants may file patents with more than one patent authority. While most patents filed by US applicants are filed with the USPTO, between almost 60% (transport 58%, health 56%) and just over 30% (photonics 32%, manufacturing 35%) of US patent applications are filed at the EPO.

In terms of EPO patents granted to applicants from EU&EFTA countries, twelve countries occur in the top five ranking across the sectors: Germany and France (8 sectors each); Italy and the United Kingdom (5 each); the Netherlands (4); Switzerland (3); Austria, Belgium and Spain (2 each); and Denmark, Finland and Sweden (1 each). For USPTO patents, the same ten countries occur in all sectors in the top five ranking: Germany, France and the United Kingdom (8 sectors each); the Netherlands (5); Switzerland and Italy (3 each); Sweden (2); Spain (1); and Austria and Belgium (1 each). For organisations, the CNRS (FR) is the leader amongst EU&EFTA universities and public research organisations for EPO patents granted.

EU&EFTA companies with patents granted include ASML Netherlands BV (NL), Osram Opto Semiconductors GmbH (DE), Mapper Lithography (NL), L'Oréal (FR), Philips Electronics NV (NL), Infineon Technology AG (DE) and Merck Patent GmbH (DE).

Companies including KK Toshiba (JP), IBM Corporation (US), Samsung Electronics (KR) and Canon KK (JP) have patents granted by the USPTO and the EPO, several of them patenting in more than three and up to all eight sectors.

Products and markets[2]

The global market for nanotechnology products was valued at USD 34.3 billion in 2015 and forecast to reach about USD 39.2 billion in 2016. Growth has been forecast at a rate of 18.2% (compound annual growth rate, CAGR) from 2016 to 2021, with an estimated market of USD 90.5 billion by 2019[3]. Most of the growth is expected to come from products that already exist in some form.

The market estimates for 2021 by sector show that manufacturing is expected to have a market value for nanotechnology of USD 90.3 billion, photonics USD 43.5 billion, transport USD 21.5 billion, ICT USD 10.7 billion, environment USD 8.4 billion (by 2020), construction USD 4.8 billion, energy USD 4 billion and health USD 0.5 billion (by 2019).

For manufacturing, the bulk of the market is expected to be in nanomaterials (mainly thin film but also solid nanoparticles and composites), nanotools accounting for about 15% of the total and including next generation lithography tools and nanomanipulators. In photonics, the bulk of the market by 2021 is expected to be due to a growth in the area of quantum dots for optoelectronics, as well as extreme UV lithography and flat-panel displays. In transport, large markets are forecast in thin films for photocatalytic coatings, solid nanoparticles for rechargeable batteries and thin films for fuel cells. Quantum dots for optoelectronics are expected to form the largest part of the market in ICT and nanotechnology to 2021. Environmental market applications are expected to be led by catalytic converters and nanotechnology for both water and air remediation. Construction nanotechnology markets are forecast to be highest for insulation and coatings and adhesives. Catalysts are expected to have high sales for energy applications in 2021, although the rate of growth in the market is quite low. Graphene-related applications, such as capacitors, are expected to emerge and also achieve large markets by 2023. Health and nanotechnology markets are forecast to be largest in solid nanoparticles for molecular imaging agents and nanomaterials for implants.

The transport sector accounts for the largest number (494) of identified products using nanotechnology in 2017, followed by health (302), manufacturing (277), and energy

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[2] Market data is mainly based on the reports of BCC Research.

[3] BCC Research (2016), Nanotechnology, a realistic market assessment, p.8

(269). Other sectors with significant numbers of products are photonics (218) and ICT (226). At the lower end are construction (156) and environment products (79). The highest growth in number of products since 2015 is seen in health (182%) and ICT (169%), the lowest increase being in photonics, manufacturing and transport although even these show a growth of around 40% since 2015.

Regulation and standards

Nanomaterials must comply with the overarching regulatory framework in place for chemical substances: REACH - the *Registration, Evaluation, Authorisation and restriction of Chemicals* in Europe since 2007. On 9 October 2017, the European Commission published its proposal for amending the REACH Annexes to address nanoform substances. The proposal introduces specific provisions for 'nanoforms' and 'sets of nanoforms' and shall apply from 1 January 2020, while at the same time allowing users to comply before that date. The Commission Regulation would require, for substances which exist in one or more nanoforms that chemical safety reports also describe which nanoforms are manufactured and imported. It would also specifically require information on all identified uses for each nanoform. The modified annexes also clarify how manufacturers and importers shall report study results for nanomaterials. The document is currently open for consultation.

Guidance documents related to nanomaterials were published in May 2017[4]:

- Nano-specific Appendix to Chapter R.6 of the Guidance on Information Requirements and Chemical Safety Assessment (QSARs and grouping of chemicals)
- How to prepare registration dossiers that cover nanoforms - best practices
- Updates to Guidance on IR&CSA (Endpoint specific guidance):
  - Appendix to Chapter R.7a for nanomaterials - Recommendations for physico-chemical endpoints
  - Appendix to Chapter R.7b for nanomaterials - Recommendations for ecotoxicological endpoints for nanomaterials (general advice, fate and specific endpoints)
  - Appendix to Chapter R.7c for nanomaterials - Recommendations for ecotoxicological endpoints for nanomaterials (specific advice and specific endpoints)

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

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

For work on standards specifically related to nanotechnology, there is the International Organisation for Standardisation (ISO) technical committee on nanotechnologies, ISO/TC 229 Nanotechnologies, and, in Europe, the European Committee for Standardisation (CEN) committee on nanotechnology (CEN/TC 352).

[4] echa.europa.eu

1 INTRODUCTION

This report is an update to the eight NanoData Landscape Compilation reports published in June 2017. Those reports were based on data from 2015 (for the reports on energy, health, ICT, manufacturing and photonics) and 2016 (for the reports on construction, environment and transport). This update reports on the outputs of research (projects, publications and patents) and how those outputs are used in the application of nanotechnology (products and markets). It also gives an update on regulations affecting nanotechnology in the EU.

The outline of this report is as follows:

- Introduction;
- Policies and programmes for nanotechnology, the EU Framework Programmes;
- Publications in nanotechnology;
- Patenting in nanotechnology;
- Products and markets; and
- The wider environment for nanotechnology - regulation and standards.

Much of the sectoral information is given in comprehensive annexes at the end of the document.

2 EU FRAMEWORK PROGRAMME AND PROJECTS

2.1 Introduction: Moving from FP7 to H2020

The progression in the European Framework Programmes from FP7 to Horizon 2020 has not just been a development in terms of increased funding (EUR 50 billion for FP7 to over EUR 70 billion for Horizon 2020) but also has seen strategic changes. In summary, the aims of the changes have been:

- To widen the knowledge base and place greater emphasis on the societal impacts of the Framework Programme research (rather than focussing on the deepening of knowledge);
- To target increased collaboration with industry; and
- To focus more on the market potential and applications resulting from the research.

Greater financial support is being provided for SMEs (with a target of 20% of the total Horizon 2020 budget). One simplification has been the combining of the Framework Programme, the European Institute for Innovation and Technology (EIT) and the Competitiveness and Innovation Framework Programme (CIP).

The Seventh Framework Programme[5] (FP7) was structured around the themes of Cooperation, Capacities, People and Ideas, as well as Euratom and the Joint Research Centre. Its successor, Horizon 2020[6], is concerned with Excellent Science, Industrial Leadership, Societal Challenges, Spreading Excellence, Science for Society, the European Institute for Innovation and Technology (EIT), Euratom and the Joint Research Centre. The thematic approach of FP7 (under the ten strands of Cooperation[7]) are covered in H2020 under Industrial Leadership and Societal Challenges. Frontiers research and the European Research Council were new in FP7 and fell under Ideas. They have been extended in H2020 under the Excellent Science pillar. Responsible Research and Innovation under H2020 seeks to improve access to scientific information, increase openness and transparency, and contribute to better policy-making.

Under Excellent Science, H2020 is addressing the areas of:

- Excellence in the science base;
- Frontier research (ERC);
- Future and emerging technologies (FET);
- Skills and career development (Marie Curie); and
- Research infrastructures.

while it is addressing Societal Challenges through actions on:

- Health, demographic change and wellbeing;
- Food security and the bio-based economy;
- Secure, clean and efficient energy;
- Smart, green and integrated transport;

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[5] https://ec.europa.eu/research/fp7/index_en.cfm

[6] http://ec.europa.eu/programmes/horizon2020/h2020-sections

[7] https://ec.europa.eu/research/fp7/index_en.cfm?pg=cooperation

- Supply of raw materials, resource efficiency and climate action; and
- Inclusive, innovative and secure societies.

Nanotechnology is seen as a horizontal and enabling technology relevant to many of these areas. In addition, it gets specific attention under the Industrial Leadership pillar with its role of supporting Leadership in Enabling and Industrial Technologies (LEIT) which has three parts:

- Nanotechnologies, advanced materials, advanced manufacturing and processing, and biotechnology;
- ICT; and
- Space.

Industrial Leadership also covers Access to Risk Finance and Innovation in SMEs.

Innovation in SMEs[8] ('SME Instrument') is a dedicated programme for SMEs aimed at supporting them (to the tune of about EUR 3 billion in 2014-2020) to develop their innovative ideas into products, processes and services for the global market. It offers support for feasibility assessment, innovation development and demonstration (including prototyping, miniaturisation, scaling-up, design, performance verification, testing, demonstration, development of pilot lines, and validation for market replication), business coaching (by experienced business coaches selected through the Enterprise Europe Network (EEN)), and access to risk finance (e.g. brokerage activities, assistance in applying for EU risk finance, and other innovation support services offered by the EEN).

Access to Risk Finance[9] aims to help companies and other organisations engaged in research and innovation (R&I) to gain easier access, via financial instruments, to loans, guarantees, counter-guarantees and hybrid, mezzanine and equity finance. InnovFin – EU Finance for Innovators - is the name under which the EU promotes a range of debt and equity products and advisory services including guarantees for intermediaries that lend to SMEs to direct loans to companies, for all sizes of research and innovation projects.

The funding rate for research is up to 100% in H2020, compared with up to 75% in FP7. For demonstration and innovation projects, the funding rates remain generally lower but have increased from 50% in FP7 to 70% in H2020 (and up to 100% for non-profit organisations). Different models were used in FP7 to cover overheads and indirect costs (ranging from 20% to 60% or actual costs) while H2020 uses a flat rate of 25%.

In terms of the administrative burden, the time to grant was on average 12 months after submission of the proposal while for H2020 the target is eight months. Ex-ante financial viability checks are only carried out on coordinators in H2020 while for FP7 they were required for all beneficiaries with an EU contribution in excess of EUR 500,000. Audit certificates were required in FP7 for all FP7 beneficiaries with an EU contribution in excess of EUR 375,000 (cumulative in periods) while for H2020 they are required for all beneficiaries with an EU contribution in excess of EUR 325,000 EUR EU contribution (only at the end of the project).

Intellectual property rules are included in the Rules for Participation for H2020, as for FP7, and include some changes, not least the increased focus in H2020 on open access to research publications. All funded projects are obliged to ensure that all of their peer-reviewed journal articles can be openly accessed, free of charge. The H2020 model grant

[8] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/innovation-smes

[9] https://ec.europa.eu/programmes/horizon2020/h2020-section/access-risk-finance

agreement makes provision for EU access rights to project results, limited to certain uses and specific purposes.

The Framework Programmes operate in the wider economic and social environment of Europe and synergies are sought between EU funding programmes to maximise their impact. For the first time in the history of the FPs, there is a legal mandate to maximise synergies between not only H2020 and the European Structural and Investment Funds (ESIF) (Common Provisions Regulation), but also with other programmes, such as COSME, Erasmus+ and the Connecting Europe Facility. Different types of synergies are proposed where ESIF can complement H2020 supports: providing funding for positively evaluated H2020 proposals that could not be funded due to insufficient budgets; funding actions to build research and innovation capacities of actors who aim to participate in H2020 or similar programmes; supporting follow-up actions to successful H2020 projects, aimed at market up-take; and combining ESIF and H2020 funds to support either coordinated parallel actions that complement each other or a single action or a group of inter-dependent actions or operations. In this, it must be assured that there is no double funding, no substitution of national, regional or private co-funding and no diversion of funding. The pilot project 'Stairway to Excellence' aims to support EU-13 regions and countries to benefit from ESIF/H2020 synergies, in order to promote excellence in all regions and EU countries, close the innovation divide and support national and regional Smart Specialisation Strategies.

2.2 Other EU funds

Over half of EU funding is channelled through the five European Structural and Investment Funds10 (ESIF), jointly managed by the European Commission and the EU countries: the European Regional Development Fund (ERDF); the European Social Fund (ESF); the Cohesion Fund (CF); the European Agricultural Fund for Rural Development (EAFRD); and the European Maritime and Fisheries Fund (EMFF). Their target is job creation and creating a sustainable and healthy European economy and environment. ESIF mainly focusses on the five areas of research and innovation; digital technologies; supporting the low-carbon economy; sustainable management of natural resources; and small businesses.

COSME is an EU programme for the Competitiveness of SMEs, a large part of its activities being dedicated towards financial instruments managed by the European Investment Fund (EIF). The COSME financial instruments aim to improve access to finance for SMEs and encourage the competitiveness of European enterprises. The COSME financial instruments run from 2014 to 2020 with a planned budget of EUR 1.3 billion. Via selected financial intermediaries, including local financial institutions or private equity funds, EIF provides risk capital financing to SMEs allowing them to reach their next development stage. Under COSME, EIF offers two different financial instruments to financial intermediaries: the Equity Facility for Growth (EFG); and the Loan Guarantee Facility (LGF). LGF is a successor to the SME Guarantee Facility (SMEG) implemented within the Competitiveness and Innovation Framework Programme (CIP) in the 2007-2013 programming period, running parallel to FP7.

The original ERASMUS programme (the European Region Action Scheme for the Mobility of University Students) was established in 1987 as an EU student exchange programme. It subsequently merged with other programmes (e.g. the Socrates programme for education and training) and in its current form, Erasmus+[11], it is a broad framework programme for education, training, youth and sport. It has a budget of EUR 14.7 billion over seven years (a 40% increase in funding compared to the Lifelong Learning Programme of 2007-2013) and aims to support 4 million European citizens. Two-thirds of its budget is to enable learning opportunities abroad for individuals (including students,

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[10] https://ec.europa.eu/info/funding-tenders/european-structural-and-investment-funds_en

[11] http://ec.europa.eu/programmes/erasmus-plus/sites/erasmusplus/files/library/erasmus-plus-factsheet_en.pdf

young people, teachers and other educators) while the other third is for partnerships and reform of the education and youth sectors.

The Connecting Europe Facility[12] (CEF) is a funding mechanism to support the development of high performing, sustainable and efficiently interconnected trans-European networks in transport, energy and digital services. It has a total budget of EUR 30.4 billion, including EUR 24.05 billion is for transport, EUR 5.35 billion for energy, and EUR 1.0 billion for telecommunications. The CEF offers financial support to projects through grants, guarantees and project bonds. The CEF budget is divided into two 'envelopes', one available to all EU Member States and the other that is available only to the Cohesion Member States[13].

2.3 Nanotechnology in the Framework Programmes

2.3.1 Participation by type of programme

2.3.1.1 Overview

Project-related data was extracted from the eCorda database for FP7. The total number of FP7 projects was 25,238 and there were 133,615 participations. 2,636 of those projects were found to be related to nanotechnology in that they contained the term "nano"[14] in their 'Title' or 'Abstract'. Nanotechnology projects formed 10.0% of FP7 projects.

The total number of H2020 projects[15] was 13,643 and there were 55,329 participations. 1,201 of those projects were found to be related to nanotechnology in that they contained the term "nano" in their 'Title' or 'Objective'. Nanotechnology projects formed 8.8% of H2020 projects to date.

FP7 and H2020 project data	Projects	
Number of FP projects, all topics	25,238	13,643
Number of nanotechnology FP projects	2,636	1,201
% of nanotechnology FP projects	10.0%	8.8%

Table 3.1. Number of projects and shares for nanotechnology in FP7 and H2020

2.3.1.2 The Seventh Framework Programme (FP7)

Nanotechnology featured most prominently in FP7 under the Cooperation theme[16], with its aim for Europe to gain or to consolidate scientific, technological end economic leadership in key sectors. The Cooperation theme covered cooperative, top-down, transnational research, with themes defined according to policy aims. Nanoscience, nanotechnologies, materials and new production technologies (NMBP) was one of ten areas for Cooperation funding, although nanotechnology also featured in the projects of other areas, such as ICT, energy and health.

[12] https://ec.europa.eu/inea/en/connecting-europe-facility

[13] In 2014-2020, the EU Cohesion Fund is providing funding for 15 Member States: Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.

[14] 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".

[15] Data from July 2017, EC open access data website https://data.europa.eu/euodp/en/data/dataset/cordisH2020projects

[16] https://ec.europa.eu/research/fp7/index_en.cfm?pg=cooperation

For nanotechnology, the Cooperation theme took 60.2% of the EC funding contribution, less than the 63.1% for FP7 overall. Ideas (European Research Council) took 22.0%, more for nanotechnology than for FP7 overall (17.1%) and People (Marie Curie Actions) 12.4%, more for nanotechnology than for FP7 overall (10.6%). Capacities (including Research Infrastructures and Research for the Benefit of SMEs) took less for nanotechnology (5.4%) than for FP7 overall (8.4%).

FP7 Summary	Number of projects		EC contribution (MEUR)		Share of EC contribution	
	All	NT	All	NT	All	NT
COOPERATION	7,834	756	28,336.3	2,803.8	63.1%	60.2%
Health	1,008	33	4,791.7	157.0	10.7%	3.4%
Food, Agri and Bio	516	25	1,850.7	97.1	4.1%	2.1%
ICT	2,328	175	7,877.0	561.3	17.5%	12.0%
NMP	805	412	3,238.6	1,595.6	7.2%	34.2%
Energy	368	24	1,707.4	81.5	3.8%	1.7%
Environment	494	10	1,719.3	26.9	3.8%	0.6%
Transport	719	12	2,284.2	61.5	5.1%	1.3%
Socio-economic Sciences	253	0	579.6	0.0	1.3%	0.0%
Space	267	14	713.3	31.7	1.6%	0.7%
Security	314	5	1,295.5	14.1	2.9%	0.3%
General Activities	26	0	312.7	0.0	0.7%	0.0%
Joint Technology Initiatives	736	46	1,966.4	177.0	4.4%	3.8%
IDEAS	4,525	572	7,673.5	1,026.1	17.1%	22.0%
European Research Council	4,525	572	7,673.5	1,026.1	17.1%	22.0%
PEOPLE	10,716	1,158	4,777.5	579.9	10.6%	12.4%
Marie-Curie Actions	10,716	1,158	4,777.5	579.9	10.6%	12.4%
CAPACITIES	2,025	149	3,772.0	249.9	8.4%	5.4%
Research Infrastructures	341	18	1,528.4	72.2	3.4%	1.5%
Research for the benefit of SMEs	1,028	70	1,249.1	86.1	2.8%	1.8%
Regions of Knowledge	84	4	126.7	7.3	0.3%	0.2%
Research Potential	206	27	377.7	55.1	0.8%	1.2%
Science in Society	183	16	288.4	16.5	0.6%	0.4%
Research Policies	26	0	28.3	0.0	0.1%	0.0%

FP7 Summary	Number of projects		EC contribution (MEUR)		Share of EC contribution	
	All	NT	All	NT	All	NT
International Cooperation	157	14	173.4	12.7	0.4%	0.3%
EURATOM	138	1	358.1	1.1	0.8%	0.0%
Fusion	4	0	5.2	0.0	0.0%	0.0%
Fission	134	1	352.8	1.1	0.8%	0.0%
TOTAL	**25,238**	**2,636**	**44,917.3**	**4,660.8**	**100.0%**	**100.0%**

Table 3.2. FP7 nanotechnology activities by programme and sub-programme

2.3.1.3 Horizon 2020 (H2020)

In H2020, nanotechnology is covered in the LEIT area together with ICT, materials, biotechnology, manufacturing and space, as well as horizontally under Excellent Science and Societal Challenges.

Excellent Science has four themes:

- Frontier research (ERC);
- Future and emerging technologies (FET);
- Marie Skłodowska-Curie Actions (MSCA); and
- Research infrastructures (INFRA).

Industrial Leadership, in addition to Access to Risk Finance and Innovation in SMEs, covers Leadership in Enabling and Industrial Technologies (LEIT) under three headings, one of which contains the sub-theme of nanotechnology as well as related technologies and their applications:

- LEIT-NMBP: Nanotechnologies, advanced materials, advanced manufacturing and processing, and biotechnology;
- LEIT-ICT: Information and communications technologies; and
- LEIT-Space.

Societal Challenges comprises actions on:

- Health, demographic change and wellbeing;
- Food security and the bio-based economy;
- Secure, clean and efficient energy;
- Smart, green and integrated transport;
- Supply of raw materials, resource efficiency and climate action; and
- Inclusive, innovative and secure societies.

Additional activities include Science with and for Society (SwafS) and EURATOM.

H2020 Summary	Number of projects		EC contribution (MEUR)		Share of EC contribution	
	All	NT	All	NT	All	NT
EXCELLENT SCIENCE	7,769	906	8,747.3	1,110.8	37.8%	57.0%
European Research Council ERC	2,931	364	4,636.3	600.3	20.0%	30.7%
Future & Emerging Technologies FET	150	35	699.6	147.8	3.0%	7.6%
Marie Skłodowska-Curie Actions MSCA	4,526	499	2,415.2	290.4	10.4%	14.9%
Research Infrastructures INFRA	162	8	996.1	72.2	4.3%	3.7%
INDUSTRIAL LEADERSHIP	3,798	246	5,274.0	664.0	22.8%	34.0%
Leadership in Enabling and Industrial Technologies (LEIT)	1,041	113	4,235.1	609.7	18.3%	31.2%
LEIT-ICT	621	32	2,457.3	195.1	10.6%	10.0%
LEIT-NMBP (total)	274	77	1,438.8	411.0	6.2%	21.0%
Nanotechnologies	62	61	333.8	326.2	1.4%	16.7%
Advanced materials	59	12	324.1	66.8	1.4%	3.4%
Biotechnology	19	1	131.8	5.8	0.6%	0.3%
Advanced manufacturing & processing	134	3	649.2	12.3	2.8%	0.6%
LEIT – Space	146	4	339.0	3.5	1.5%	0.2%
Access to Risk Finance	8	0	8.3	0.0	0.0%	0.0%
Innovation in SMEs	2,749	133	1,030.6	54.3	4.5%	2.8%
SOCIETAL CHALLENGES	1,762	26	7,919.3	133.7	34.2%	6.8%
Health, Demographic Change and Well-Being	322	8	1,884.3	39.3	8.1%	2.0%
Food Security, Sustainable Agriculture, Forestry Marine Maritime, Inland Water Research and the Bio-economy	186	5	886.9	26.3	3.8%	1.3%
Secure, Clean, Efficient Energy	380	4	1,871.0	17.3	8.1%	0.9%
Smart, Green, Integrated Transport	436	6	1,417.0	39.9	6.1%	2.0%
Climate Action, Environment, Resource Efficiency and Raw Materials	173	2	948.0	6.7	4.1%	0.3%
Europe in a Changing World – Inclusive, Innovative & Reflecting	133	0	334.1	0.0	1.4%	0.0%

H2020 Summary	Number of projects		EC contribution (MEUR)		Share of EC contribution	
	All	NT	All	NT	All	NT
Societies						
Secure Societies - Protecting Freedom and Security of Europe and its Citizens	132	1	578.0	4.2	2.5%	0.2%
OTHER	314	23	1,219.2	45.4	5.3%	2.3%
Spreading Excellence and Widening Participation	128	15	348.9	29.1	1.5%	1.5%
Science with and for Society - SWAFS	75	3	150.2	4.6	0.6%	0.2%
Fast Track to Innovation Pilot	87	5	186.3	11.6	0.8%	0.6%
Euratom	24	0	534.0	0.0	2.3%	0.0%
TOTAL	**13,643**	**1,201**	**23,160**	**1,954**	**100%**	**100%**

Table 3.3. H2020 nanotechnology activities by programme and sub-programme

Over half of the nanotechnology funding in H2020 has, to date, been given to Excellent Science (57%) and over a third to Industrial Leadership (34%). These proportions are greater than for H2020 overall, with 37.8% for Excellent Science and 22.8% for Industrial Leadership.

Under Excellent Science, almost a third (30.7%) was for the European Research Council (significantly more than the 20% for H2020 overall) and almost 15% for Marie Skłodowska-Curie Actions (MSCA) (again nearly 1.5 times the figure for MSCA in H2020 overall (10.4%)).

Within Industrial Leadership, all but 2.8% of the funding for nanotechnology is allocated to Leadership in Enabling and Industrial Technologies (LEIT). The LEIT funding for nanotechnology (31.2%) is significantly more than the figure for H2020 overall (18.3%). The bulk of the nanotechnology funding is under LEIT-NMBP (21%) with 16.7% of that being in the nanotechnologies sub-category, with most of the rest of the nanotechnology LEIT-NMBP being allocated to advanced materials. The share of funding for LEIT-ICT was approximately the same for H2020 (10.6%) and nanotechnology in H2020 (10.0%).

Nanotechnology has so far received a smaller share of funding under the SME Initiative than H2020 overall (4.5% for H2020 and 2.8% for H2020 nanotechnology).

2.3.2 Participation by type of participating organisation

The tables below show the participations in the Framework Programmes for the Higher Education Sector (HES), Public Research Organisations (PROs), companies (PRC) and other organisations. As well as the number of participations (Particip.), the table shows the total EC funding and share of funding.

Total FP6 and FP7			NT in FP6 and FP7		
Particip.	EC Funding (MEUR)	Share of Funding	Particip.	EC Funding (MEUR)	Share of Funding

HEI	76,777	25,736.0	41.8%	7,671	3,019.5	47.5%
PRO	53,384	17,304.4	28.1%	4,696	1,778.1	28.0%
PRC	54,495	13,903.9	22.6%	5,514	1,384.5	21.8%
Other	24,961	4,626.8	7.5%	1,059	174.2	2.7%
Total	209,617	61,571	100.0%	18,940	6,356.2	100.0%

Table 3.4. Participation in FP6 and FP7, FP6 and FP7 nanotechnology, including funding and share of funding

	Total H2020			**NT in H2020**		
	Particip.	EC Funding (MEUR)	Share of Funding	Particip.	EC Funding (MEUR)	Share of Funding
HEI	17,893	8,776	37.9%	1,491	858.1	43.9%
PRO	11,617	5,760	24.9%	906	576.7	29.5%
PRC	17,792	6,219	26.9%	1,224	443.5	22.7%
Other	8,027	2,405	10.4%	212	75.5	3.9%
Total	55,329	23,160	100%	3,833	1,953.8	100%

Table 3.5. Participation in H2020 and H2020 nanotechnology, including funding and share of funding

Comparing the percentages, higher education institutions (HEIs) continue to have a higher share of funding in nanotechnology (43.9%) than in H2020 as a whole (37.9%), the same being true in FP6 and FP7. However, HEIs have received a smaller share to date in H2020 than in FP6 and FP7 relative to the other participant types, with small rises in the percentage of nanotechnology funding received by public research organisations (from 28.0% to 29.5%), companies (up from 21.8% to 22.7%) and other organisations (up from 2.7% to 3.9%). The pattern for H2020 overall is a decrease in that share funding to higher education institutions (down from 41.8% to 37.9%), a decrease for public research organisations (down from 28.1% to 24.9%), an increase for companies (up from 22.6% to 26.9%) and an increase for other types of organisations (up from 7.5% to 10.4%), relative to FP6 and FP7.

The next section looks at publications in nanotechnology between 2000 and 2016.

3 PUBLICATIONS IN NANOTECHNOLOGY[17]

3.1 Global publication trends

Around 2.3 million publications globally were identified[18] from the Web of Science as being related to nanoscience and Technology (NST)[19] between 2000 and 2016. Of these:

- 800,000 (35%) were related to ICT and nanotechnology;
- 286,000 (13%) were related to manufacturing and nanotechnology;
- 270,000 (12%) were related to health and nanotechnology;
- 200,000 (9%) were related to energy and nanotechnology;
- 113,000 (5%) were related to photonics and nanotechnology;
- 66,000 (2%) were related to environment and nanotechnology;
- 24,000 (0.9%) were related to transport and nanotechnology; and
- 21,000 (0.8%) were related to construction and nanotechnology.

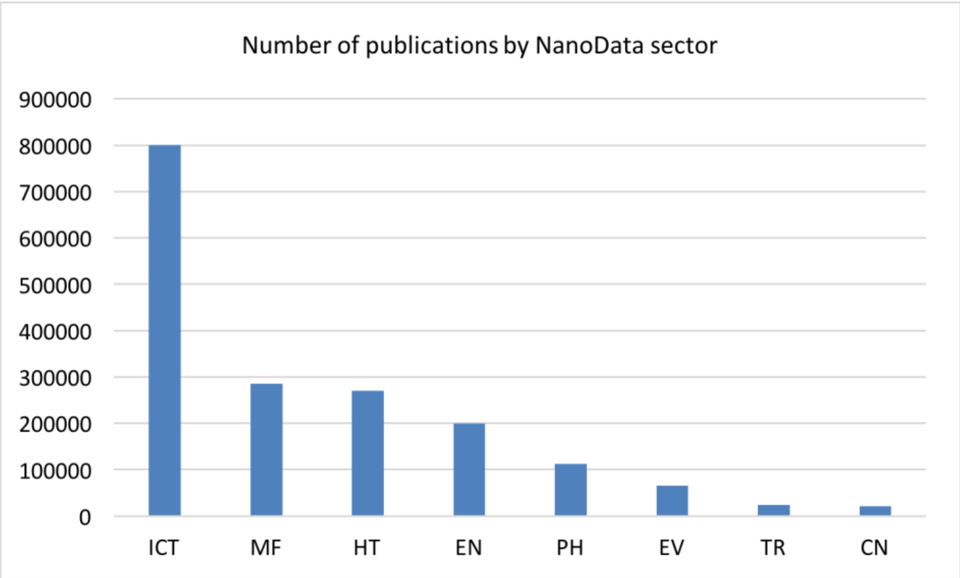

Figure 4.1. Number of publications by NanoData sector, 2000-2016

Looking at the global numbers of publications over time[20], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The trends by sector were as follows:

- Up 7% in ICT, from 11% to 18%;
- Up 6% in manufacturing, from 58% to 64%;

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[17] It should be noted that, in attributing publications, full counting is used, meaning that publications may be assigned to more than one actor. Where a person, organisation or a country is said to have a number of publications, they contributed to that number of publications, but they may not have been the only contributor.

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

[19] 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.

[20] See tables in Annex: Publication data

- Up 4% in health, from 2% to 6%;
- Up 20% in energy, from 35% to 55%;
- Up 23% in photonics, from about 45% to almost 68%;
- Up 5% in environment, from 10% to 15%;
- Stable in transport at 16%; and
- Up 3% in construction from 15% to 18%.

3.2 European Union and EFTA publication trends

Over the period from 2000-2016, the number of nanoscience and nanotechnology publications in the EU&EFTA countries has increased year on year, doubling from over 27,000 in 2000 to nearly 55,000 in 2016. However, global publication output has grown at a higher rate and the percentage of EU&EFTA publications has decreased in the same time period from 40% of total output to 26%.

Year	Number of publications		
	NST	NST EU&EFTA	% NST EU&EFTA
2000	68,949	27,470	40%
2001	74,841	29,337	39%
2002	80,103	30,737	38%
2003	86,574	31,283	36%
2004	96,671	34,220	35%
2005	105,772	35,603	34%
2006	115,714	38,174	33%
2007	122,991	39,503	32%
2008	131,215	41,002	31%
2009	137,770	42,085	31%
2010	145,011	43,808	30%
2011	160,078	47,159	29%
2012	168,244	48,447	29%
2013	182,921	51,316	28%
2014	194,732	52,609	27%
2015	203,104	54,166	27%
2016	207,608	54,697	26%

Table 4.1. Nanoscience and nanotechnology publication output by year worldwide and in the EU and EFTA countries (2000-2016)

The proportion of EU&EFTA publications in nanoscience and nanotechnology decreased in all of the sectors (except construction where it remained stable), largely due to the increase in publishing in China. For example, for ICT, the number of publications in the EU&EFTA countries rose from nearly 10,000 in 2000 to over 20,000 in 2016 but the proportion dropped from 40% to 25% relative to global output (see figure below).

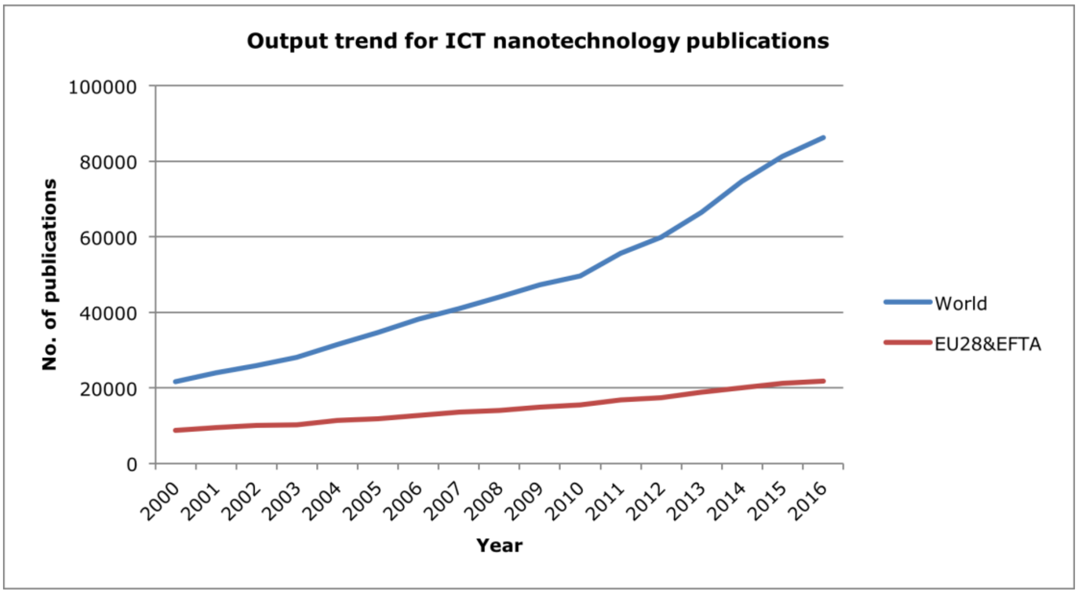

Table 4.2. ICT nanotechnology publication output by year worldwide and in the EU and EFTA countries (2000-2016)

For the other sectors, EU&EFTA publication output trends 2000-2016 were as follows:

- Publications on health and nanotechnology increased four-fold in number for the EU&EFTA from over 2,000 to about 9,000, while the worldwide output increased six-fold from 5,000 to over 30,000;
- Publications on photonics and nanotechnology increased almost five-fold in number for the EU&EFTA from about 800 to 4,000, while the worldwide output increased almost eight-fold from under 2,000 to almost 14,000;
- Publications on energy and nanotechnology increased six-fold from 1,000 to 6,000 approximately for the EU&EFTA, while the worldwide output increased sixteen-fold from under two thousand to almost thirty thousand;
- Publications on manufacturing and nanotechnology increased two-fold in number from 3,000 to 6,000 approximately for the EU&EFTA, while the worldwide output increased three-fold from 8,000 to 25,000;
- Publications on environment and nanotechnology increased five-fold in number from under 500 to over 2,500 for the EU&EFTA, while the worldwide output increased nine-fold from over 1,000 to under 10,000;
- Publications on transport and nanotechnology increased 2.5 times in number from under 300 to over 800 for the EU&EFTA, while the worldwide output increased four-fold from 600 to almost 2,500; and
- Publications on construction and nanotechnology increased six-fold in number from under 200 to over 1,000 for the EU&EFTA, the worldwide output also increasing six-fold from 500 to almost 3,000.

Full details are given in the Annex: Publications.

3.3 Publication output by sub-sector: health and energy

3.3.1 Health

For health, five sub-sectors were identified (cancer, cardiovascular disease, diabetes, infectious diseases and neurodegenerative diseases), plus the category Other (remaining publications not in the five sub-sectors). The majority of publications in health and in health nanotechnology relate to cancer as seen below. It is noticeable that particularly in cancer, the share of nanotechnology publications (NST) is much higher than in health in general while for infectious diseases it is less.

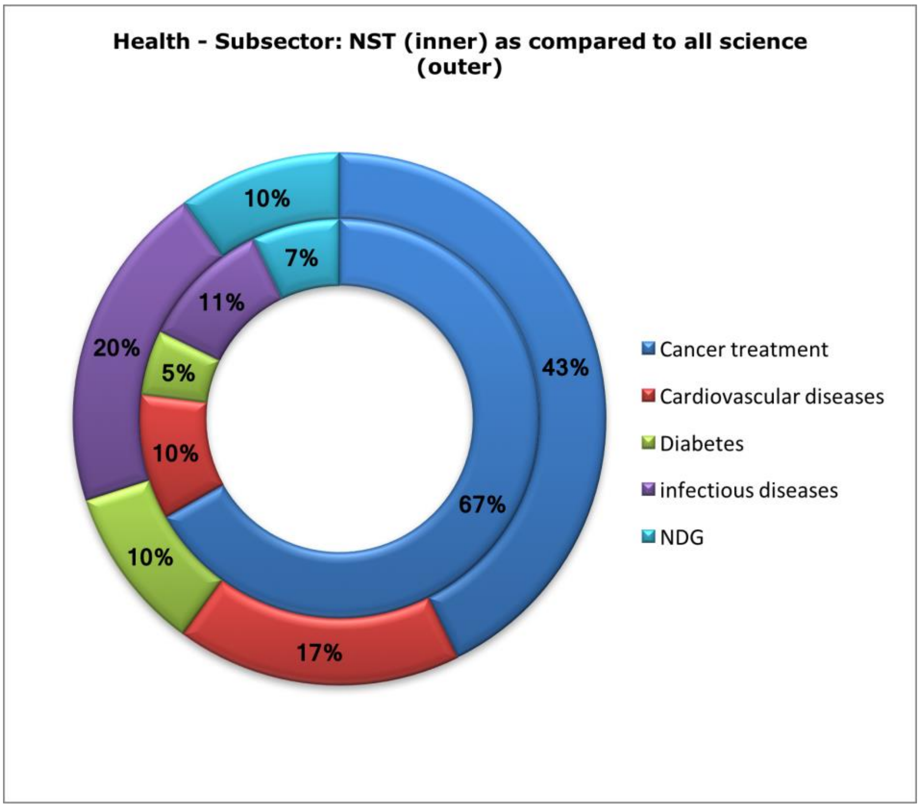

Figure 4.2. Distributions of subsectors within health and NST for health

Sub-sector	No. of publications	
	Sub-sector in all sciences	Sub-sector in NST
Cancer	209,4336	76,315
Cardiovascular disease	849,940	11,586
Diabetes	491,379	6,042
Infectious diseases	983,676	12,186
Neurodegenerative diseases	487,496	8,131
Other	4,975,012	24,1037

Table 4.3. Publications in health and health nanotechnology by sub-sector

3.3.2 Energy

For energy, four sub-sectors were identified (alternatives, hydrogen, solar and storage). The majority of publications are in solar and storage as seen in the table below.

Sub-sector	No. of publications	
	Sub-sector in all sciences	Sub-sector in NST
Solar	147,791	92,175
Storage	93,925	61,885
Hydrogen	36,478	28,262
Alternatives	61,322	3,343

Table 4.4. Publications in energy and energy nanotechnology by sub-sector

It is noticeable that particularly in alternatives, the share of nanotechnology publications (NST) is much smaller than in energy research in general. This is an indication that nanoscience and nanotechnology are not yet much investigated in the area of alternative energies.

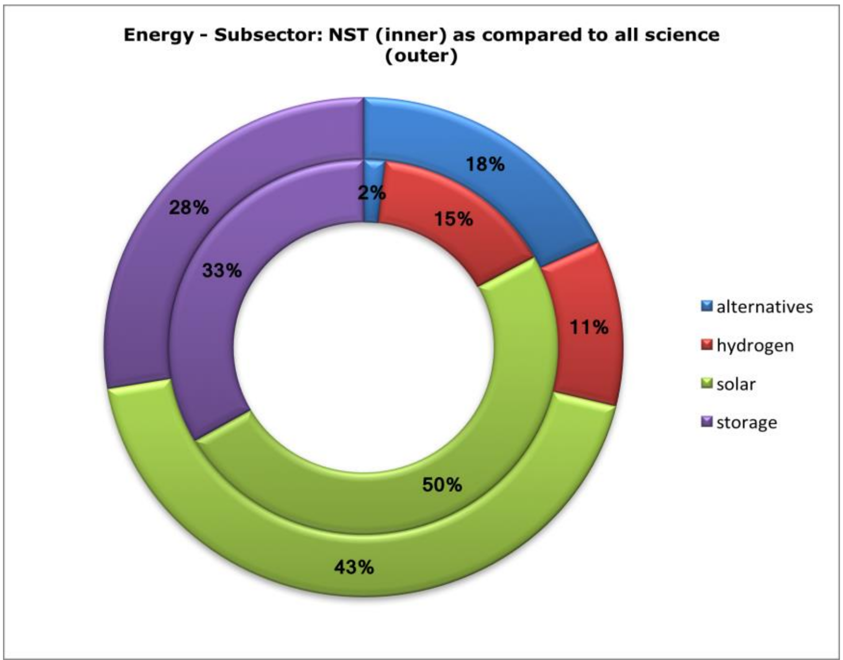

Figure 4.3. Distributions of subsectors within energy and NST for energy

3.4 Publication output by region and country

For all sectors, the most prolific region for publications in nanoscience and nanotechnology is Asia, followed by the EU&EFTA and North America.

Region	Number of publications							
	ICT	MF	EN	HT	PH	EV	TR	CN
Asia	419,031	158,468	116,294	112,740	56,012	28,683	8,767	7,124
EU28&EFTA	255,411	84,476	51,263	87,452	36,215	21,595	9,090	8,651
North America	166,130	51,245	41,353	71,418	29,711	14,915	6,353	4,042
Middle East	44,155	13,078	8,756	15,887	4,862	5,591	1,345	2,247
South & Central America	25,134	8,554	3,986	8,875	2,250	2,830	1,023	1,138

Region	Number of publications							
	ICT	MF	EN	HT	PH	EV	TR	CN
Oceania	17,447	5,309	5,115	6,775	2,767	2,415	464	877
Africa	12,410	4,527	2,949	4,370	1,485	1,944	365	880

Table 4.5. Number of publications by region and sector (2000-2016)

By country, the most prolific publisher in 2016 was China followed by the US in all sectors[21]. Other countries that featured in the top ranks for the sectors are India, South Korea, Germany, Japan, the United Kingdom and France.

- In ICT and nanotechnology, China had more than twice the number of publications as the US and around six times the next highest producers of publications (India, Korea, Germany and Japan).
- The performance was similar for manufacturing.
- In health and nanotechnology, China had 1.5 times the output of the US, over three times the output of India and about five times the output of the followers Germany, United Kingdom and Korea.
- In energy and nanotechnology, China produced 2.5 times the output of the US and over four times the output of South Korea, five times that of Japan and seven times that of Germany.
- In photonics and nanotechnology, the output of China was 1.5 times that of the US and 4.5 times that of Germany, India and the United Kingdom.
- In environment and nanotechnology, the output of China was more than double that of the US and four times that of India.
- In transport and nanotechnology, the output of China was 1.5 times that of the US and four times that of the next ranked Germany, followed closely by India and the United Kingdom.
- In construction and nanotechnology, the output of China was 1.8 times that of the US and four times that of the next ranked Spain, followed closely by the United Kingdom, India, South Korea and France.

For the EU28 and EFTA countries in 2016, the most prolific (in addition to Germany and the United Kingdom) were France, Spain and Italy. Germany had the greatest number of publications for all sectors except in construction which was led by Spain and environment which was led by the United Kingdom. Apart from its first place amongst EU&EFTA countries in environment, the United Kingdom ranked second in all sectors except manufacturing where France was in second place. Spain ranked second in environment. Other countries not yet mentioned that featured in the top fifteen for publications included Poland (particularly strong in ICT and manufacturing); Switzerland (between 6th and 9th place in all sectors); the Netherlands, Belgium and Sweden (in the top ten in all sectors); and Denmark (in the top ten in all except manufacturing); as well as Ireland (in health); and Greece (in energy).

Rank	Sector

[21] Note that the figures have not been adjusted for population size or GDP

	ICT	MF	EN	HT	PH	EV	TR	CN
1	DE	DE	DE	DE	DE	UK	DE	ES
2	UK	FR	UK	UK	UK	ES	UK	UK
3	FR	UK	FR	IT	FR	DE	IT	FR
4	ES	ES	ES	FR	IT	FR	FR	DE
5	IT	IT	IT	ES	ES	IT	ES	IT

Table 4.6. Ranking of EU&EFTA countries by number of publications by sector (2016)

Full details are given in the Annex: Publications.

3.5 Publication output by organisation type

Identified from the publication data from 2016, the main players in the R&D landscape of nanoscience and nanotechnology are higher education institutions, research and technology organisations and industry. The leading higher education institution (HEI) is the Chinese Academy of Sciences (with between 4800 and 80 publications per sector) except in construction. Also featuring prominently are the Russian Academy of Sciences (1800 publications in ICT and 395 in manufacturing) and a number of Chinese universities (e.g. Tsinghua University) while CNRS (FR) leads the EU& EFTA HEIs (being placed between second and sixth place globally in all sectors (with 1100 publications in ICT), except construction where it is ninth). The Spanish National Research Council (CSIC) is fourth in construction and seventh in transport but the publication numbers are low (43 and 26 respectively).

Looking at EU&EFTA higher education institutions alone, organisations in the top five of one or more sectors are the CNRS (FR), the Max Planck Gesellschaft (DE), CNR (IT), CSIC (ES), the University of Cambridge (UK), EPFL (CH), University College London (UK), the University of Aveiro (PT), Imperial College London (UK), Ghent University (BE), Delft University (NL), the Polytechnic University of Catalonia (ES) and the University of Birmingham (UK).

While publishing with a much lower level of productivity, some companies are active in publishing in nanoscience and nanotechnology, the most significant producer across all sectors except health being Samsung with over 170 publications in ICT and 57 in energy, for example. Also featuring in the top publishing companies in 2016 in sectors not including health were IBM, Toyota, Intel, NTT, BASF, STMicroelectronics, Sinopec and LG Chem (each with over 30 publications). For health, the leaders were Genea Biocells (28), Merck (24), Bristol Meyers Squibb (23) and Genentech (21). Publication numbers were particularly low in environment (the highest being 10 by BASF), construction (the highest being 10 by Jiangsu Sobute New Materials Company Limited) and transport (the highest being 6 by Posco).

Further details are given in the Annex: Publications by sector.

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

4 PATENTING IN NANOTECHNOLOGY

4.1 Overview

This section looks at the patenting activity in nanotechnology by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies. Full details are given in the Annex: Patent Data.

The patents and patent families (groups of patents related to the same invention) were identified by searching using a combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (e.g. transport)[22]. 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[23] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[24] that are members of the treaty.

4.2 Number and evolution over time of nanotechnology patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[25,26] of granted patent and patent applications were found in the period 1993-2013[27]. All of these were from the European Patent Office (EPO), US Patent and Trademark Office (USPTO) or the World Intellectual Property Organisation (WIPO)[28]. The number of patent families are shown below by sector and for all nanoscience and nanotechnology (NST total).

Sector	Patent families	
	Number	Share of total NST
NST total	50,780	100%
ICT	7,119	14.0%
Health	3,433	6.8%

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

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

[24] 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

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

[26] 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/.

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

[28] 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.

Sector	Patent families	
	Number	Share of total NST
Manufacturing	3,222	6.3%
Construction	2,254	4.4%
Energy	2,068	3.6%
Photonics	2,037	4.0%
Environment	531	1.0%
Transport	329	0.6%

Table 5.1. Absolute numbers and percentages of patent families for nanotechnology

4.3 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 five patent authorities through which PCT applications were filed are shown by sector in the table.

Rank	Receiving authority (patent office) by sector							
	ICT	MF	HT	EN	PH	EV	TR	CN
1	USPTO	USPTO	USPTO	USPTO	USPTO	USPTO	USPTO	USPTO
2	Japan	Japan	EPO	Japan	Japan	Japan	Japan	EPO
3	EPO	EPO	Japan	EPO	EPO	EPO	EPO	Japan
4	WIPO	Korea	WIPO	Korea	UK	WIPO	Korea	Korea
5	Korea	France	UK	WIPO	WIPO	France	Sweden	WIPO

Table 5.2. Top five receiving authorities for PCT applications by sector (1993-2013)

Further details are given in the Annex: Patent data by sector.

4.4 Activity by country of applicant

4.4.1 Patent applications

As shown in the table below, the greatest number of patent applications by sector is in ICT (for both EU&EFTA and the rest of the World). The highest percentage of EU&EFTA patent applications by sector is in photonics (23%), followed by energy (21%) and construction (20%), the lowest percentages being in manufacturing and environment (14%). The sectors in which there is relatively little patent activity in terms of numbers of applications related to nanotechnology are environment and transport.

Sector	EU28&EFTA patent applications (1993-2013)			
	Number			EU28&EFTA share
	Total	EU&EFTA	Rest of World	
ICT	7,119	1,037	6,082	15%

Manufacturing	3,222	463	2,759	14%
Health	3,433	609	2,824	18%
Energy	2,068	433	1,635	21%
Photonics	2,037	282	924	23%
Environment	551	76	455	14%
Transport	329	57	272	17%
Construction	2,254	449	1,805	20%

Table 5.3. Patent applications for EU&EFTA and the rest of the World by sector (1993-2013)

The table below shows the top five countries of applicants by sector, with EU28&EFTA countries marked in bold. The US leads in countries of applicant for all sectors, with Japan in second place except in health (Germany). Korea is in third place for ICT, manufacturing, energy and environment, Germany being in third for photonics, transport and construction. EU countries in the top five for one or more sectors are Germany (all sectors), France (3), the Netherlands (3) and the United Kingdom (2).

Rank	**Country of applicant by sector**							
	ICT	MF	HT	EN	PH	EV	TR	CN
1	US	US	US	US	US	US	US	US
2	JP	JP	DE	JP	JP	JP	JP	JP
3	KR	KR	JP	KR	DE	KR	DE	DE
4	DE	NL	UK	DE	UK	DE	FR	KR
5	NL	DE	FR	CN	KR	FR	KR	NL

Table 5.4. Top five countries of applicant by sector (1993-2013)

Applicants may file patents with more than one patent authority, e.g. at the USPTO and at the EPO. The vast majority of patents by US applicants are filed with the USPTO, for example 99% for ICT, 92% for manufacturing and 82% (the lowest percentage) for health. Between almost 60% (transport 58%, health 56%) and just over 30% (photonics 32%, manufacturing 35%) of US patent applications are filed at the EPO. Between 73% (construction and environment) and 51% (manufacturing) of US applicants file via the PCT route.

Among the applicants from EU&EFTA countries, those filing patents for ICT, manufacturing and transport most commonly do so at the USPTO. For health, energy, photonics, environment and construction, the differences in the percentage of filings among the different patent authorities are not large. In some cases, there is a slight preference for the PCT route, mainly for UK applicants filing in health, energy, environment and construction while French applicants have a slight preference for USPTO filings in energy, environment and construction.

Further details are given in the Annex: Patent data by sector.

4.4.2 Granted patents

In terms of EPO patents granted to applicants from EU&EFTA countries, applicants from Germany have the highest number of patents granted in all of the eight sectors. Twelve countries occur in the top five ranking across the sectors: Germany and France (8 sectors); Italy and the United Kingdom (5 each); the Netherlands (4); Switzerland (3); Austria, Belgium and Spain (2 each); and Denmark, Finland and Sweden (1 each).

Rank (EPO)	EU&EFTA country of applicant for patents granted by sector							
	ICT	MF	HT	EN	PH	EV	TR	CN
1	DE	DE	DE	DE	DE	DE	DE	DE
2	FR	NL	FR	FR	FR	FR	FR	FR
3	NL	FR	UK	UK	UK	AT	CH	NL
4	UK	UK	CH	AT	IT	BE	IT	SE
5	BE	CH	IT	IT	DK	FI	NL	IT

Table 5.5. Ranking by number of EPO patents granted: EU&EFTA applicants by country of applicant by sector (1993-2013)

In terms of USPTO patents granted to applicants from EU&EFTA countries, applicants from Germany have the highest number in six of the eight sectors and are in second place in the other two, following the Netherlands in manufacturing and France in environment, as shown in the table below. The same ten countries occur in all sectors in the top five ranking: Germany, France and the United Kingdom (8 each); the Netherlands (5); Switzerland and Italy (3 each); Sweden (2); Spain (1); and Austria and Belgium (1 each).

Rank (USPTO)	EU&EFTA country of applicant for patents granted by sector							
	ICT	MF	HT	EN	PH	EV	TR	CN
1	DE	NL	DE	DE	UK	DE	DE	DE
2	NL	DE	FR	FR	DE	FR	FR	NL
3	FR	FR	UK	UK	FR	ES	SE	FR
4	UK	UK	CH	AT	NL	UK	UK	UK
5	BE	CH	IT	IT	IT	NL	CH	SE

Table 5.6. Ranking by number of USPTO patents granted: EU&EFTA applicants by country of applicant by sector (1993-2013)

Further details are given in the Annex: Patent data.

4.5 Patenting activity by type of organisation

4.5.1 Universities and Public Research Organisations

4.5.1.1 Patent applications

Among the top patenting universities and public research organisations are:

- The University of California (US) with 73 patent families in health, 69 in ICT, 65 in manufacturing, 59 in photonics and 57 in energy;
- Massachusetts Institute Technology (US) with 53 in photonics, 50 in health, 32 in energy and 30 each in ICT and manufacturing;
- The University of Texas with 66 in health and 31 in manufacturing; and
- The University of Michigan (US) with 28 in health, and 23 each in energy and

photonics.

Other prominent patenting universities in the US in nanotechnology include Caltech, Northwestern University and Princeton.

In the EU&EFTA countries, the leader amongst universities and public research organisations is the CNRS in France with patent families as follows:

- 38 in ICT (ranking 23rd amongst all organisations and 4th amongst universities and public research organisations);
- 33 in manufacturing (ranking 12th amongst all organisations and 2nd amongst universities and public research organisations);
- 27 in photonics (ranking 10th amongst all organisations and 5th amongst universities and public research organisations);
- 23 in health (ranking 10th amongst all organisations and 5th amongst universities and public research organisations);
- 22 in energy (ranking 10th amongst all organisations and 5th amongst universities and public research organisations); and
- less than ten each in the other sectors.

Other strong performers amongst EU&EFTA universities and public research organisations are:

- CEA (FR) with 67 patent families in ICT (ranking 14th amongst all organisations, above the CNRS), 42 in manufacturing (ranking 12th amongst all organisations, above the CNRS), 25 in photonics, 18 in energy and 12 in construction; and
- Fraunhofer Gesellschaft (DE) with 19 patent families in construction and 12 in photonics; and
- IMEC (BE) with 27 patent families in ICT and 11 in photonics.

Other organisations are visible but with less than ten patent families per sector each.

The strongest non-US non-EU&EFTA performers include the Electronics and Telecommunications Research Institute (KR); the Japanese Science and Technology Agency (JP); Tsinghua University (CN); the National Institute of Advanced Science and Technology (JP); the Industrial Technology Research Institute (TW); and the University of Tokyo (JP).

4.5.1.2 Granted patents

The CNRS (FR) is also the leader amongst EU&EFTA universities and public research organisations for EPO patents granted in nanotechnology and photonics (12), health (8), manufacturing (7), energy (7) and transport (3). In the other sectors, CEA (FR) leads in ICT (17) followed by the CNRS (FR) (15); Fraunhofer Gesellschaft (DE) leads in construction (5); and the University of Seville (ES) leads in nanotechnology and environment, albeit with just one EPO patent granted.

The University of Seville (ES) also leads in USPTO patents granted in nanotechnology and the environment with eight, CNRS (FR) having three. Overall in terms of USPTO patents granted to EU&EFTA universities and public research organisations, the lead organisations are the CEA (FR) and the CNRS (FR). For example, the CEA has 41 USPTO patents granted in ICT and 38 in manufacturing, while the CNRS has 16 in manufacturing, 14 in ICT and 9 in energy.

4.5.2 Private Companies[29]

4.5.2.1 Patent applications

The most prolific companies for patent applications across PCT, EPO and USPTO are

- KK Toshiba (JP), with 239 patent families in ICT, 38 in manufacturing and 26 in photonics;
- Samsung Electronics (KR), with 181 patent families in ICT, 82 in manufacturing, 68 in energy, 47 in photonics, 22 in construction and 10 in environment;
- Canon KK (JP), with 70 patent families in photonics, 52 in manufacturing and 33 in construction;
- TDK Corporation (JP) with 159 patent families in ICT and 17 in photonics;
- Sony Corporation (JP) with 130 patent families in ICT;
- ASML Netherland BV (NL) with 125 patent families in manufacturing and 30 in construction;
- Fujitsu (JP) with 122 patent families in ICT;
- Hitachi Ltd (JP) with 121 patent families in ICT and 21 in photonics;
- Molecular Imprints Inc. (US) with 109 patent families in manufacturing and 48 in construction;
- Infineon Technology AG (DE) with 82 patent families in ICT;
- Hitachi Global Storage Technology Netherlands BV (NL) with 78 patent families in ICT; and
- Mapper Lithography (NL) with 55 patent families in manufacturing.

The leading EU&EFTA companies for patent applications are therefore ASML Netherland BV (NL), Infineon Technology AG (DE), Hitachi Global Storage Technology Netherlands BV (NL) and Mapper Lithography (NL). Other EU&EFTA companies that have over twenty patent applications are Merck Patent GmbH (DE), BASF (DE) and Osram Opto Semiconductors GmbH (DE). Companies with between ten and twenty patent applications each are Evonik Degussa GmbH (DE), Philips Electronics NV (NL), L'Oréal (FR), Elan Pharmaceuticals (IE) and MidaTech Ltd (UK). Companies with less than ten patent applications each include Rhodia (FR), Bayer AG (DE), Lanxess Deutschland GmbH (DE), Saab (SE), Michelin (FR), Michelin (CH), Mesophotonics Ltd (UK) and Solvay (BE). It is noticeable that the majority are companies based in Germany.

In health, there are less patent applications with the list headed by Immunomedics Inc. (US) with 55 patent families; Philips Electronics NV (NL) with 24 (and also 17 in photonics) and L'Oréal (FR) with 21. In transport, companies have less than ten patent families each, the list being headed by Bridgestone Corporation (JP).

4.5.2.2 Granted patents

EU&EFTA companies with EPO patents granted include:

- L'Oréal (FR), with 20 in health;

[29] In some cases, the companies may be holding companies.

- Osram Opto Semiconductors GmbH (DE), with 18 in photonics;
- Philips Electronics NV (NL), with 17 in photonics and 15 in ICT;
- Infineon Technology AG (DE), with 17 in ICT;
- Mapper Lithography (NL), with 12 in manufacturing;
- ASML Netherlands BV (NL), with 11 in manufacturing; and
- Merck Patent GmbH (DE), with 10 in energy.

Leading non-EU&EFTA companies with EPO patents granted include:

- IBM Corporation (US), with 26 patents in ICT and 12 in manufacturing;
- Samsung Electronics (KR), with 20 patents in ICT;
- Canon KK (JP), with 20 patents in photonics; and
- Immunomedics Inc. (US), with 19 patents in health.

EU&EFTA companies with USPTO patents granted include:

- ASML Netherlands BV (NL), with 81 in manufacturing and 23 in construction;
- Hitachi Global Storage Technology Netherlands BV (NL), with 68 in ICT;
- Mapper Lithography (NL), with 32 in manufacturing;
- Osram Opto Semiconductors GmbH (DE), with 25 in photonics;
- L'Oréal (FR), with 11 in health;
- Evonik Degussa GmbH (DE), with 11 in construction; and
- Merck Patent GmbH (DE), with 9 in energy and 5 in health.

Leading non-EU&EFTA companies with USPTO patents granted include

- KK Toshiba (JP), with 200 patents in ICT and 35 in manufacturing, 26 in photonics and 13 in construction;
- IBM Corporation (US), with 156 patents in ICT and 44 in manufacturing;
- TDK Corporation (JP), with 128 patents in ICT and 17 in photonics;
- Samsung Electronics (KR), with 119 patents in ICT, 54 in manufacturing, 32 in energy, 47 in photonics, 10 in construction and 7 in environment;
- Sony Corporation (JP), with 102 patents in ICT;
- Hitachi Ltd (JP) with 98 patents in ICT and 21 in photonics;
- Molecular Imprints Inc. (US), with 73 patents in manufacturing and 40 in construction;

- Canon KK (JP) with 70 patents in photonics, 37 in manufacturing and 27 in construction;
- Nuflare Technology Inc. (JP) with 50 in manufacturing; and
- Immunomedics Inc. (US) with 39 patents in health.

Particularly noticeable are the companies, such as KK Toshiba (JP), Samsung Electronics (KR) and Canon KK (JP), that patent in the USPTO across at least three and up to six sectors of the eight under consideration here.

Further details are given in the Annex: Patent data by sector.

The next section looks at products and markets for nanotechnology.

5 PRODUCTS AND MARKETS FOR NANOTECHNOLOGY

5.1 Introduction

This section reports firstly on commercialised products using nanotechnology, in particular the changes in number of products since 2015, and, secondly, on the markets for products using nanotechnology. It provides an overview, with additional information for each of the sectors being available in the Annex.

5.2 Products

Commercialised products were identified in all application markets of nanotechnology corresponding to the eight sectors in both 2015 and 2017, as shown in the figures below. In all cases an increase in the number of products was seen. In some cases, the products may be included in more than one sector.

In 2017, the transport sector accounts for the largest number of identified products (494, up from 363 in 2015). There are also a large number of products in health (302, up from 107 identified in 2015, the largest relative increase), manufacturing (277, up from 134 in 2015), and energy (269, up from 168 in 2015). Other sectors with significant numbers of products are photonics (218) and ICT (226).

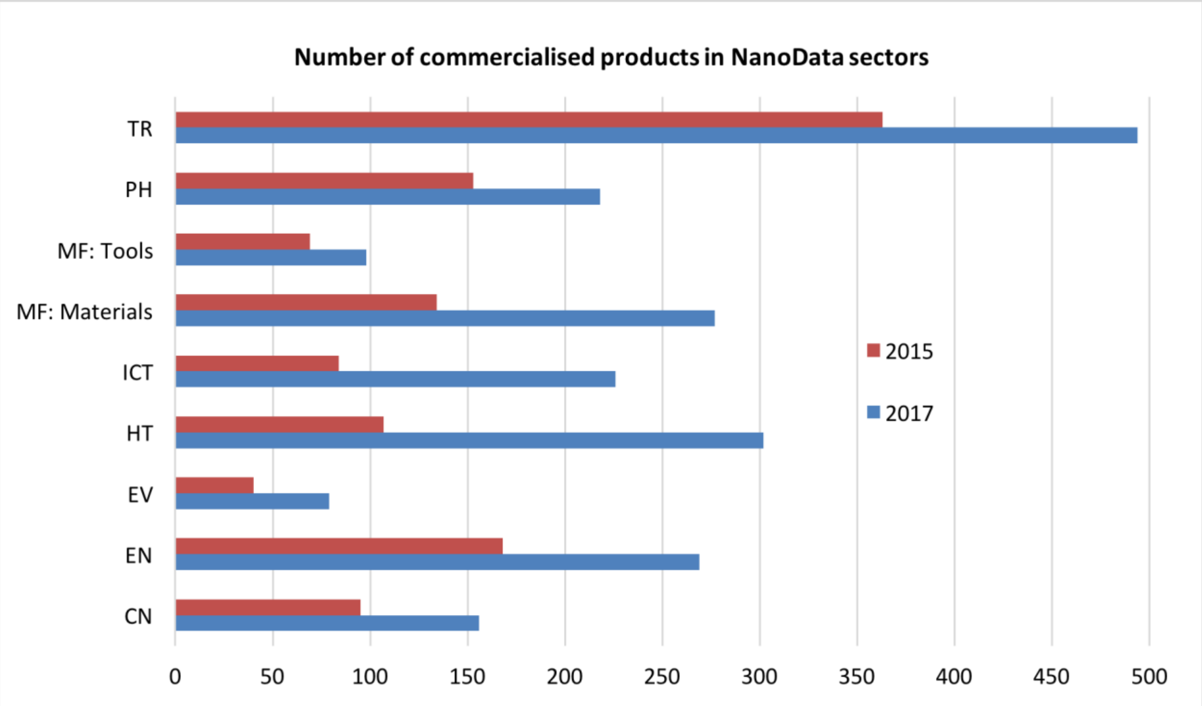

Figure 6.1. Commercialised products in application markets of nanotechnology, 2015 and 2017

Source: JIIP 2017

Growth rates in the number of commercialised products from 2015 to 2017 show the biggest increase in health, the number of products in 2017 being 182% of the number of products in 2015. Similar growth is seen for ICT (169%). A doubling of the number of products between 2015 and 2017 is seen for nanomaterials in manufacturing (107%) and for environment products using nanotechnology (98%). The remaining sectors show significant but lower growth in the number of products, ranging from 42% to 64%, as shown in the figure below.

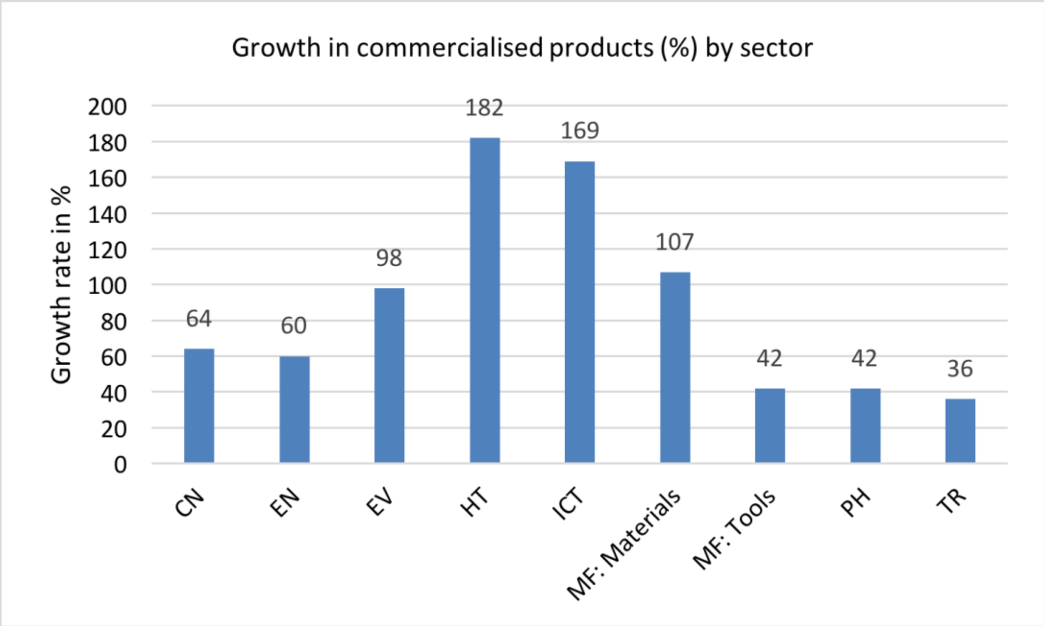

Figure 6.2. Growth in numbers of commercialised products by application market, 2015 to 2017

Source: JIIP 2017

The next section looks at the markets for nanotechnology applications.

5.3 Markets for nanotechnology applications

The global market for nanotechnology products was valued at USD 34.3 billion in 2015 and forecast to reach about USD 39.2 billion in 2016. Growth was forecast at a rate of a rate of 18.2% (compound annual growth rate, CAGR) from 2016 to 2021, with an estimated market of USD 90.5 billion by 2019[30].

This section covers the eight sectors in the following order:

- ICT;
- Manufacturing;
- Health;
- Energy;
- Photonics;
- Environment;
- Transport; and
- Construction

5.3.1 ICT applications of nanotechnology

5.3.1.1 Overview

Global sales for nanotechnology products in the ICT sector accounted for USD 2.8 billion in 2015 and are forecast to be USD 10.7 billion in 2021. The figure below shows the forecast growth in commercialised products (USD 10.4 billion in 2021) and the expected growth in emerging products (USD 420.2 million in 2021).

[30] BCC Research (2016), Nanotechnology, a realistic market assessment, p.8

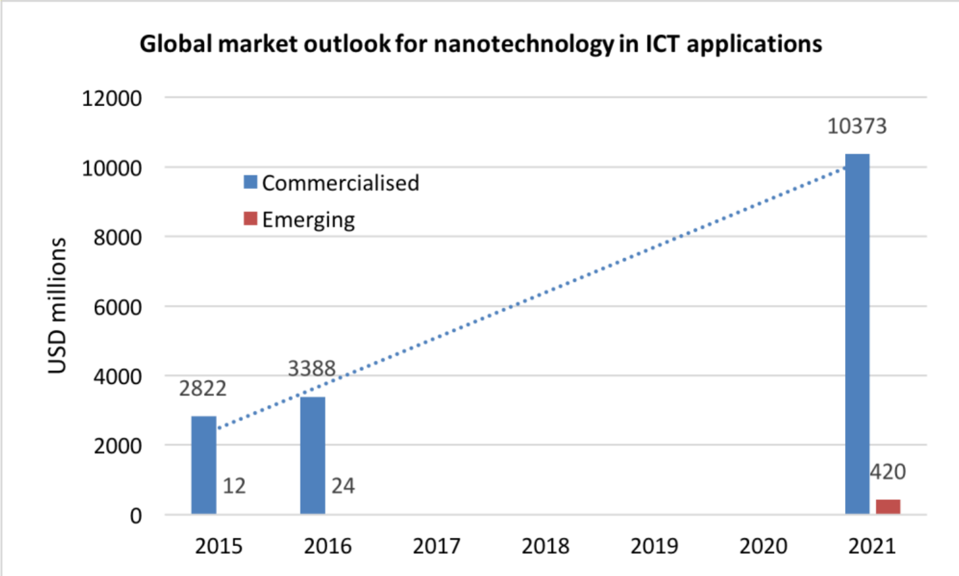

Figure 6.3. Global market outlook for nanotechnology in ICT applications to 2021

Source: BCC Research 2016

Growth is forecast to be driven mainly by products that are already commercialised. There are inherently no global sales in emerging application markets for 2015 and 2016 but they are expected to reach sales of USD 420 million in 2021. In comparison, the global market volume for products that are already commercialised is estimated to grow and to reach USD 2.3 billion in that same year.

Application markets with remarkable projected growth to 2021 are quantum dots for optoelectronics (CAGR 164.3%) and quantum dots for electronics (CAGR 18.5%), printed electronics (CAGR 35.6%) and low-k dielectric coatings (CAGR 33.8%).

Application area	Application market	CAGR% 2016-2021
Materials to make ICT	Quantum dots for optoelectronics	164.3
Materials to make ICT	Quantum dots for electronics	18.5
Materials to improve ICT	Low-k dielectric coatings	33.8
Materials to make ICT	Printed electronics	35.6

Table 6.1. The most dynamic application markets in nanotechnology for ICT to 2021

Source: BCC Research 2014, 2015

Application markets for nanotechnology with projected negative growth to 2021 are found in storage: magnetic recording media (CAGR -20%), optical recording media (CAGR -2.8%), and hard disk media and heads (-9.7%). The main driver of this trend is the increasing online availability of media content (i.e. via Spotify, iTunes, Netflix etc.). The market for nanoimprint lithography is expected to stagnate (CAGR 0%).

Sector	Application market	CAGR% 2016-2021
Storage	Magnetic recording media	-20
	Optical recording media	-2.8
	Hard disk media and heads	-9.7

Table 6.2. The least dynamic application markets in ICT to 2021

Source: BCC 2014

5.3.1.2 Forecasts for individual application markets in ICT and nanotechnology

Market data and forecasts can be identified for thirteen application markets within nanotechnology for ICT.

Quantum dots for optoelectronics are showing the most dynamic projected development to 2021 with a CAGR in application markets almost nine times high as the expected average growth of the total global market for nanotechnology products (CAGR 164.3%).

Printed electronics and low-k dielectric coatings are application markets that are forecast to grow more than twice as much as the whole nanotechnology market, while application markets in data storage show prospects of either below average or negative growth.

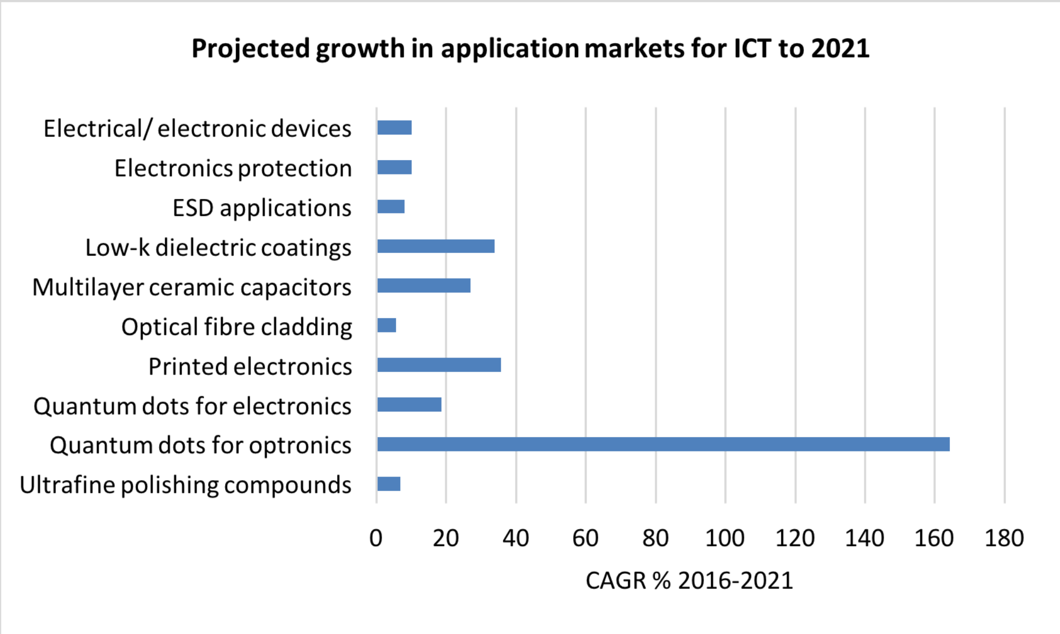

Figure 6.4. Projected growth in ICT application markets to 2021

Source: BCC Research 2016

In emerging application markets, growth forecasts are not available for ICT applications. Applications with noteworthy potential sales volumes are, on the one hand, optical communication products such as add/drop filters, optical switches and optical amplifiers and, on the other hand, data storage devices in the form of nanostructured holographic memory.

Nanomaterial	Application market	Sales 2019 (USD millions)
CNT	Printed electronics	36
	Field emission devices	7.5
Nanocomposites	Add/drop filters	53
	Optical switches	15
	Optical amplifiers	100
Devices	Nanostructured holographic memory	50

Table 6.3. Global sales forecast for 2019 in emerging ICT application markets

Source: BCC Research 2015

With a projected CAGR to 2019 of 44%, the global market for graphene is forecast to develop more dynamically than the total market for nanotechnology products (CAGR: 19.8%). No data on the estimated growth of application markets is available to 2019, but the forecasts for sales show good growth prospects for graphene in high performance computing (CAGR 35%), with projected sales of USD 26 million in 2018 and USD 117 million in 2023.

5.3.2 Manufacturing applications of nanotechnology

5.3.2.1 Overview

The commercial applications of nanotechnology identified 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 34.2 billion in 2015 and USD 90.3 billion in 2021. The figure below shows the forecast growth in nanotools (to USD 13.1 billion in 2021) and in nanomaterials (to USD 77.3 billion in 2021). It is seen that much of the growth is expected to be driven by nanomaterials.

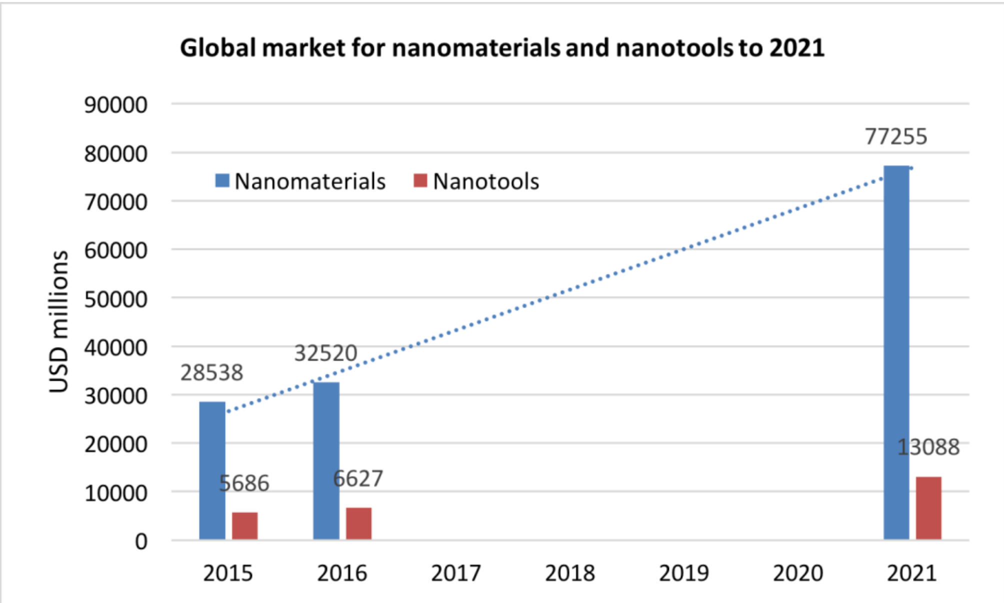

Figure 6.5. Global market outlook for nanomaterials and nanotools to 2021

Source: BCC Research 2016

Shares of nanotools and nanomaterials are expected to remain almost stable from 2021 to 2021. The nanomaterials share of the market will remain close to 80% (at USD 77 billion in 2021) and the nanotools share will remain close to 15%.

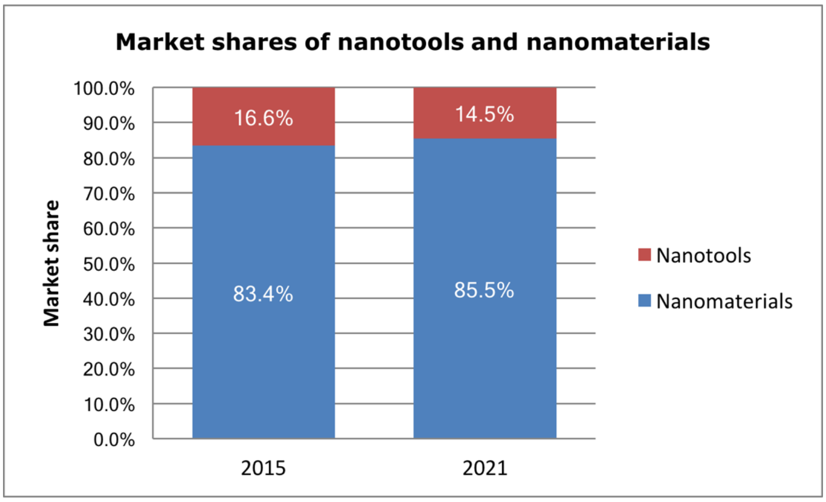

Figure 6.6. Market shares of nanotools and nanomaterials, 2015 and 2021

Source: BCC Research

The markets for nanotools and instruments are considered now, followed by the markets for nanomaterials.

5.3.2.2 Market trends for nanotools and instruments

The global market for commercialised nanotools includes nanomanipulators, near-field optical microscopes, nanomachining tools and nanolithography tools. This market is expected to grow from USD 5.7 billion in 2015 and USD 6.6 billion in 2016 to about USD 13 billion in 2021.

With a projected CAGR to 2019 of 14.6% the global markets for nanotools will develop less dynamic than the total market for nanotechnology products (CAGR: 18.2%).

Application market	CAGR% 2016-2021	Sales 2021 (USD M)
Advanced optical nanolithography tools	5,500.0	1.4
Nanomanipulators	1,041.8	11.6
Near-field optics	91.5	5.2
Nanomachining tools	30.4	4.0
Next-generation lithography tools	6,425.0	51.7

Table 6.4. Application markets in nanotools to 2021

Source: BCC Research 2016

Commercialised application markets for nanotools show all poor estimated growth rates to 2021 reaching from 4% (nano-machining tools) to 5% (near-field optics) and 12% (nanomanipulators). Growth in this application area will thus be driven by the emerging application market for extreme ultraviolet lithography. This particular market is expected to grow with a CAGR of 52.8%, while global sales for nanoimprint lithography are likely to stagnate to 2021 and remain marginal in terms of global sales.

Application market	Sales 2021 (USD M)	CAGR% 2016-2021
Extreme ultraviolet lithography	6,250	52.8
Nanoimprint lithography	50	0

Application market	Sales 2021 (USD M)	CAGR% 2016-2021
Maskless optical lithography	120	--

Table 6.5. Emerging markets in nanotools to 2021

Source: BCC Research 2016

5.3.2.3 Market trends for nanomaterials

The global market for nanomaterials was worth USD 28.5 billion in 2015 and is expected to grow to USD 77.3 billion in 2021.

Nanomaterial	Sales (USD millions)			CAGR% 2015-2021
	2015	2016	2021	
Nanoscale thin films	21,893.6	25,003.5	57,847.6	18.3
Solid nanoparticles	3,281.8	3,670.3	8,810.4	19.1
Nanostructured monolithics	2,054.6	2,268.5	5,141.7	17.8
Nanocomposites	1,301.6	1,569.4	5,284.3	27.5
Carbon Nanotubes	6.2	8.0	171.1	84.5
Total	28,537.9	32,519.8	77,255.1	18.9

Table 6.6. Global market for nanomaterials by type to 2021

Source: BCC Research 2016

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 2015, accounting for 76.7% of total worldwide nanomaterial consumption, reflecting their widespread use in catalytic converters. Solid nanoparticles accounted for 11.5% of the market and nanostructured monolithics 7.2%, as shown below.

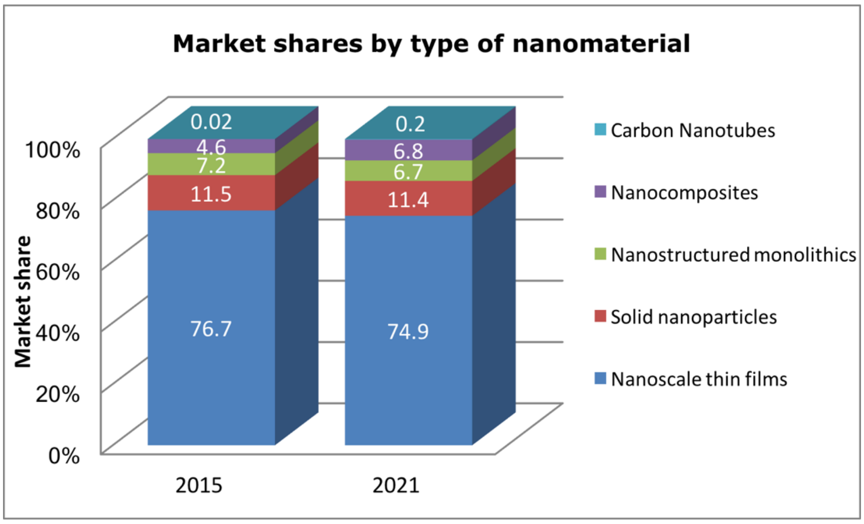

Figure 6.7. Market shares of types of nanomaterials, 2013 and 2019

Source: BCC Research 2014

It is forecast that the market for thin films will stagnate in percentage terms, to decrease to 74.9% by 2021, with the market share of nanostructured monolithics forecast to fall to 6.7%. Solid nanoparticles are also expected to hold their relative market share, at 11.8%. The market for nanocomposites is forecast to grow to 6.7% of the total and nanotubes to 0.2%.

5.3.3 Health applications of nanotechnology

5.3.3.1 Overview

The global market for medical and medicinal products using nanotechnology (nanomedicine) is forecast[31] to grow with a CAGR of 16.3% to reach a total of USD 528 million in 2019, as shown in the figure below.

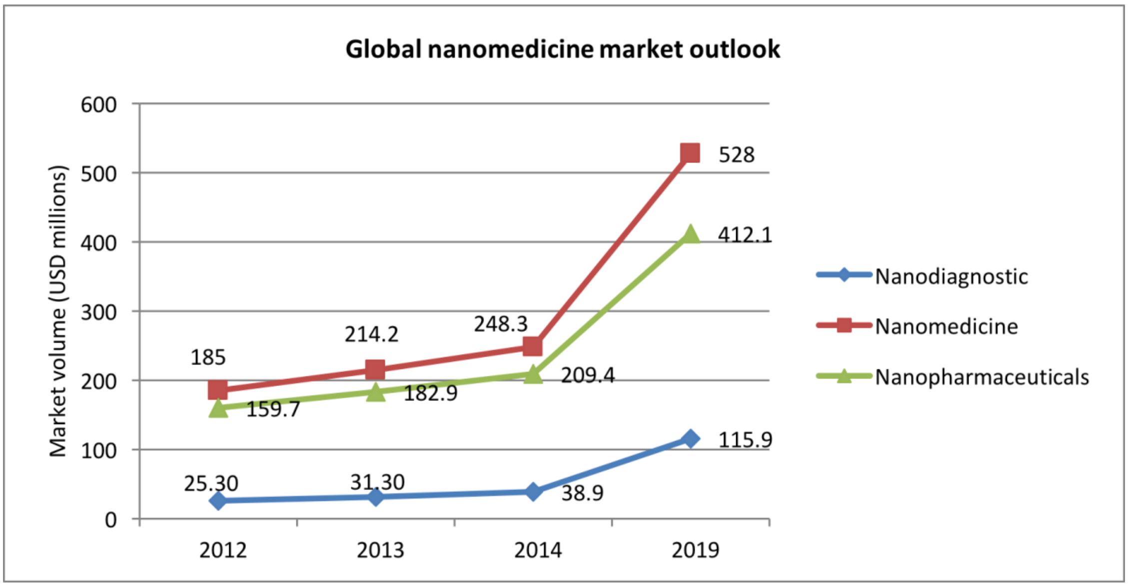

Figure 6.8. Global market outlook for nanomedicine to 2019 (USD million)
Source: BCC Research 2015

The largest component of this forecast growth is expected to be from pharmaceuticals using nanotechnology, with a CAGR of 14.3% and an expected global sales volume of USD 412 billion in 2019. While the market for diagnostics using nanotechnology is expected to have a higher CAGR (24.4%), growing faster than nanopharmaceuticals, global sales for nanodiagnostics accounted for only USD 25 billion in 2013 and are expected to reach USD 116 billion in 2019[32].

Application markets with particularly high projected growth to 2021 are cellulose nanoparticles for biomedical applications (CAGR 94%), biomedical markers/detection aids (CAGR 43.5%), and transfection reagents (CAGR 39.3%).

Application	Application market	CAGR% 2016-2021
Pharmaceuticals	Cellulose nanoparticles for biomedical applications	94.0
Diagnostics	Biomedical markers and detection aids	43.5
	Transfection reagents	39.3

Table 6.7. The most dynamic application markets in health applications to 2021[33]

[31] BCC Research (2014), Nanotechnology in Medical Applications: The Global Market p. 8

[32] Ibid

[33] Data for cellulose nanoparticles is only available for the period 2014 to 2019

Source: BCC Research 2015, 2016

Application markets for nanotechnology with low projected growth to 2021 are found in MRI contrast agents (CAGR 4%), drug delivery vehicles (CAGR 7%) and high-performance liquid chromatography (HPLC) (CAGR 8%).

Sector	Application market	CAGR% 2016-2021
Diagnostics	Nano- high-performance liquid chromatography	8.1
Pharmaceuticals	Drug delivery vehicles	7.1
Diagnostics	MRI contrast agents	3.6

Table 6.8. The least dynamic application markets in health applications to 2021

Source: BCC 2016

5.3.3.2 Forecasts for individual application markets in health and nanotechnology

Market data were identified for twelve separate application markets (see figure below) within nanotechnology for health. Data on growth were available for all of these except for drug production and mixing systems and for surface disinfectants.

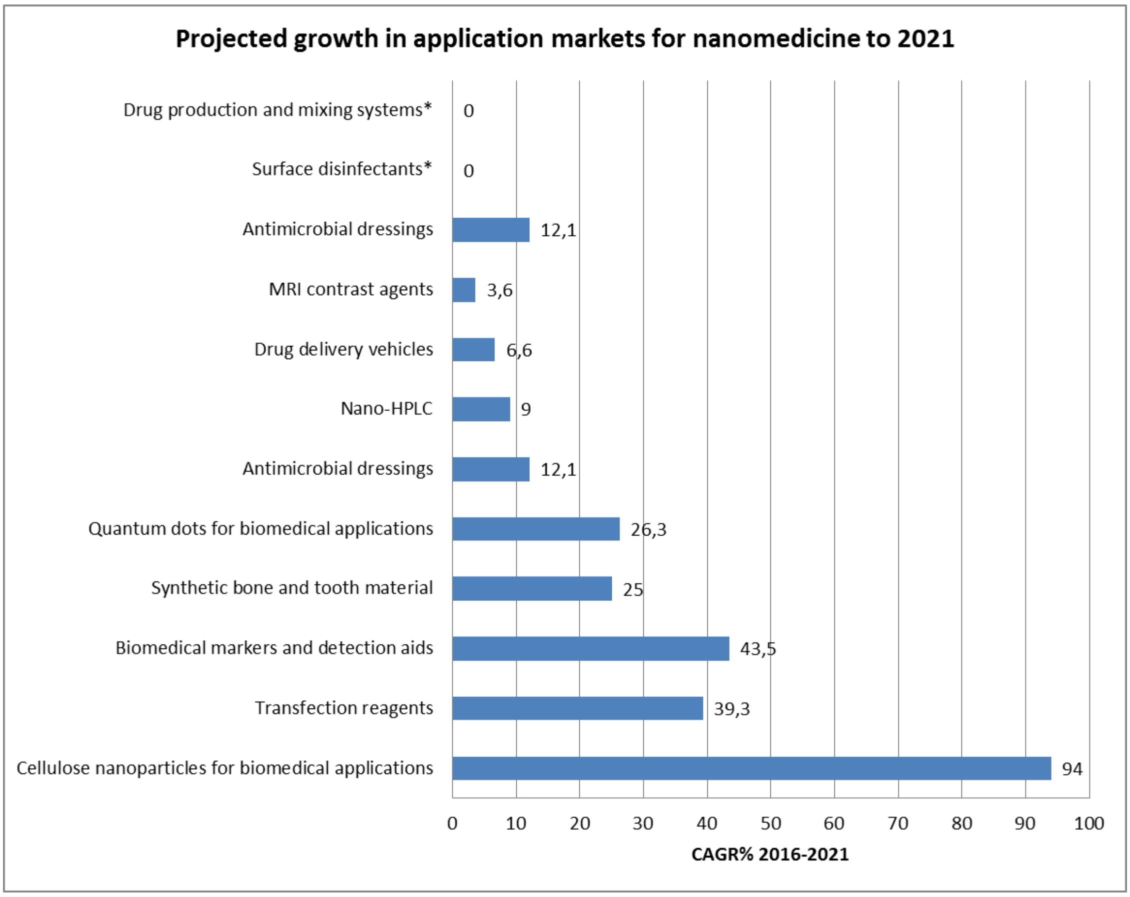

Figure 6.9. Projected growth in markets for health applications to 2021[34]

Source: BCC Research 2015, 2016 (*no growth data)

Cellulose nanoparticles for biomedical applications are forecast to have the most dynamic development to 2021, with a CAGR of 94%, almost five times the expected average growth of the total global market for nanotechnology products (CAGR 18.2%). The sales

[34] Data on cellulose nanoparticles are only available for the period 2014-2019

volume of these products is starting almost from zero (i.e. USD 0.2m in 2014 rising to USD 5.5m in 2019).

Transfection reagents and biomedical markers and detection aids are application markets that are forecast to grow more than twice as fast as the nanotechnology market as a whole. Commercialised transfection agents are already available in the market, and significant continued growth is expected[35]. MRI contrasting agents, drug delivery vehicles and nano-enabled HPLC (high-performance liquid chromatography) show growth prospects significantly below average growth rates. This may partly reflect the relative maturity of these parts of the market. Silver is already much used for anti-microbial solutions and recent studies have shown that resistance to these nanoparticles is on the rise, which may result in a stagnation or reduction in the market for them, or at least a reduced market growth rate[36].

Market growth forecasts are not available for emerging applications in health applications. Applications with noteworthy potential sales volumes include molecular imaging agents and medical implants.

Nanomaterial	Application market	Sales 2021 (USD M)
Solid nanoparticles	Molecular imaging agents	210.0
Thin films	Nano-magnetic-coated drug delivery devices	6.3
Thin films	Biocompatible coatings	7.3
Nanostructured monolithics	Medical implants	147.5
Nanocomposites	Orthopaedic implants	50.0

Table 6.9. Global sales and growth forecasts in emerging application markets for health applications to 2021 (USD millions)

Source: BCC Research 2015

5.3.4 Energy applications of nanotechnology

5.3.4.1 Overview

Global sales for nanotechnology products in the energy sector account for USD 1.9 billion in 2015 and an estimated USD 4 billion in 2021.

Growth is mainly driven by products that are already commercialised. Global sales in emerging application markets (currently without visible sales) are forecast to be USD 876 million in 2021. The global market volume for commercial products is, in comparison, estimated as USD 3.1 billion for the same year.

[35] Interview with Dr. Felicity Sartain, Director, Profiscio & Dr. Eric Mayes, CEO, Endomag Ltd

[36] Interview with Dr. Felicity Sartain, Director, Profisicio

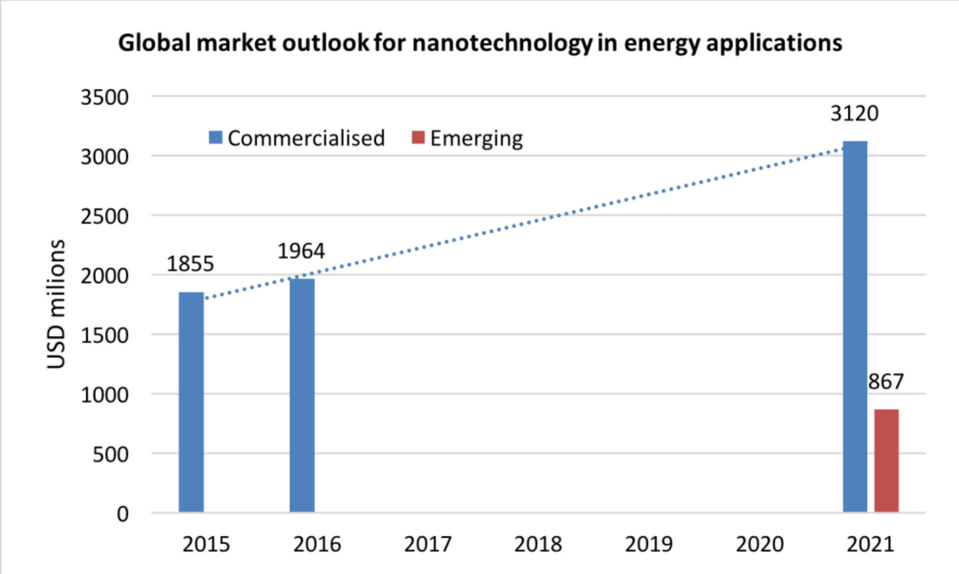

Table 6.10. Global market outlook for nanotechnology in energy applications to 2021

Source: BCC Research 2016

Application market	CAGR% 2016-2021	Sales 2021 (USD M)
Fuel and explosive additives	0.1	30
Refinery catalysts	3.4	232
Catalysts	3.5	1,888

Table 6.11. The least dynamic application markets in energy to 2021

Source: BCC 2014

The market for nanoparticulate fuel and explosive additives (CAGR 0.1%) is expected to stagnate. Application markets with modest growth prospects to 2021 are refinery catalysts (CAGR 3.4%) and catalysts (CAGR 3.5%).

Application markets with remarkable projected growth to 2019 are solar photovoltaics (CAGR 123%), quantum dots for photovoltaics (CAGR 27%), and synthetic fuel production (CAGR 40%).

Application market	CAGR% 2016-2021	Sales 2021 (USD M)
Solar photovoltaics	123.3	50
Quantum dots for photovoltaics	27.2	120
Synthetic fuels production	40.2	26

Table 6.12. The most dynamic application markets in energy to 2021

Sources: BCC 2014, 2015

5.3.4.2 Forecasts for individual application markets in energy and nanotechnology

Market data and forecasts could be identified for eleven application markets within nanotechnology for energy (see figure below).

Photovoltaics is showing the most dynamic projected development to 2021 with a CAGR in application markets of more than five times the expected average growth of the total global market for nanotechnology products (CAGR 18.2%).

Application markets in energy storage are forecast to grow almost twice as much as the whole nanotechnology market, while catalysts and fuel additives show growth prospects below average.

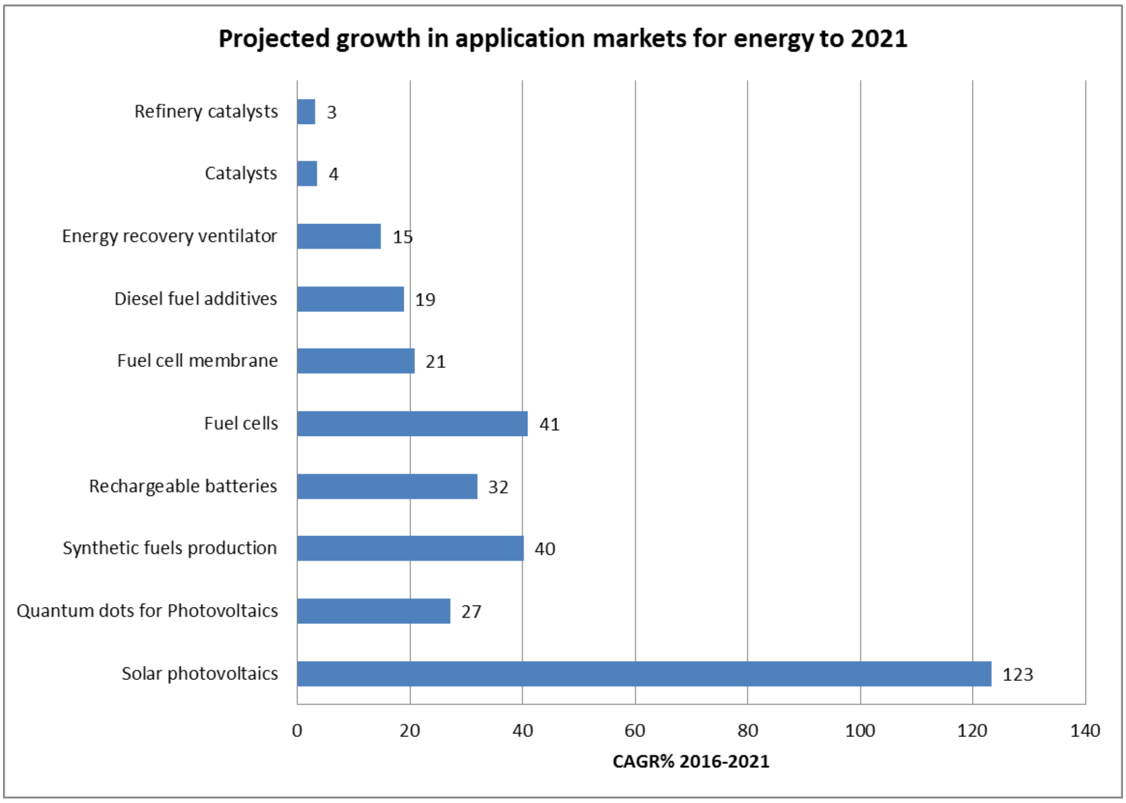

Figure 6.10. Projected growth in commercialised energy application markets to 2021

Source: BCC Research 2016

In emerging application markets, a growth forecast is only available for fuel cell membranes (i.e. nanostructured monolithics), which, at CAGR 27%, is expected to be above the 18.2% average growth expected for nanotechnology products overall.

Material	Application	Sales (USD millions)		CAGR%
		2016	2021	2016-2021
Cellulose nanoparticles	Oil	0	8	--
Nanoscale thin films	Transparent electrodes	0	117	–
Nanostructured monolithics	Fuel cell membranes	125	414	27
	Aero capacitors/ other electrochemical devices	Neg.*	399	–
Nanocomposites	Fuels cells	0	287	–

Table 6.13. Global sales and growth forecasts in emerging energy application markets to 2021[37]

[37] Data for Cellulose nanoparticles is only available for 2014-2019

Source: BCC Research 2015, 2016

With a projected CAGR to 2019 of 44%, the global market for graphene is forecast to develop more dynamically (CAGR: 19.8%) than the total market for nanotechnology products. No data on the estimated growth of application markets is available to 2019 but, for this emerging technology field, sales forecasts are available[38] for 2018 to 2023.

Application	Sales (USD millions)		CAGR%
	2018	2023	2018-2023
Capacitors	35	435	66
Photovoltaics	10	48	37
Batteries and fuel cells	0	62	--

Table 6.14. Global sales and growth in emerging application markets for graphene to 2023

Source: BCC Research

The forecasts show remarkable growth prospects for capacitors (CAGR 66%), but no estimates are available for batteries and fuel cells.

5.3.5 Photonics applications of nanotechnology

The commercial applications of nanotechnology in the field of photonics include: lasers and parts thereof, nano-engineered photonics materials, communications and all-optical signal processing, and nanoscale functional imaging and spectroscopy.

Global sales for nanotechnology products in the photonics sector account for USD 11.7 billion in 2015 and are forecast to be USD 43.5 billion in 2021. The figure below shows the forecast growth in commercialised products (USD 36 billion in 2021) and the expected growth in emerging products (USD 7.5 billion in 2021). It is seen that much of the growth is expected to be driven by already commercialised products.

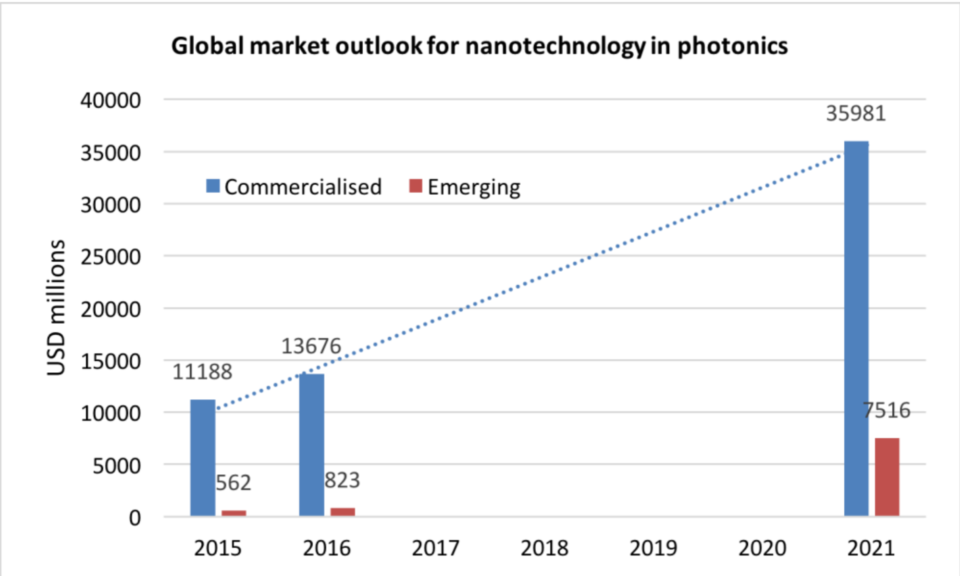

Table 6.15. Global market outlook for nanotechnology in photonics to 2021

Source: BCC 2016

[38] BCC Research

Application markets with remarkable projected growth to 2021 are quantum dots for optoelectronics (CAGR 164.3%) extreme ultraviolet lithography (CAGR 52.8%) and flat panel displays (CAGR 33.8%).

Application market	CAGR% 2016-2021
Quantum dots for optoelectronics	164.3
Extreme ultraviolet lithography	52.8
Flat-panel displays	28.4

Table 6.16. The most dynamic application markets in nanotechnology for photonics to 2021

Source: BCC Research 2015, 2016

Optical recording media (CAGR -2.8%) is the only application market for nanotechnology with projected negative growth to 2021 in the photonics sector., and hard disk media and heads (-9.7%). The main driver of this trend is the increasing online availability of media content (i.e. via Spotify, iTunes, Netflix etc.). The markets for nanoimprint lithography and light-emitting diodes (LEDs) are expected to stagnate (CAGR 0%).

Application market	CAGR% 2016-2021
Optical recording media	-2.8
Light-emitting diodes (LEDs)	0.0
Nanoimprint lithography	0.0

Table 6.17. The least dynamic application markets in photonics to 2021

Source: BCC 2016

5.3.6 Environmental applications of nanotechnology

5.3.6.1 Overview

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

Global sales of nanotechnology products for *air remediation* applications accounted for nearly USD 9.4 billion in 2014. During the forecast period of 2015 to 2020, the market is expected to grow at a compound annual growth rate (CAGR) of 10.3%, to reach USD 16.7 billion in 2020. The nanotechnology market for *water remediation* applications totalled nearly USD 8.2 billion in 2014, and is expected to grow at a CAGR of 12.4% to reach USD 16.6 billion in 2020. *Soil remediation* applications accounted for nearly USD 5.9 billion in 2014 with forecast growth of CAGR 6.4% to reach USD 8.4 billion in 2020[39].

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

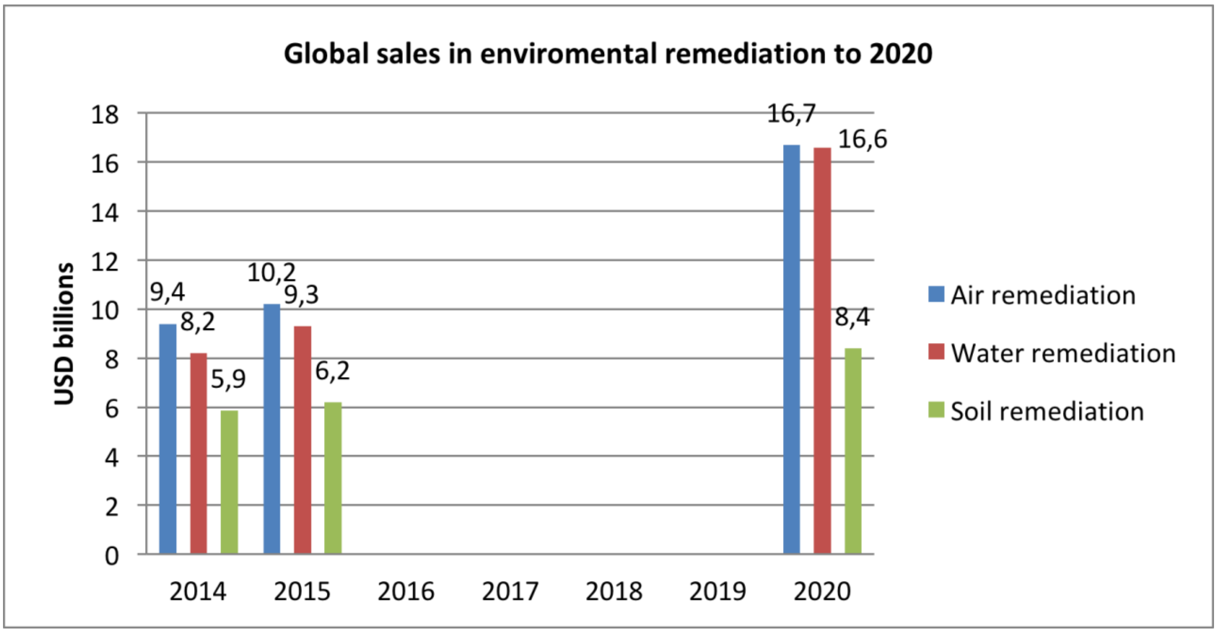

Table 6.18. Global market outlook for nanotechnology in environmental remediation applications to 2020

Source: BCC Research 2015

5.3.6.2 Forecasts for individual application markets in environment

Market data and forecasts could be identified for seven application markets within nanotechnology for environmental remediation.

Application market	Sales 2021 (USD M)	CAGR% 2016-2021
Nanoporous membranes	1,256	16.9
Nanotechnology for water remediation*	16,645	12.4
Nanotechnology for air remediation*	16,728	10.3
Nanotechnology for soil remediation*	8,427	6.4
Catalytic converters	17,606	5.5
CNT based water filtrations systems	no data	no data
Nanocomposite water purification filters	150	41.1

Table 6.19. Global sales and growth in commercialised environmental remediation application markets to 2021

Source: BCC Research 2015, 2016 (*values for 2020, CAGR 2015-2020)

With the exception of nanocomposite water purification filters (CAGR 41.1%), all application markets in nanotechnology for environmental remediation are projected to grow more slowly than the total market for nanotechnology products (18.2%). However, it should be noted that rather high sales volumes are expected in 2020 for all areas of environmental remediation.

There is no data available on market development in emerging application markets. The market for water desalination membranes based on nanostructured monolithics is expected to reach sales of USD 150 million in 2019, while the market size for cellulose nanoparticles in membranes and filters is projected to be USD 28 million in 2019.

Application market	Sales 2021 (USD millions)	CAGR% 2016-2021

Application market	Sales 2021 (USD millions)	CAGR% 2016-2021
Water desalination membranes	150	No data
Cellulose nanoparticles in membranes, filters	27.7	No data

Table 6.20. Global sales and growth in emerging environmental remediation application markets to 2021

Source BCC Research 2016

5.3.7 Transport applications of nanotechnology

5.3.7.1 Overview

Global sales for nanotechnology products in the transport sector were estimated to be USD 15.2 billion in 2016 and are forecast to grow to USD 21.5 billion by 2021. The figure below shows the forecast growth by 2021 of commercialised products (USD 2.3 billion in 2021) and emerging products (USD 0.89 billion in 2021), much of the growth being expected in products that have already been commercialised.

Growth is seen to be largely driven by products that have already been commercialised. Global sales of emerging products are expected to have a value of USD 773 million in 2021. The global market volume for commercial products is much higher at an estimated USD 20.7 billion for the same year.

Application markets with modest growth prospects to 2021 are tubes for high-pressure discharge lamp (CAGR 7.5%), nanostructured structural steel (CAGR 9%) and photocatalytic coatings (CAGR 10.4%).

Application markets with remarkable projected growth to 2019 are cellulose nanoparticles in coatings, paint and films (CAGR 131.6%), rechargeable batteries and fuel cells (both CAGR 36%).

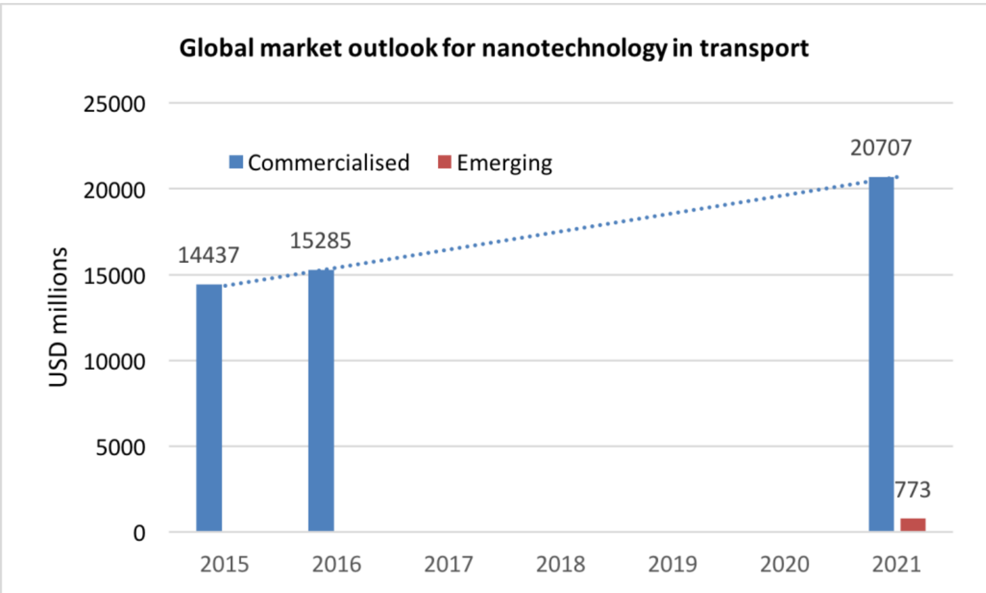

Figure 6.11. Global market outlook for nanotechnology in transport applications to 2021

Source: BCC Research 2014

Nanomaterial	Application market	CAGR% 2016-2021	Sales 2021 (USD M)
Nanostructured monolithics	High-pressure discharge lamp tubes	8	5
	Nanostructured structural steel	90	10
Nanoscale thin films	Photocatalytic coatings	10	219

Table 6.21. The least dynamic application markets in transport to 2021

Source: BCC Research 2014

Nanomaterial	Application market	CAGR% 2014-2019	Sales 2019 (USD M)
Cellulose nanoparticles	Cellulose nanoparticles in coatings, paint, films	132	67
Solid nanoparticles	Rechargeable batteries	36	450
Nanoscale thin films	Fuel cells	36	122

Table 6.22. The most dynamic application markets in energy to 2021

Sources: BCC 2014, 2015

5.3.7.2 Forecasts for individual application markets in transport and nanotechnology

Market data and forecasts could be identified for thirteen application markets within nanotechnology for transport.

The market for cellulose nanoparticles in coatings and paints is showing the most dynamic projected development to 2019 with a CAGR (131.6%) of more than six times the expected average growth of the total global market for nanotechnology products (CAGR 18.2%).

Application markets in energy storage (fuel cells) are forecast to grow twice as much as the whole nanotechnology market, while hydrophobic/oleophobic nanocomposites and nanocomposites in automotive components show growth prospects only slightly above average.

In emerging application markets, a growth forecast is only available for ultra-thin batteries and capacitors (i.e. carbon nanotubes (CNTs)) fuel cell membranes (i.e. nanostructured monolithics) with an estimated growth that is expected to be above the average growth of the total market for nanotechnology products (CAGR 18.2%).

With a projected CAGR to 2019 of 44%, global markets for graphene will develop more dynamically than the total market for nanotechnology products (CAGR: 19.8%). No data on estimated growth of application markets is available to 2019 but sales forecasts are available to 2023.

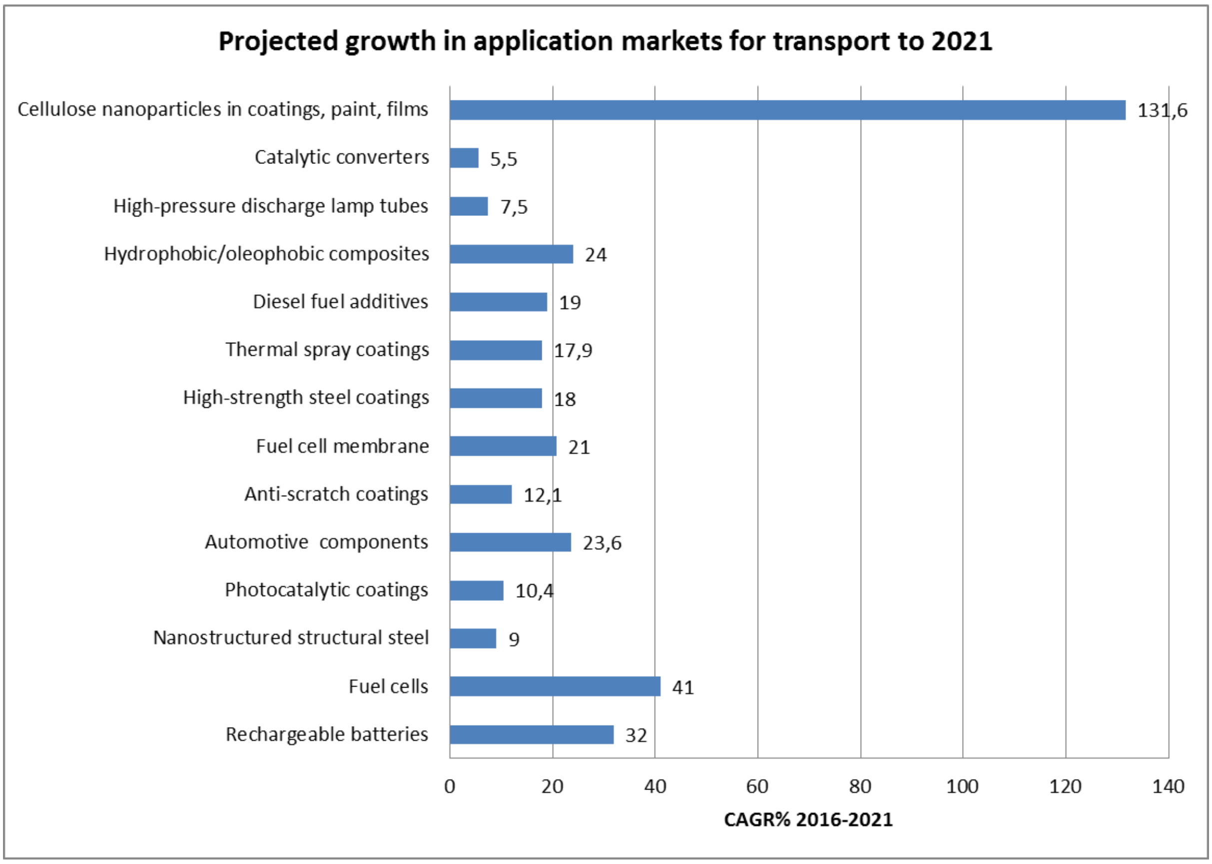

Figure 6.12. Projected growth in commercialised transport application markets to 2021[40]

Source: BCC Research 2016

Material	Application	Sales (USD M)		CAGR%
		2016	2021	2016-2021
Carbon nanotubes	Conductive fibres	0	75	--
Carbon nanotubes	Ultra-thin batteries and capacitors	0	22.6	124.1
Nanostructured monolithics	Fuel cell membranes	69	414.4	27
Nanostructured monolithics	Aerocapacitors/ other electrochemical devices	Neg.*	398.6	–
Nanocomposites	Fuel cells	0	287	–

Table 6.23. Global sales and growth forecasts in emerging transport application markets to 2021

Application	Sales (USD millions)		CAGR%
	2018	2023	2018-2023
Capacitors	35	435	66
Structural materials	51	190	30

[40] Data for cellulose nanoparticles are only available for 2014-2019

Application	Sales (USD millions)		CAGR%
	2018	2023	2018-2023
Batteries and fuel cells	0	62	--

Table 6.24. Global sales and growth in emerging application markets for graphene (USD millions)

Source: BCC Research

The forecasts show strong growth prospects for capacitors (CAGR 66%) and a growth above average (CAGR 30%) in structural materials (i.e. graphene-polymers and other graphene composites). No data on estimated market growth is available for batteries and fuel cells.

5.3.8 Construction applications of nanotechnology

5.3.8.1 Overview

Global sales for nanotechnology products in the building and construction sector accounted for USD 1.8 billion in 2015 and are forecast to be USD 4.8 billion in 2021. The figure below shows the forecast growth in commercialised products (to USD 4.77 billion in 2021) and the expected growth in emerging products (to USD 375 million in 2021). It is seen that much of the growth is expected to be driven by products that are already commercialised.

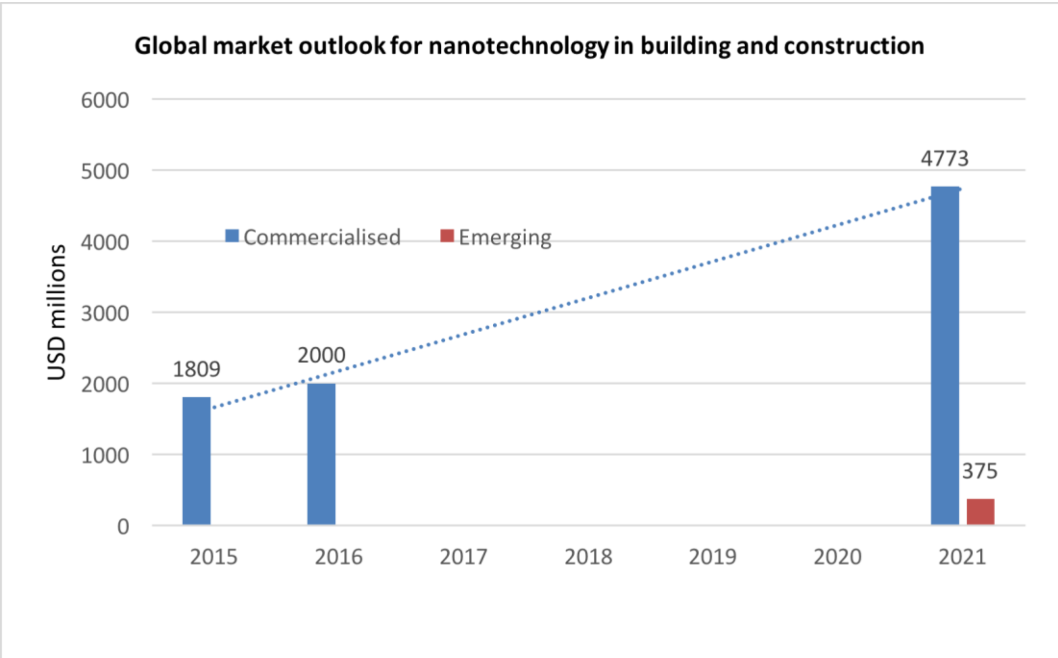

Figure 6. 13. Global market outlook for nanotechnology in building and construction to 2021

Source: BCC Research 2016

A comparison of global sales estimates by type of nanomaterial shows that solid nanoparticles accounted for the largest market share in 2015 and the market is expected to decrease to half its size by 2021. Thin films, in contrast, are expected to significantly increase their relative share to 2021.

The share of nanostructured monolithics is expected to almost double by 2021, while sales of nanocomposites are projected to increase in relative share only on a comparatively modest scale. Carbon nanotubes are currently forecast to play only a marginal role in terms of shares of sales.

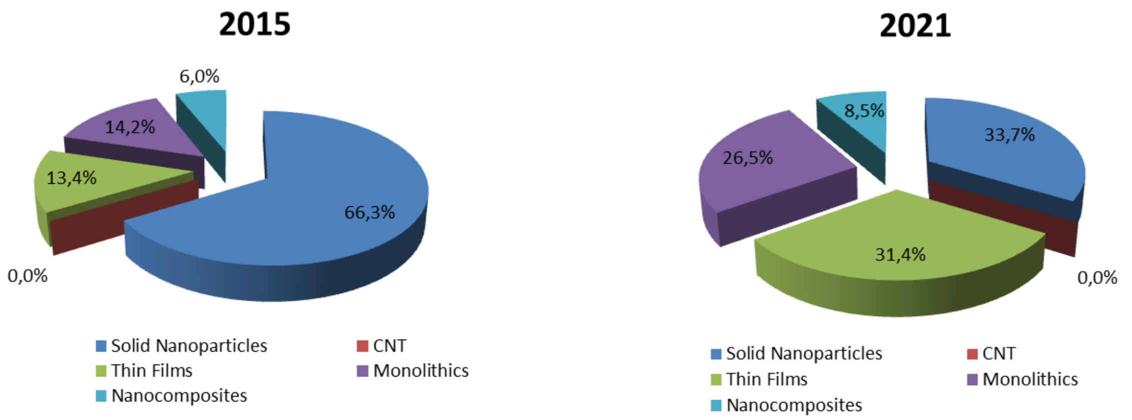

Figure 6.14. Global sales estimates for nanotechnology in building and construction by material type, 2015 and 2021

Source: BCC Research 2016

5.3.8.2 Forecasts for application markets in construction

Market data and forecasts could be identified for nine application markets within nanotechnology for construction.

Application market	Sales 2021 (USD M)	CAGR% 2014-2019
Coatings and adhesives	1,608	5
Nanostructured structural steel	10	9
Photocatalytic coatings	266	10
Anti-scratch coatings	202	14
High-strength steel coatings	4	9
Wire and cable sheathing	84	23
Hydrophobic/ oleophobic composites	320	25
Insulation	2,125	31
Cellulose nanoparticles in coatings, paint, films	67	132

Table 6.25. Projected growth and market size in commercialised application markets for construction to 2021[41]

Source: BCC Research 2014, 2016 (*values for 2020, CAGR 2015-2020)

Application market	Sales 2021 (USD M)	CAGR% 2014-2021
Conductive fibres from nano-composites	160	No data
Conductive fibres from carbon nanotubes	75	No data

Table 6.26. Projected growth and market size in emerging application markets for construction to 2021

[41] Data for cellulose nanoparticles are only available for 2014-2019

Source BCC Research 2014

Application markets in nanotechnology for construction that are projected to grow faster than the total market for nanotechnology products (18.2%) are cellulose nanoparticles in coatings, paint, films (CAGR 132%), insulation (i.e. aerogels) (CAGR 31%), hydrophobic/oleophobic composites (CAGR 25%) and fire-resistant wire and cable sheathing (CAGR 23%).

Emerging application markets are seen in conductive fibres, either from nano-composites or carbon nanotubes.

Further details are given in the Annex: Products and markets by sector.

The next section looks at regulation and standards for nanotechnology.

6 THE WIDER CONTEXT: REGULATIONS AND STANDARDS FOR NANOTECHNOLOGY

6.1 Regulation in the European Union

6.1.1 REACH

Nanomaterials must comply with the overarching regulatory framework in place for chemical substances: *Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).* The European Commission periodically assesses the regulation regarding its applicability and effectiveness to address nanomaterials. With the *First Regulatory Review on Nanomaterials SEC (2008) 2036* and the *Second Regulatory Review on Nanomaterials SWD (2012) 288 final*, the Commission gave REACH a central role in regulating nanomaterials. *"There are no provisions in REACH referring explicitly to nanomaterials. However, nanomaterials are covered by the 'substance' definition in REACH",* states the 2008 EC Communication.

Since 2013, there has been ongoing work to adapt the Annexes of REACH to specifically cover nanomaterials. An impact assessment and a large consultation on this issue have been run by the European Commission but discussions are still ongoing. However, the rules of ECHA (the European Chemicals Agency) prevent the modification of the regulation two years prior to the next round of registration, which is set for June 2018. This rule also applies to guidance documents that the Agency provides to support registrants. In 2016, ECHA nevertheless announced that four guidance documents related to nanomaterials would be released in May 2017, one year prior to the next registration deadline. On 25 May 2017[42], the agency published:

- How to prepare registration dossiers that cover nanoforms - best practices;
- Nano-specific Appendix to Chapter R.6 of the Guidance on Information Requirements and Chemical Safety Assessment (QSARs and grouping of chemicals);
- Updates to Guidance on IR&CSA (Endpoint specific guidance):
  - Appendix to Chapter R.7a for nanomaterials - Recommendations for physico-chemical endpoints;
  - Appendix to Chapter R.7b for nanomaterials - Recommendations for ecotoxicological endpoints for nanomaterials (general advice, fate and specific endpoints); and
  - Appendix to Chapter R.7c for nanomaterials - Recommendations for ecotoxicological endpoints for nanomaterials (specific advice and specific endpoints).

On 9 October 2017, the European Commission published its proposal for amending the REACH Annexes to address nanoform substances. The proposal, in the form of a Commission Regulation to amend Annexes I, III, VI, VII, VIII, IX, X, XI and XII, introduces specific provisions for 'nanoforms' and 'sets of nanoforms' and shall apply from 1 January 2020, while at the same time allowing users to comply before that date. The Commission Regulation would require, for substances which exist in one or more nanoforms that chemical safety reports also describe which nanoforms are manufactured and imported. It would also specifically require information on all identified uses for each nanoform. The modified annexes also clarify how manufacturers and importers shall report study results for nanomaterials. The document is currently open for consultation.

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[42] echa.europa.eu

6.1.2 *Definition of a nanomaterial*

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

The definition is the following:

"2. 'Nanomaterial' means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50% may be replaced by a threshold between 1 and 50%."

Developed in 2011, this definition is undergoing a review process with a planned conclusion date of December 2014. An outcome of this review could be a revision of the definition. The process of review of this definition is still ongoing. Other definitions have been developed inside the legal text of several sectorial regulations which address nanomaterials (from biocides to food).

In the proposal for amending the REACH Annexes to address nanoform substances, the European Commission introduced a new term: nanoform. This term is based on the *Recommendation on the Definition of a Nanomaterial* as it states:

'(…) a form of a natural or manufactured substance 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 1 nm- 100 nm, including also by derogation fullerenes, graphene flakes and single wall carbon nanotubes with one or more external dimensions below 1 nm, is a nanoform of a substance.'

6.1.3 *Databases and reporting schemes*

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.

Under the Belgian Presidency of the European Union, in 2010, the European Union opened the discussion on a 'harmonised database of nanomaterials'. This was followed by a 2012 letter to the European Commission calling for a European Reporting Scheme and signed by ten European Member States, plus Croatia. In the meantime, some European Member States have been proceeding.

6.1.3.1 *Belgium*

The Belgian FPS (Public Health, Food Chain Safety and Environment) has also been working on a similar scheme. In February 2014, the Belgian Council of Ministers validated the Royal Decree regarding the Placement on the Market of Substances manufactured at the nano-scale (*Koninklijk besluit betreffende het op de markt brengen van als nanodeeltjes geproduceerde stiffen* or *Arrêté royal relatif à la mise sur le marché des substances manufacturées à l'état nanoparticulaire*). The registration of substances began on 1 January 2016, while mixtures had to be registered from 1 January 2017. The definition of nanomaterials used is that of the EC Recommendation 2011/696/EU, but excluding naturally occurring and incidental nanomaterials, as well as pigments. Also excluded are nanomaterials which fall under other EU legislation (e.g. biocides, food products).

6.1.3.2 *Denmark*

Following a public consultation, the Danish Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register - BEK nr 644 came into force in June 2014. With this Order, the Ministry of the Environment creates a national mandatory database of nanomaterial-containing products that registered the first products for the year 2014 in the year 2015. The definition of nanomaterials included in the executive order follows the European Commission definition.

Certain activities or products are excluded from the registration requirement: nano-products sold between businesses and products that fall under specific regulations (e.g. food, feed, pharmaceuticals, medical devices, cosmetics, pesticides and waste). The following specific products in which nanomaterials are used are also excluded:

- Nano-sized products of substances in REACH Annex V
- Products where the material is not consciously produced in nano-size
- Products where the nanomaterial is in a fixed matrix
- Products where the nanomaterial is used as printing ink directly on the product or on labels on the product
- Textiles where the nanomaterial is used as printing ink or to colouring of the textile
- Paints and wood protection products containing titanium dioxide where the sole purpose for the titanium dioxide is to colour the product
- Products of rubber or rubber parts that contain the nanomaterials carbon black or silicon dioxide.
- Products imported for private use
- Products used for research and development.

6.1.3.3 France

As part of the electoral promises of the 2007 Presidential Elections, the 'Grenelle de l'Environnement', a large environmental debate was organised in France and resulted in major environmental acts: *Grenelle Acts (Lois Grenelle I & II)* which enacted the future creation of a mandatory reporting scheme for nanomaterials. France hence took steps towards setting up the first registration scheme for substances at the nano-scale in Europe; in 2012, the Decree[43] 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 grammes". The French legislation refers to, and is applicable to, substances as defined in article 3 of EC Regulation no. 1907/2006 (REACH), that are intentionally produced at nanometre scale, containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for a minimum proportion of particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm. Furthermore: "in specific cases and where warranted by concerns for the environment, health, safety or competitiveness, this minimum proportion may be reduced".

A Joint Order (Ministerial Order of 6 August 2012) issued by the Ministers of environment, agriculture, health labour and industry states "The minimum proportion of the number size distribution is specified to be 50%".

[43] 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

6.1.3.4 Other European Countries

Other EU Member States and associated countries have been considering options for a registration scheme for nanomaterials.

- Norway is considering such a register under its Pollution Control Authority (SFT). Since 2013, the Norwegian Product Register has required information for chemicals containing 'a substance in nano form' with a 'tickbox' system.

- Sweden has given the mandate to its chemical agency (KEMI) to develop a reporting scheme. In the spring of 2016, KEMI declared that it aimed to establish a Swedish registry in 2019 which would register manufactured and imported quantities during 2018.

- Italy is also considering setting up a similar system.

With these initiatives, EU Member States have been leading the way and encouraging the European Commission to act. An overview of regulations for nanotechnology use in Europe is given below.

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

Table 7.1. Overview of regulations for nanotechnology use in Europe

The Second Regulatory Review on Nanomaterials of 2012 included an impact assessment of potential transparency measures (which include approaches similar to the reporting schemes set in action in several Member States). The *Study to Assess the Impact of Possible Legislation to Increase Transparency on Nanomaterials on the Market* was led by RPA and BiPro. Three reports were published to help the EC to decide on an eventual EU-wide registry of nanomaterials. Early in 2016, the European Commission has stated that it will not go forward with an EU-wide nanomaterial registry but would rather support the establishment of a knowledge base entitled the 'Nanomaterials Observatory' which would contain publicly available information on nanomaterials and their use in Europe. The EU - Observatory for Nanomaterials (EU-ON) was formally launched by ECHA in June 2017; it takes the form of a website, hosted by the chemicals agency, available at https://euon.echa.europa.eu/, where information on nanomaterials and regulation can be found.

6.2 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 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'. This new rule addressing nanomaterials under TSCA was promulgated in January 2017 and was initially intended to come into force in May 2017, this was however postponed to 14 August 2017.

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'. In 2015, Canada required manufacturers and importers to register information on a selection of 206 substances at the nanoscale under the *Canadian Environmental Protection Act (CEPA 1999*). Following the registration of those substances, Environment and Climate Change Canada have started prioritising the substances for further regulatory action.

European products are also subject to regulatory frameworks in other countries if they are to be marketed abroad. Marketing authorisations have to be applied for in each region or country and there are considerable differences between, for example, the US (implemented by the FDA[44]), Canada, Australia, China and Japan.

6.3 Standardisation and nanotechnology

At the international level, the International Organisation for Standardisation (ISO) is responsible for the standardisation of nanotechnologies with its TC 229.

In Europe, the equivalent group is the European Committee for Standardisation committee on nanotechnology (CEN/TC 352) which has, for example, a working group on health safety and environmental aspects. While standardisation bodies have nanotechnology committees, nanotechnologies are cross-sectoral and are therefore relevant in other specific TCs of ISO. The EU FP7 project NanoSTAIR[45] identified all ISO/TCs working with nanotechnologies.

Further details are given in the Annex: Regulations and standards by sector.

[44] US Food and Drug Administration http://www.fda.gov/

[45] http://cordis.europa.eu/result/rcn/157623_en.html

7 CONCLUDING SUMMARY

This Landscape Compilation Update Report 2017 shows that the domain of nanotechnology has grown since 2015 in terms of the numbers of publications produced worldwide annually, the number of nanotechnology-related products and the size of markets for those products and for nanomaterials.

Changes in nanotechnology-related programmes in the EU can be expected to impact on the development of the field in the coming years in terms of outputs and their commercialisation. In particular, the main funding policy around nanotechnology, Horizon 2020, has an increased emphasis (over its predecessor) on societal impacts, collaboration with industry, market-related application of research results, and increased financial support for SMEs. Recent changes in the regulatory area are also expected to impact on the environment for nanotechnology in Europe. The most recent development is the proposal to implement (from 1 January 2020) amendments to the annexes of REACH to address nanoforms of substances.

The growth in nanotechnology is taking place at the global level, in some respects being even stronger in other parts of the world than in the EU. While the number of global nanotechnology publications is growing, the proportion coming from the EU28&EFTA countries forms a decreasing percentage of those, with strong growth being seen in Asia, particularly China. Within the EU, the countries that lead in nanotechnology research and development and its application are mainly, and remain, Germany, France and the United Kingdom and organisations in those countries contribute to the highest numbers of publications.

The greatest number of patents identified for nanotechnology is in the ICT sector, with over twice the number of patents of any of the other NanoData sectors, the strongest patenting countries in the EU28 being Germany, the Netherlands, France the United Kingdom and Belgium, with organisations such as the CEA (FR) and CNRS (FR) and IMEC (BE). EU companies with patents in ICT include Infineon (DE), Philips (NL) and NXP (NL).

The largest number of products in which nanotechnology is being applied in some way are found in the transport sector (nearly 500 in 2017), followed by health, manufacturing (a large part of which are the nanomaterials used in other products) and energy (all with about half the number of products of transport (250-300). Of the sectors considered, construction (156) and environment (79) have the lowest numbers of products. The highest growth in product numbers since 2015 is seen in health and ICT. There is strong growth in products that are applicable across multiple sectors, such as materials, coatings and composites. Markets for nanotechnology-related products are forecast to grow in all sectors and by over 150% in health (e.g. for diagnostic imaging and implants) and ICT (e.g. in optical electronics).

This document has provided a detailed overview of the landscape for nanotechnology in the EU in 2017 and is complemented by the annexes, which now follow.

ANNEX 1: PUBLICATION DATA BY SECTOR[46]

This Annex presents publication data by sector, in each case including:

- Nanotechnology publication data over time globally (2000-2016);
- Nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016);
- The nanotechnology publication output time trend in EU28&EFTA and the world (indexed to year 2000=1);
- The number of nanotechnology publications by region (2000-2016);
- Nanotechnology publication output by country (2016) (world and EU28 and EFTA countries);
- Nanotechnology publication output by higher education institutions (2016); and
- Nanotechnology publication output by companies (2016).

Where applicable, data is also reported on sub-sectors (e.g. in health and energy).

The order of the sectors is determined by the level of production of nanotechnology publications, starting with ICT as it has the most publications and following in the order:

- Information and communications technologies (ICT);
- Manufacturing (MF);
- Health (HT);
- Energy (EN);
- Photonics (PH);
- Environment (EV);
- Transport (TR) and
- Construction (CN).

[46] It should be noted that, in attributing publications, full counting is used, meaning that publications may be assigned to more than one actor. Where a person, organisation or a country is said to have a number of publications, they contributed to that number of publications, but they may not have been the only contributor.

INFORMATION AND COMMUNICATIONS TECHNOLOGIES (ICT)

Around 2.3 million publications globally were identified[47] from the Web of Science as being related to nanoscience and technology (NST)[48] between 2000 and 2016. Of these 800,000 (35%) were related to ICT and nanotechnology. Looking at the global numbers of publications over time[49], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications rose by 7% in ICT, from 11% to 18%.

Year	ICT in all science	ICT & NST	% NST
2000	192,832	21,690	11%
2001	200,627	23,943	12%
2002	212,195	25,869	12%
2003	227,622	28,059	12%
2004	244,026	31,505	13%
2005	261,918	34,707	13%
2006	280,233	38,136	14%
2007	295,265	40,975	14%
2008	321,655	44,086	14%
2009	342,061	47,226	14%
2010	353,458	49,643	14%
2011	380,441	55,609	15%
2012	402,765	59,828	15%
2013	429,750	66,478	15%
2014	448,485	74,690	17%
2015	468,491	81,200	17%
2016	482,216	86,176	18%

Table A1.1. Publication output in ICT and in ICT and nanotechnology (NST) globally over time (2000-2016)

For ICT, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from nearly 9,000 in year 2000 to nearly 22,000 in 2016 but the proportion dropped from 40% to 25% relative to global output in the same timeframe (see figure below).

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

[48] 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.

[49] See tables in Annex: Publication data

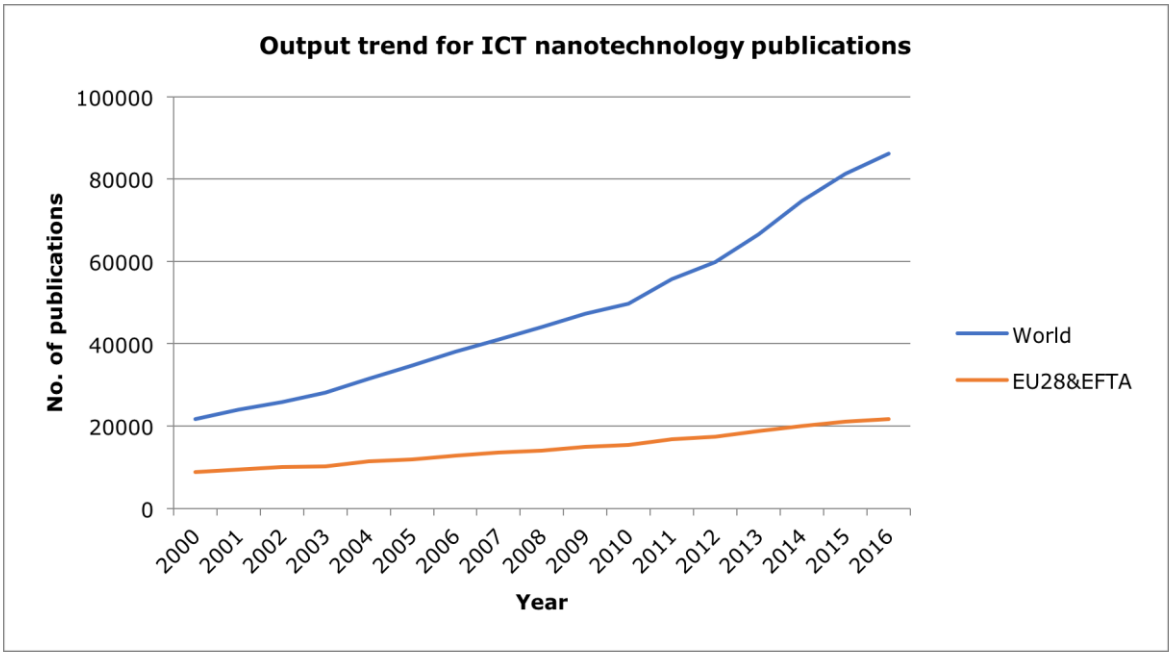

Figure A1.1. ICT nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

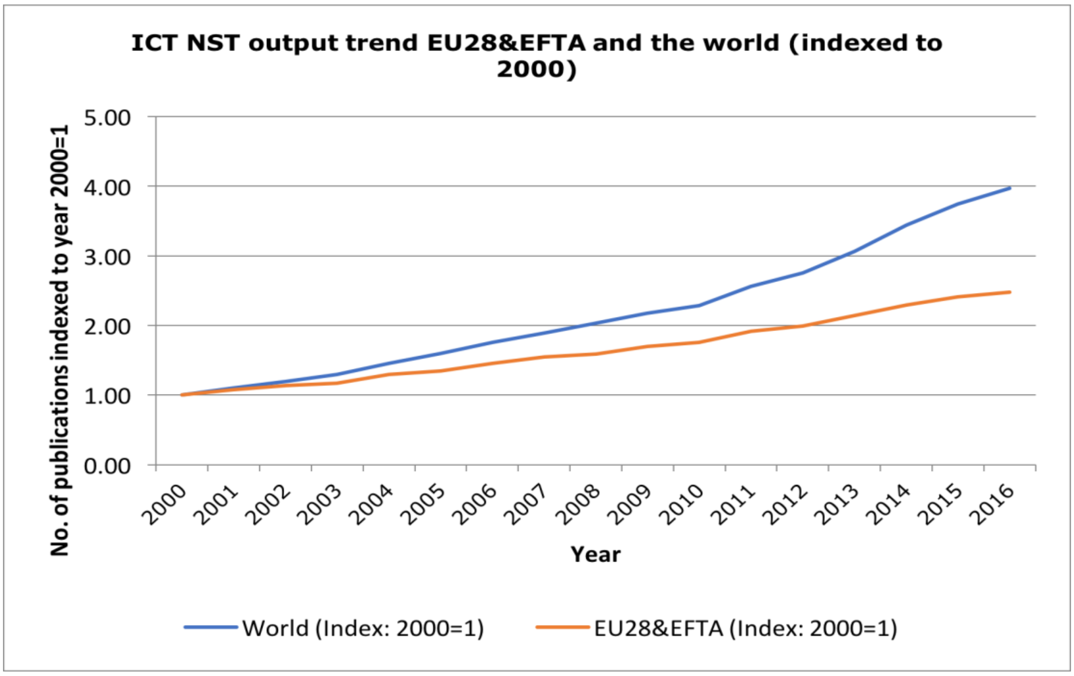

Figure A1.2. Output trend for nanotechnology and ICT in EU28&EFTA and the world

The most prolific region in NST for ICT is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub
Asia	419,031
EU28&EFTA	255,411

Region	Npub
North America	166,130
Middle East	44,155
South & Central America	25,134
Oceania	17,447
Africa	12,410

Table A1.2. Number of publications by region for ICT and nanotechnology (2000-2016)

In 2016, the most prolific country in NST for ICT is China, followed at a distance by the US and at a further distance by India, South Korea, Germany and Japan. In EU28&EFTA the most prolific countries are (besides Germany, UK, and France), Spain, Italy and Poland.

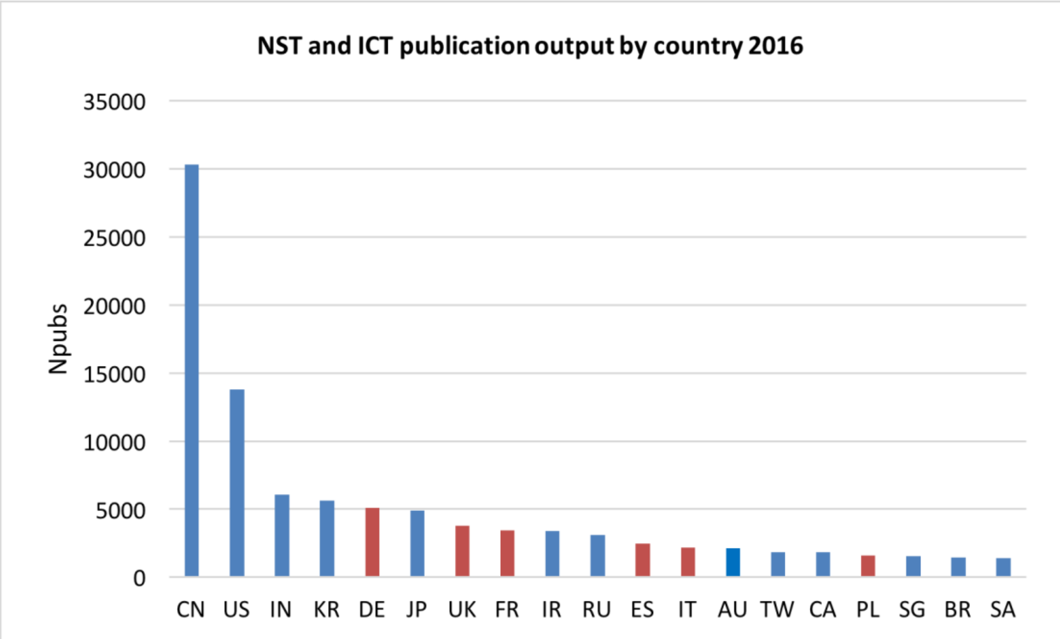

Figure A1.3. Publication output by country in ICT and nanotechnology (2016)

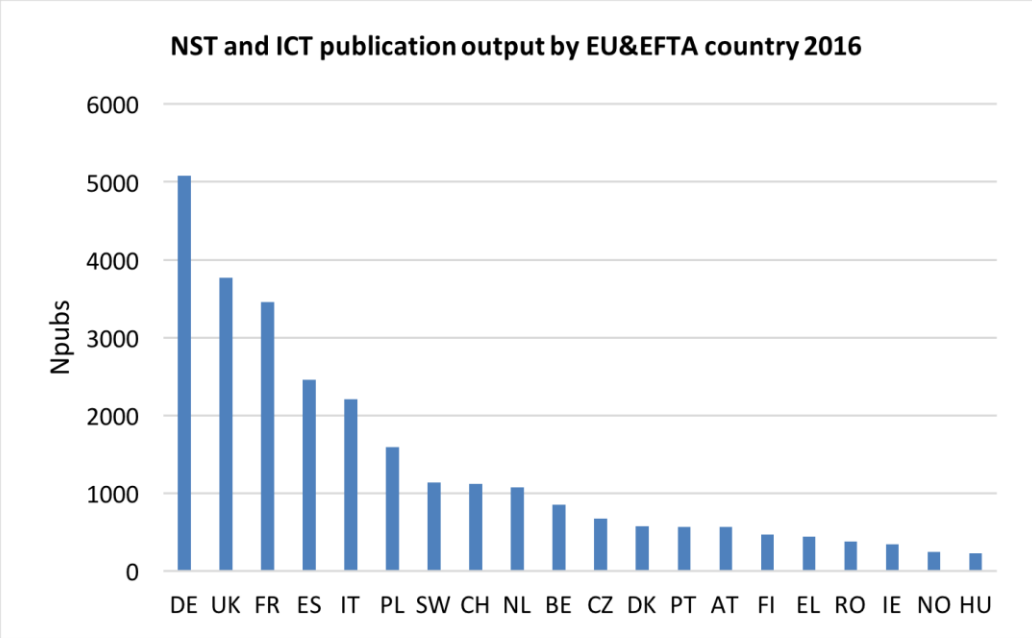

Figure A1.4. Publication output by EU&EFTA country in ICT and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST ICT are higher education institutions, research and technology organisations[50] and industry. The most active organisations in NST for ICT publications in 2016 are shown in the table below. The higher education organisations contributing to the most NST for ICT publications globally in 2016 were the Chinese Academy of Sciences, Russian Academy, the CNRS and Tsingua University (all of them with more than 1000 publications).

Within EU28&EFTA, the CNRS, Max Planck CNR and CSIC (all PRO's), University of Cambridge, CEA, Polish Academy and Imperial College are the most active organisations, contributing to the highest numbers of publications.

Institution	Country	Npub
Chinese Academy of Sciences	CN	4809
Russian Academy of Science	RU	1795
Centre National de la Recherche Scientifique (CNRS)	FR	1106
Tsinghua University	CN	1076
Peking University	CN	802
Jilin University	CN	768
Nanyang Technological University	SG	753
University of Science and Technology of China	CN	749
Zhejiang University	CN	728

[50] It should be noted that in these overviews, the (public) research organisations are much more present than in the previous report. This is due to a major cleaning of WoS addresses (conducted at CWTS in the past few years). There is a growing consciousness of the role of PRO's that has triggered this effort. It does not yet make sense to present results on the level of individual institutes of PROs like the Max Planck Gesellschaft, for instance, as they are often missing and only the umbrella organisation is mentioned.

Institution	Country	Npub
Nanjing University	CN	719
Max Planck[51]	DE	672
Harbin Institute of Technology	CN	662
Soochow University	CN	630
National University of Singapore	SG	624
Tianjin University	CN	615
Huazhong University of Science & Technology	CN	606
Xi'an Jiaotong University	CN	600
Council for Scientific and Industrial Research	IN	594
Consiglio Nazionale delle Ricerche (CNR)	IT	581
Shanghai Jiao Tong University	CN	578
Fudan University	CN	575
Spanish National Research Council (CSIC)	ES	569
Islamic Azad University	IR	535
Seoul National University	KR	519

Table A1.3. Publication output in ICT and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
Centre National de la Recherche Scientifique (CNRS)	FR	1106
Max Planck Society	DE	672
Consiglio Nazionale delle Ricerche (CNR)	IT	581
Spanish National Research Council (CSIC)	ES	569
University of Cambridge	UK	436
Commissariat a l'Energie Atomique (CEA)	FR	385
Polish Academy of Sciences	PL	335
Imperial College London	UK	333
Karlsruhe Institute of Technology	DE	329
Ecole PolyTechnique Federale de Lausanne (EPFL)	CH	323

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

Institution	Country	Npub
ETH Zurich	CH	301
University of Oxford	UK	301
Communauté Université Grenoble-Alpes	FR	295
Technische Universität Dresden	DE	293
University of Manchester	UK	287
KTH Royal Institute of Technology	SE	286
Czech Academy of Sciences	CZ	268
Technical University of Denmark	DK	263
University of Paris XI - Paris-Sud	FR	259
Forschungszentrum Jülich	DE	249
University College London	UK	246
Delft University of Technology	NL	230
Katholieke Universiteit Leuven	BE	230
RWTH Aachen University	DE	229

Table A1.4. Publication output in ICT and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for ICT (2016) are shown in the table below. The companies contributing to the most nanotechnology ICT publications globally in 2016 were Samsung, IBM, Toyota and Intel, as shown in the table of the top publishing companies worldwide. Some companies appear more than once, having subsidiaries in different countries.

Company	Country	Npub
Samsung Electronics	KR	172
IBM Corporation	US	88
Toyota Motor Co Ltd	JP	52
Intel Corporation	US	48
NTT Advanced Technologies Corporation	JP	36
BASF	DE	35
STMicroelectronics	FR	35
Sinopec	CN	34
LG Chemicals Ltd	KR	31

Company	Country	Npub
Toshiba Co. Ltd	JP	25
Hewlett Packard Corporation	US	21
Nippon Kayaku Co. Ltd	JP	20
Philips Research	NL	19
IBM Corporation	CH	18
Hitachi Ltd	JP	17
General Motors	US	17

Table A1.5. Publication output in ICT and nanotechnology by companies (2016)

MANUFACTURING (MF)

Around 2.3 million publications globally were identified[52] from the Web of Science as being related to nanoscience and technology (NST)[53] between 2000 and 2016. Of these 286,000 (13%) were related to manufacturing and nanotechnology. Looking at the global numbers of publications over time[54], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications rose by 6% in manufacturing, from 58% to 64%.

Year	Sector in all science	Sector in NST	% NST
2000	13,230	7,710	58%
2001	14,457	8,683	60%
2002	15,632	9,611	61%
2003	17,340	10,704	62%
2004	19,531	12,236	63%
2005	21,254	13,813	65%
2006	23,547	15,593	66%
2007	24,636	16,240	66%
2008	26,182	17,404	66%
2009	27,046	17,681	65%
2010	27,665	18,433	67%
2011	30,660	20,481	67%
2012	31,655	21,109	67%
2013	34,988	23,083	66%
2014	36,712	24,253	66%
2015	38,017	24,741	65%
2016	38,487	24,672	64%

Table A1.6. Publication output in manufacturing and in manufacturing and nanotechnology (NST) globally over time (2000-2016)

For manufacturing, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from nearly 3,000 in year 2000 to over 6,000 in 2016 but the proportion dropped from 38% to 26% relative to global output in the same timeframe (see figure below).

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

[53] 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.

[54] See tables in Annex: Publication data

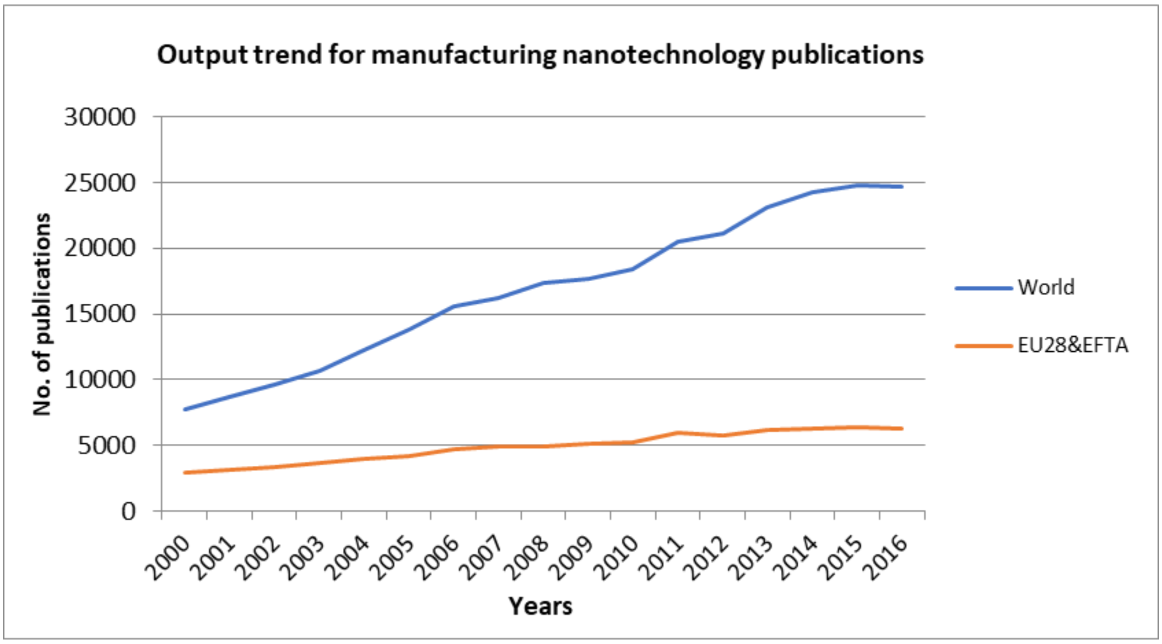

Figure A1.5. Manufacturing nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

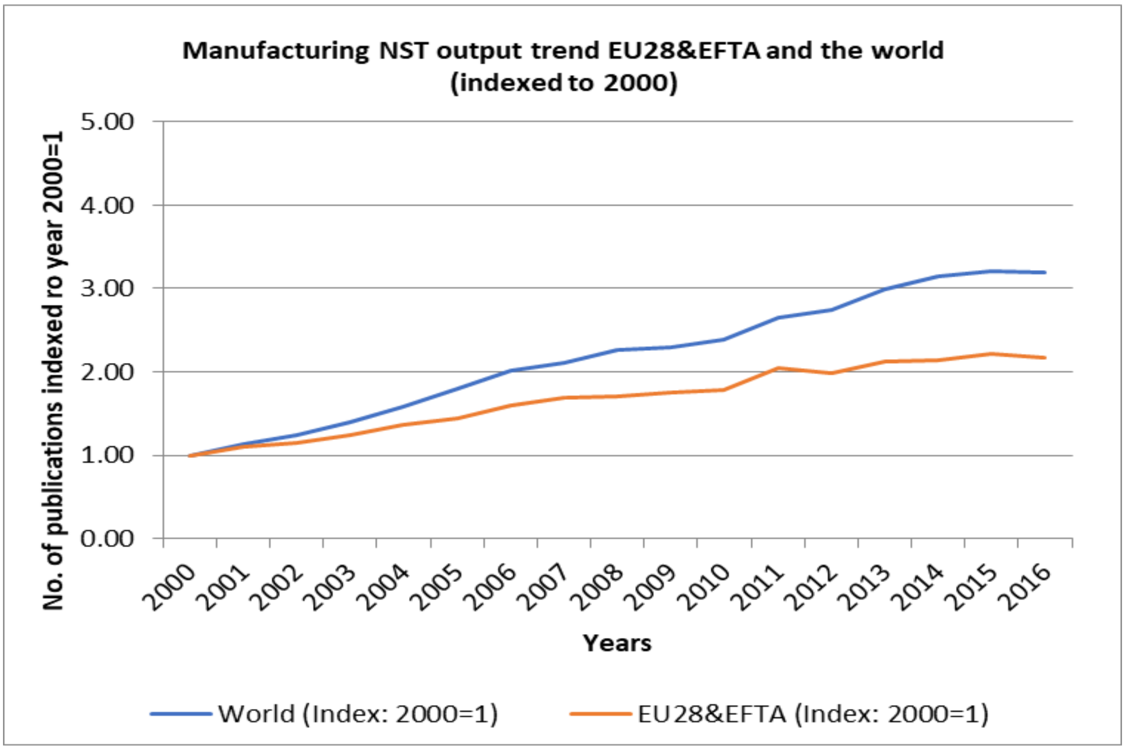

Figure A1.6. Output trend for nanotechnology and manufacturing in EU28&EFTA and the world

The most prolific region in NST for manufacturing is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub

Region	Npub
Asia	158,468
EU28&EFTA	84,476
North America	51,245
Middle East	13,078
South & Central America	8,554
Oceania	5,309
Africa	4,527

Table A1.7. Number of publications by region for manufacturing and nanotechnology (2000-2016)

In 2016, the most prolific country in NST for manufacturing is China, followed at a distance by the US and at a further distance by India, South Korea, Japan, Germany, France and the United Kingdom. In EU28&EFTA, the most prolific countries are (besides Germany, UK, and France), Spain, Italy and Poland.

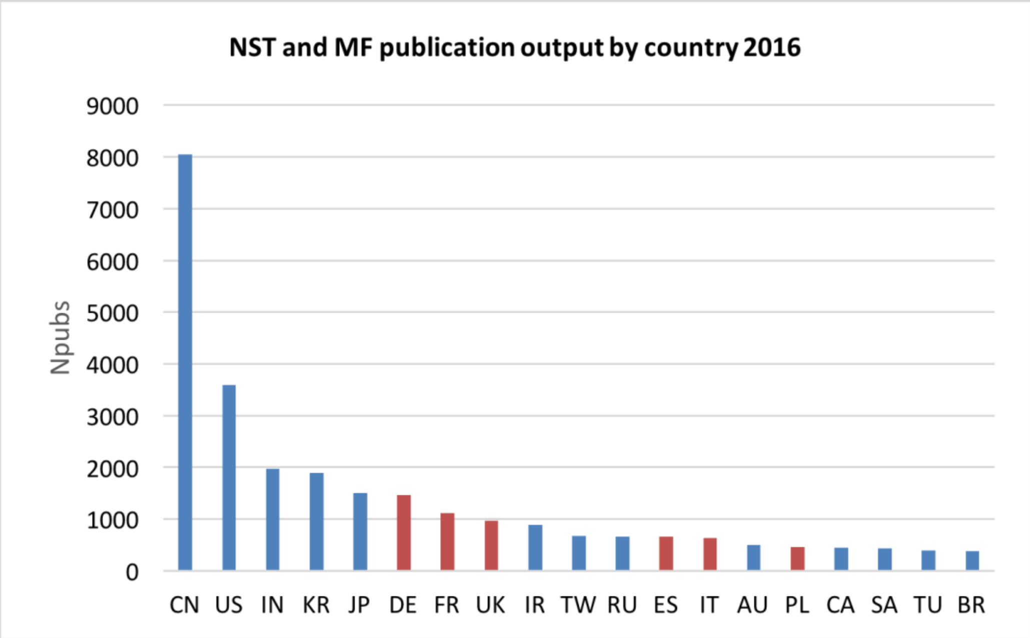

Figure A1.7. Publication output by country in manufacturing and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST manufacturing are higher education institutions, research and technology organisations and industry. The most active organisations in NST for manufacturing publications in 2016 are shown in the table below. The higher education organisations contributing to the most nanotechnology manufacturing publications globally in 2016 were the Chinese Academy of Sciences, Russian Academy of Sciences, CNRS, Jilin University, Peking University, Zhejiang University and Tsinghua university (all of them with more than 200 publications).

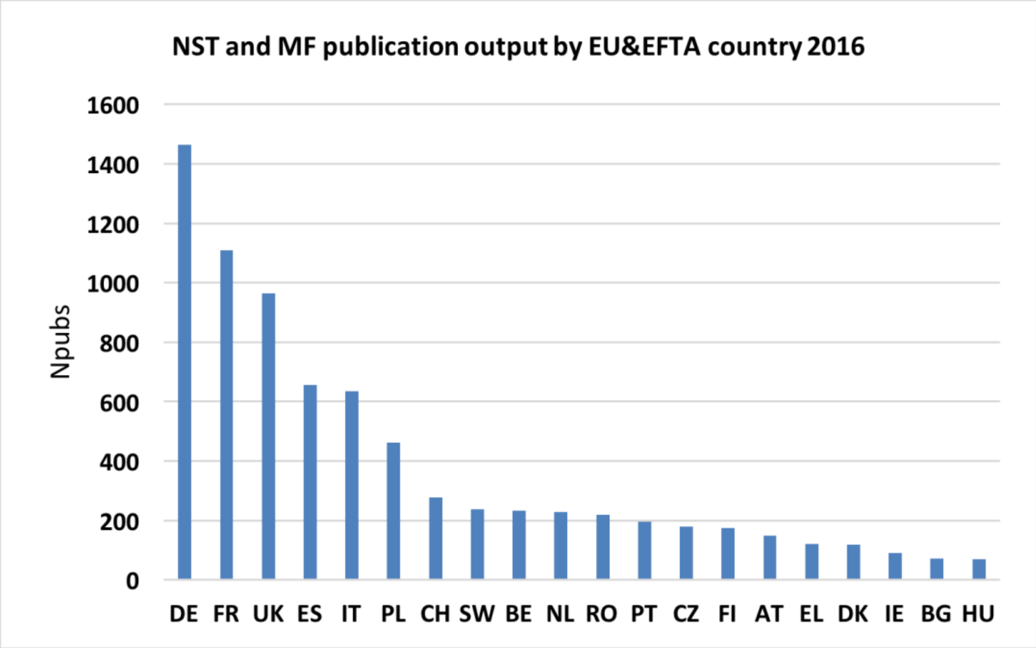

Figure A1.8. Publication output by EU&EFTA countries in manufacturing and nanotechnology (2016)

Within EU28&EFTA, the CNRS[55], the CNR[56], the CSIC[57], Max Planck (all PRO's) and the University of Cambridge are the most active organisations.

Institution	Country	Npub
Chinese Academy of Sciences	CN	1,298
Russian Academy of Science	RU	395
Centre National de la Recherche Scientifique	FR	352
Jilin University	CN	241
Peking University	CN	222
Zhejiang University	CN	210
Tsinghua University	CN	209
Sungkyunkwan University	KR	191
Council for Scientific and Industrial Research	IN	191
Harbin Institute of Technology	CN	190
University of Science and Technology of China	CN	190
Tianjin University	CN	186
Nanyang Technological University	SG	182

[55] Centre National de la Recherche Scientifique, France
[56] Consiglio Nazionale delle Ricerche, Italy
[57] Spanish National Research Council

Institution	Country	Npub
Nanjing University	CN	180
Shanghai Jiao Tong University	CN	172
Consiglio Nazionale delle Ricerche	IT	167
Spanish National Research Council (CSIC)	ES	165
Soochow University	CN	159
University of Electronic Science & Technology of China	CN	152
Fudan University	CN	152
Seoul National University	KR	151
Max Planck Society	DE	150
ISLAMIC AZAD UNIV	IR	145
Huazhong University of Science and Technology	CN	142

Table A1.8. Publication output in manufacturing and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
Centre National de la Recherche Scientifique	FR	352
Consiglio Nazionale delle Ricerche	IT	167
Spanish National Research Council	ES	165
Max Planck Society	DE	150
University of Cambridge	UK	136
Polish Academy of Sciences	PL	121
Commissariat a l'Energie Atomique	FR	106
Communauté Université Grenoble-Alpes	FR	101
Karlsruhe Institute of Technology	DE	88
Ecole PolyTechnique Federale de Lausanne	CH	86
Czech Academy of Sciences	CZ	86
Technische Universität Dresden	DE	80
University of Manchester	UK	79
ETH Zurich	CH	76

Table A1.9. Publication output in manufacturing and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for manufacturing (2016) are shown in the table below. The companies contributing to the most nanotechnology manufacturing publications globally in 2016 were Samsung, IBM, NTT, and Intel, as shown in the table of the top publishing companies worldwide.

Company	Country	Npub
Samsung Electronics	KR	43
IBM Corporation	US	20
NTT Advanced Technologies Corporation	JP	12
Intel Corporation	US	11
LG Chemicals Ltd	KR	9
Toyota Motor Co Ltd	JP	9
SK Hynix	KR	8
Sumitomo Metal Mining Co., Ltd.	JP	7
BASF	DE	7
Texas Instruments Inc.	US	7

Table A1.10. Publication output in manufacturing and nanotechnology by companies (2016)

HEALTH (HT)

Around 2.3 million publications globally were identified[58] from the Web of Science as being related to nanoscience and Technology (NST)[59] between 2000 and 2016. Of these 270,000 (12%) were related to health and nanotechnology. Looking at the global numbers of publications over time[60], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications rose by 4% in health, from 2% to 6%.

	Sector in all science	Sector in NST	% NST
2000	222,247	4,923	2%
2001	229,985	5,311	2%
2002	240,143	5,919	2%
2003	256,119	6,859	3%
2004	273,543	7,879	3%
2005	290,655	9,243	3%
2006	310,281	10,606	3%
2007	338,092	12,049	4%
2008	366,713	14,020	4%
2009	387,837	15,706	4%
2010	412,493	18,150	4%
2011	440,142	20,338	5%
2012	472,468	22,377	5%
2013	500,577	25,338	5%
2014	515,211	27,654	5%
2015	534,242	29,540	6%
2016	543,388	30,829	6%

Table A1.11. Publication output in health and in health and nanotechnology (NST) globally over time (2000-2016)

For health, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from over 2,000 in year 2000 to almost 9,000 in 2016 but the proportion dropped from 43% to 29% relative to global output in the same timeframe (see figure below).

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

[59] 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.

[60] See tables in Annex: Publication data

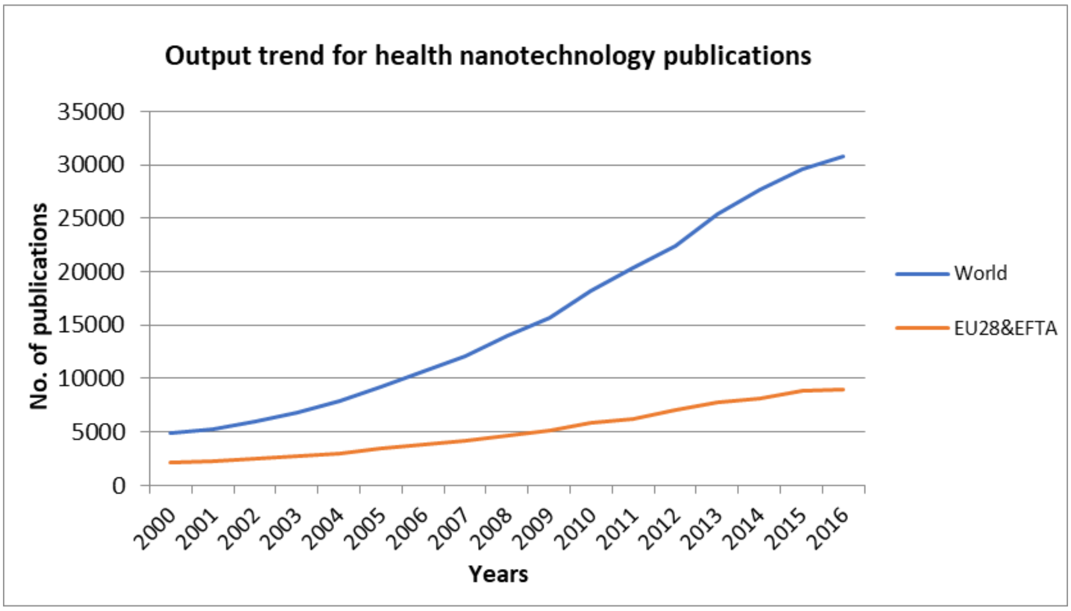

Figure A1.9. Health nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

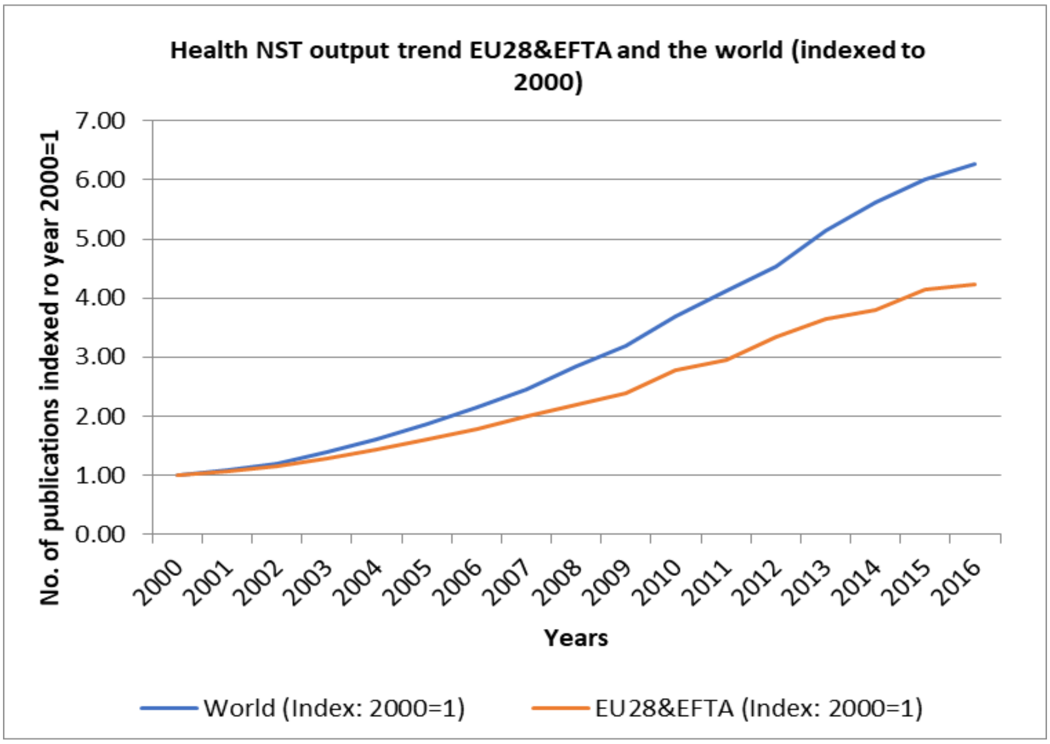

Figure A1.10. Output trend for nanotechnology and health in EU28&EFTA and the world

The most prolific region in NST for health is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub
Asia	112,740
EU28&EFTA	87,452

Region	Npub
North America	71,418
Middle East	15,887
South & Central America	8,875
Oceania	6,775
Africa	4,370

Table A1.12. Number of publications by region for health and nanotechnology (2000-2016)

In 2016, the most prolific countries in NST for health were China and the USA followed on a distance by India, Germany and the UK.

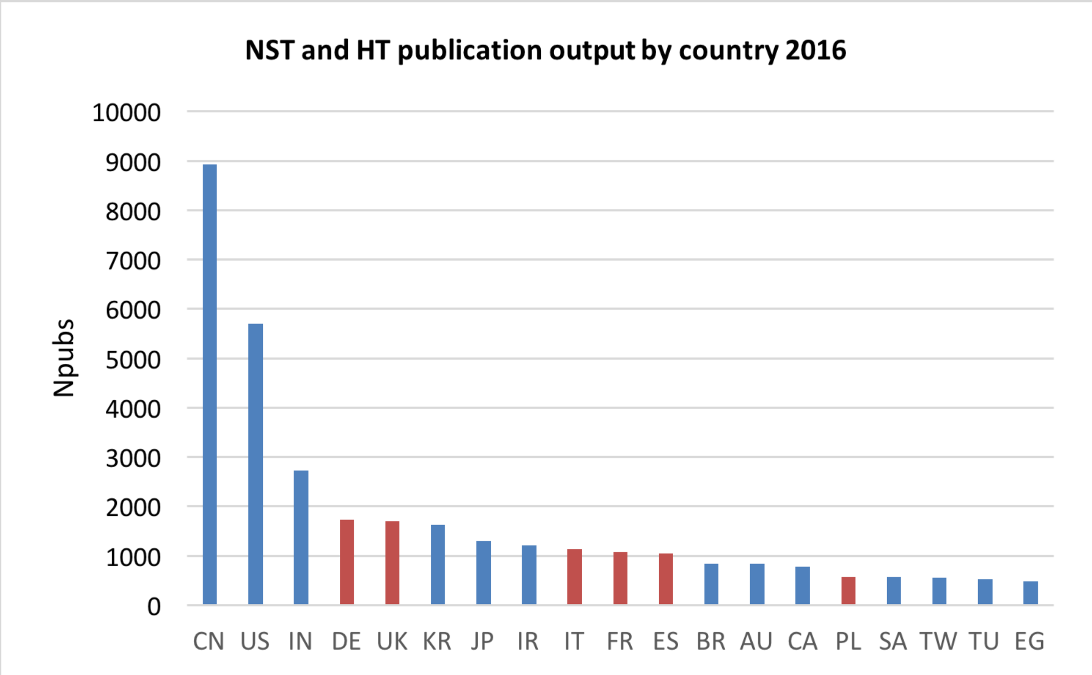

Figure A1.11. Publication output by country in health and nanotechnology (2016)

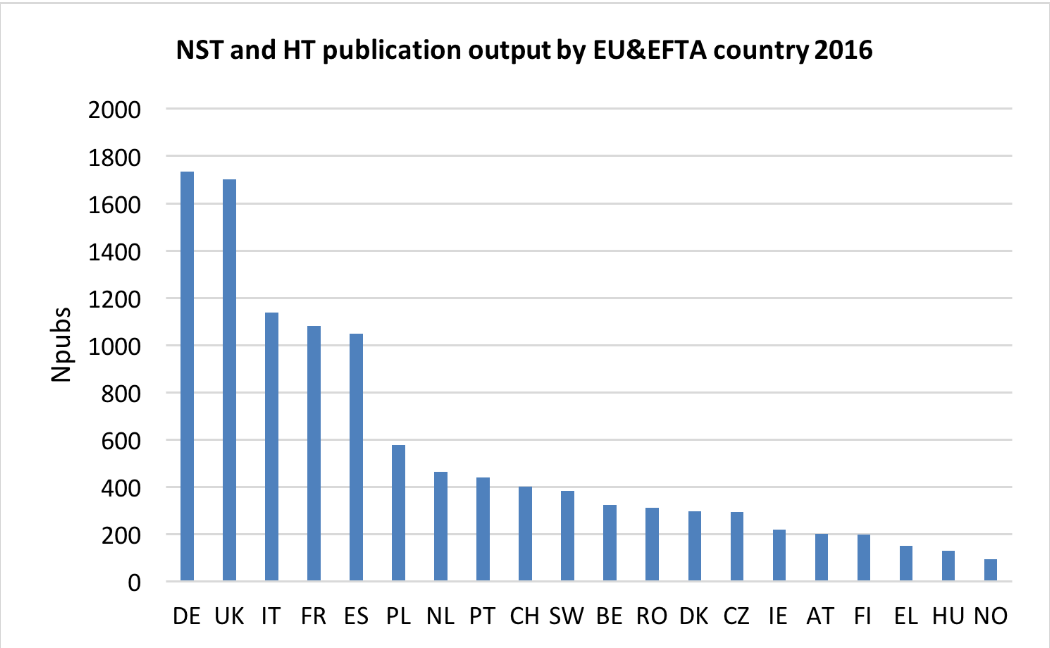

Figure A1.12. Publication output by EU&EFTA country in health and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST health are higher education institutions, research and technology organisations and industry. The most active organisations in NST for health publications in 2016 are shown in the table below. The higher education organisations contributing to the most nanotechnology health publications globally in 2016 were the Chinese Academy of Sciences, Shanghai Jiao Tong University, Sichuan University, Zhejiang University and CNRS (all of them with more than 300 publications).

Within EU28&EFTA, the CNRS, CNR and Max Planck and CSIC (all PRO's), UCL, University Copenhagen and Czech academy of sciences are the most active organisations.

Institution	Country	Npub
Chinese Academy of Sciences	CN	1282
Shanghai Jiao Tong University	CN	331
Sichuan University	CN	320
Zhejiang University	CN	308
Centre National de la Recherche Scientifique	FR	302
Jilin University	CN	283
Fudan University	CN	281
Harvard University	US	276
Soochow University	CN	264
Council for Scientific and Industrial Research	IN	264
King Saud University	SA	239
Russian Academy of Science	RU	232
Nanjing University	CN	232
National University of Singapore	SG	229
Peking University	CN	229
Tsinghua University	CN	227
Massachusetts Institute Technology	US	200
Consiglio Nazionale delle Ricerche	IT	190
Max Planck Society	DE	184
Nanyang Technological University	SG	179
Spanish National Research Council	ES	179
Shandong University	CN	179

Institution	Country	Npub
Seoul National University	KR	175
Wuhan University	CN	173

Table A1.13. Publication output in health and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
Centre National de la Recherche Scientifique	FR	302
Consiglio Nazionale delle Ricerche	IT	190
Max Planck Society	DE	184
Spanish National Research Council	ES	179
University College London	UK	158
University of Copenhagen	DK	150
Czech Academy of Sciences	CZ	137
University of Cambridge	UK	135
ETH Zurich	CH	115
University of Porto	PT	112
Polish Academy of Sciences	PL	110
Freie Universität Berlin	DE	106
Ghent University	BE	103

Table A1.14. Publication output in health and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for health (2016) are shown in the table below. The companies contributing to the most nanotechnology health publications globally in 2016 were Genea Biocells, Merck, Bristol Myers Squibb , Genentech, and AstraZeneca, as shown in the table of the top publishing companies worldwide.

Company	Country	Npub
Genea Biocells	AU	28
Merck & Co. Inc.	US	24
Bristol-Myers Squibb	US	23
Genentech, Inc.	US	21
H. Lundbeck A/S	DK	20
AstraZeneca	UK	20
Bioneer AS	DK	17

Company	Country	Npub
BASF	DE	16
IBM Corporation	US	16
Roslin Cells Ltd	UK	16

Table A1.15. Publication output in health and nanotechnology by companies (2016)

ENERGY (EN)

Around 2.3 million publications globally were identified[61] from the Web of Science as being related to nanoscience and technology (NST)[62] between 2000 and 2016. Of these 200,000 (9%) were related to energy and nanotechnology. Looking at the global numbers of publications over time[63], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications rose by 20% in energy, from 35% to 55%.

	Sector in all science	Sector in NST	% NST
2000	5,721	1,975	35%
2001	6,296	2,242	36%
2002	6,900	2,640	38%
2003	7,600	3,075	40%
2004	9,022	3,810	42%
2005	10,366	4,701	45%
2006	12,530	5,934	47%
2007	14,042	6,755	48%
2008	16,448	7,983	49%
2009	19,783	9,984	50%
2010	23,574	12,239	52%
2011	28,850	15,327	53%
2012	32,657	17,638	54%
2013	38,998	20,991	54%
2014	44,834	25,145	56%
2015	50,090	27,695	55%
2016	53,489	29,405	55%

Table A1.16. Publication output in energy and in energy and nanotechnology (NST) globally over time (2000-2016)

For energy, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from just over 800 in year 2000 to nearly 6,500 in 2016 but the proportion dropped from 41% to 22% relative to global output in the same timeframe (see figure below).

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

[62] 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.

[63] See tables in Annex: Publication data

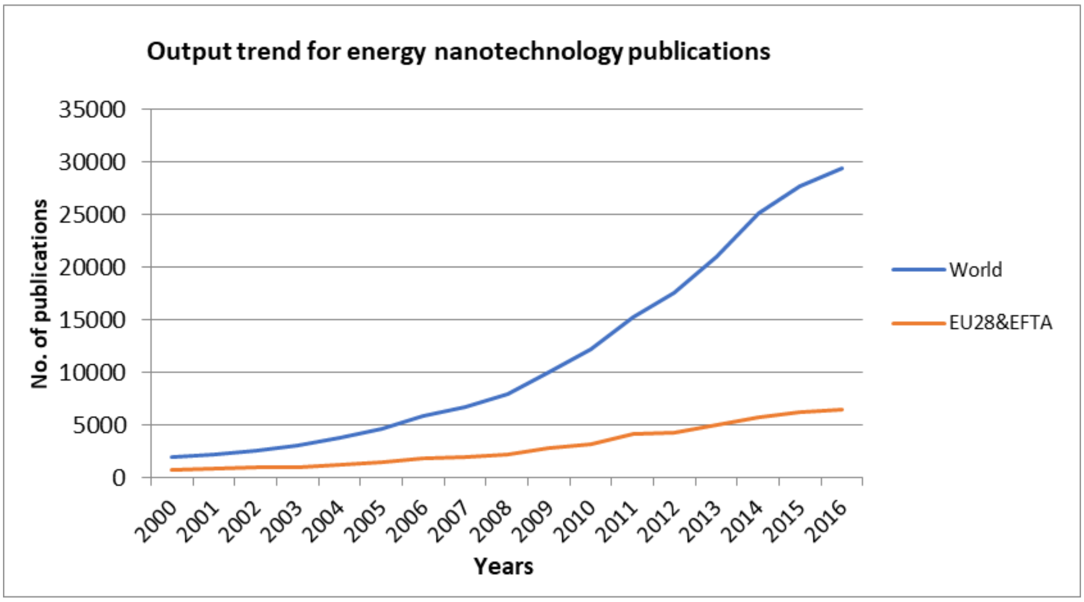

Figure A1.13. Energy nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

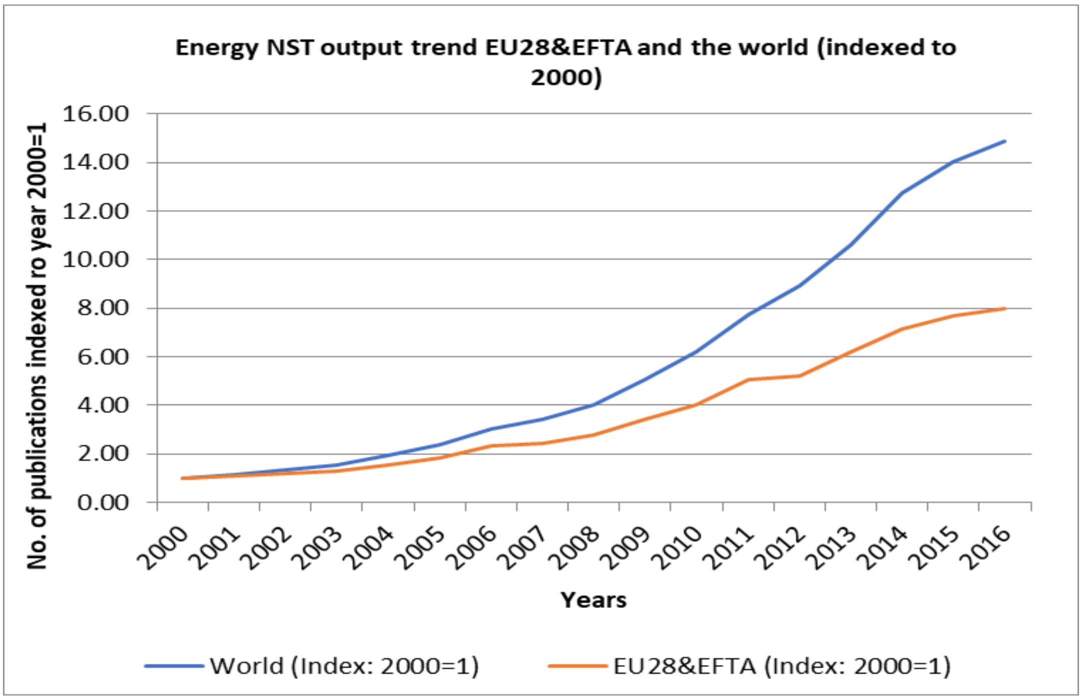

Figure A1.14. Output trend for nanotechnology and energy in EU28&EFTA and the world

The most prolific region in NST for energy is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub
Asia	116,294
EU28&EFTA	51,263
North America	41,353
Middle East	8,756
South & Central America	3,986
Oceania	5,115
Africa	2,949

Table A1.17. Number of publications by region for energy and nanotechnology (2000-2016)

In 2016, the most prolific countries in NST for energy were China and the USA followed South Korea, India, Japan, Germany and the UK.

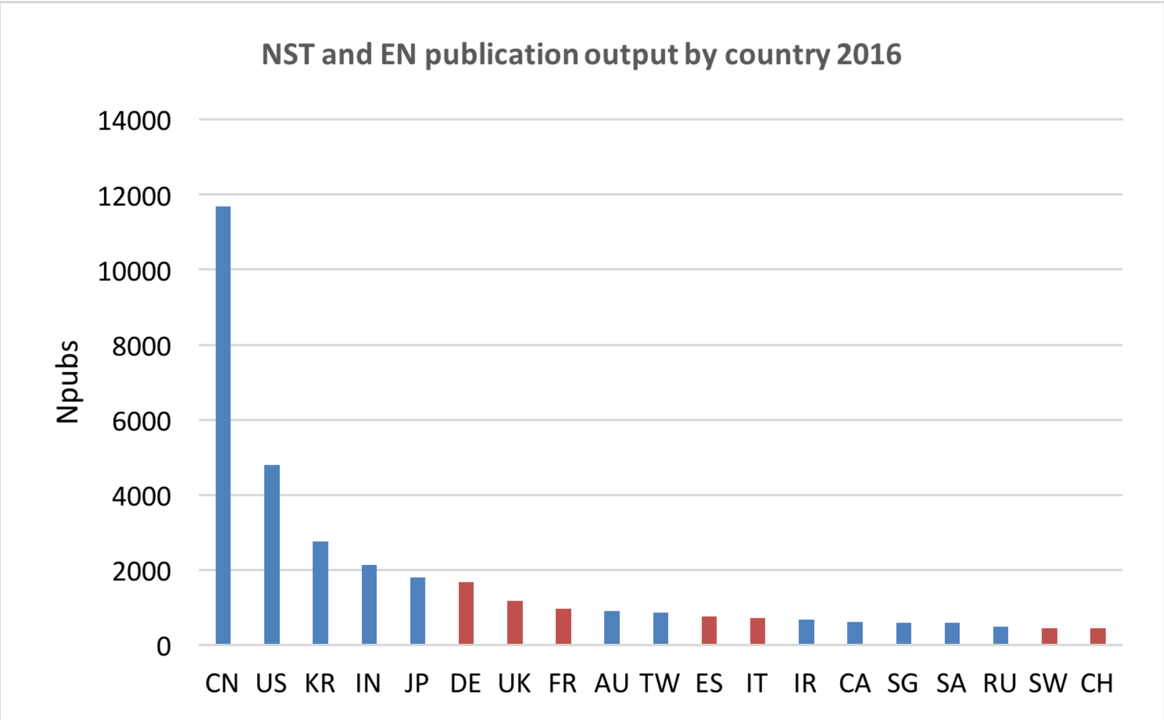

Figure A1.15. Publication output by country in energy and nanotechnology (2016)

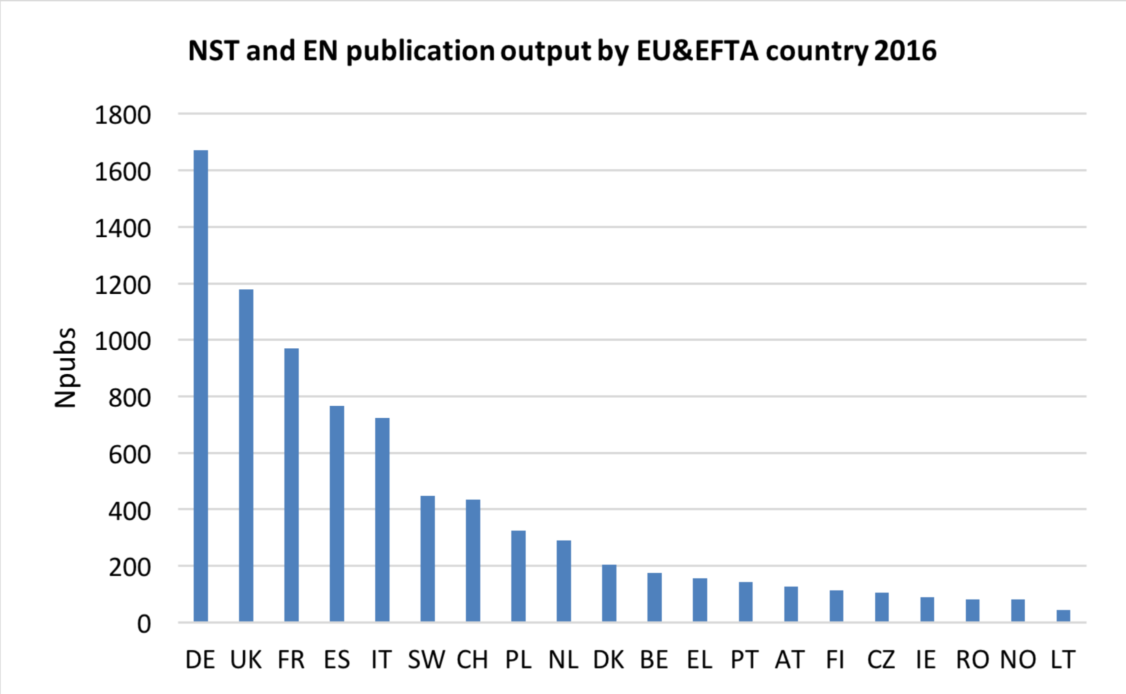

Figure A1. 16. Publication output by EU&EFTA country in energy and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST energy are higher education institutions, research and technology organisations and industry. The most active organisations in NST for energy publications in 2016 are shown in the table below. The higher education organisations contributing to the most nanotechnology energy publications globally in 2016 was the Chinese Academy of Sciences. Then on a distance: Tsinghua University, Nanyang Technology University (SG), and Jilin University, Council for Scientific and Industrial Research (IN), CNRS, Soochow and Huazhong University of S&T (all of them with more than 300 publications). Clearly this sector is dominated by China.

Within EU28&EFTA, the CNRS, EPFL Max Planck, CNR (IT) and CSIC are the most active organisations.

Institution	Country	Npub
Chinese Academy of Sciences	CN	2,029
Tsinghua University	CN	358
Nanyang Technological University	SG	354
Jilin University	CN	354
Council for Scientific and Industrial Research	IN	340
Centre National de la Recherche Scientifique	FR	332
Soochow University	CN	332
Huazhong University of Science and Technology	CN	315
University of Science and Technology of China	CN	293
Zhejiang University	CN	286

Institution	Country	Npub
Harbin Institute of Technology	CN	281
Xi'an Jiaotong University	CN	279
Russian Academy of Science	RU	277
Peking University	CN	272
Fudan University	CN	264
Nanjing University	CN	249
Georgia Institute of Technology	US	238
Ecole Polytechnique Federale de Lausanne	CH	237
Tianjin University	CN	237
Wuhan University of Technology	CN	227
Sungkyunkwan University	KR	226
Max Planck Society	DE	219
Shanghai Jiao Tong University	CN	217
Lawrence Berkeley National Laboratory	US	208
Korea University	KR	208
Seoul National University	KR	208

Table A1.18. Publication output in energy and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
Centre National de la Recherche Scientifique	FR	332
Ecole Polytechnique Federale de Lausanne	CH	237
Max Planck Society	DE	219
Consiglio Nazionale delle Ricerche	IT	182
Spanish National Research Council	ES	168
University of Cambridge	UK	165
Imperial College London	UK	161
University of Oxford	UK	135
Helmholtz Centre Berlin for Materials & Energy	DE	135
Karlsruhe Institute of Technology	DE	134
Uppsala University	SE	128

Institution	Country	Npub
Forschungszentrum Jülich	DE	116
Technische Universität Dresden	DE	109
KTH Royal Institute of Technology	SE	107
Istituto Italiano di Tecnologia	IT	106
Technical University of Denmark	DK	105
University College London	UK	102
Friedrich-Alexander-Universität Erlangen-Nürnberg	DE	98
Commissariat a l'Energie Atomique	FR	96
Polish Academy of Sciences	PL	83
Communauté Université Grenoble-Alpes	FR	76
Delft University of Technology	NL	71
Fraunhofer Association	DE	69
University of Bath	UK	66
Linköping University	SE	66

Table A1.19. Publication output in energy and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for energy (2016) are shown in the table below. The companies contributing to the most nanotechnology energy publications globally in 2016 were Samsung, Toyota, IBM and LG, as shown in the table of the top publishing companies worldwide.

Company	Country	Npub
Samsung Electronics	KR	57
Toyota Motor Co Ltd	JP	32
IBM Corporation	US	18
LG Chemicals Ltd	KR	15
Panasonic Corporation	JP	14
Polyera Corporation	US	13
Abengoa	ES	11
EDF R&D	FR	10
BASF	KR	10

Table A1.20. Publication output in energy and nanotechnology by companies (2016)

PHOTONICS (PH)

Around 2.3 million publications globally were identified[64] from the Web of Science as being related to nanoscience and Technology (NST)[65] between 2000 and 2016. Of these 113,000 (5%) were related to photonics and nanotechnology. Looking at the global numbers of publications over time[66], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications rose by 23% in photonics, from 45% to 68%.

	Sector in all science	Sector in NST	% NST
2000	3,935	1,766	45%
2001	4,293	2,043	48%
2002	4,792	2,372	49%
2003	5,292	2,753	52%
2004	6,016	3,220	54%
2005	7,229	4,087	57%
2006	8,025	4,733	59%
2007	8,822	5,374	61%
2008	9,815	6,116	62%
2009	10,380	6,397	62%
2010	11,245	7,202	64%
2011	12,815	8,320	65%
2012	14,185	9,287	65%
2013	16,036	10,574	66%
2014	17,502	11,772	67%
2015	18,704	12,676	68%
2016	20,275	13,686	68%

Table A1.21. Publication output in photonics and in photonics and nanotechnology (NST) globally over time (2000-2016)

For photonics, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from nearly 800 in year 2000 to nearly 4,000 in 2016 but the proportion dropped from 45% to 28% relative to global output in the same timeframe (see figure below).

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

[65] 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.

[66] See tables in Annex: Publication data

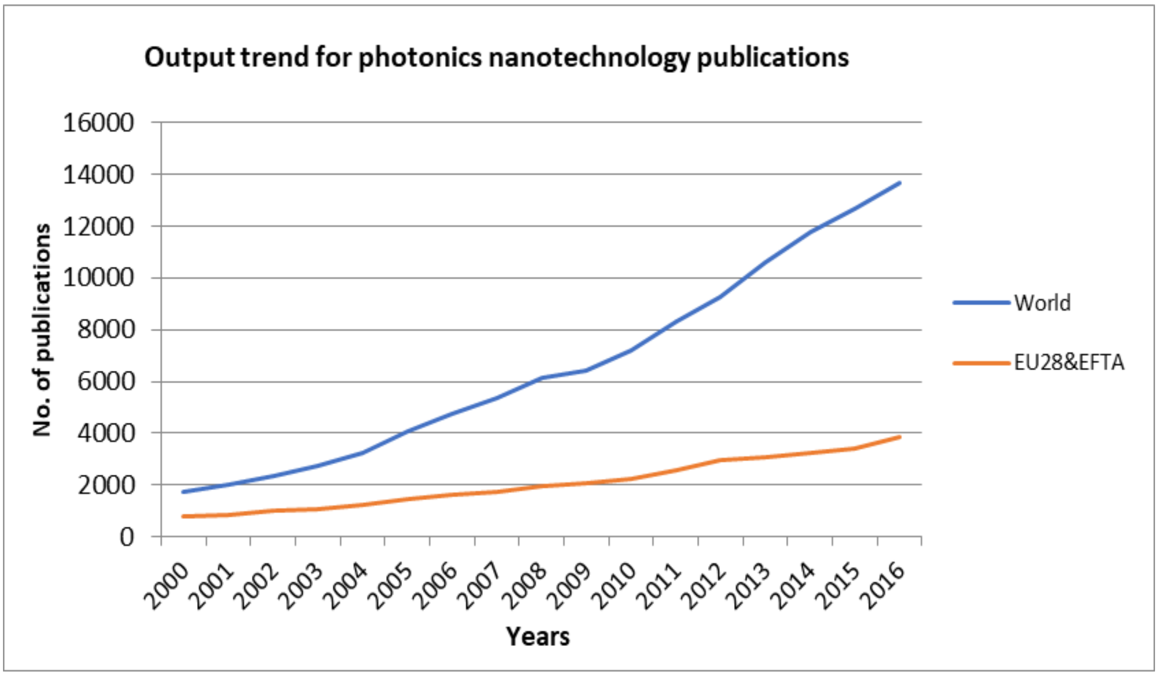

Figure A1.17. Photonics nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

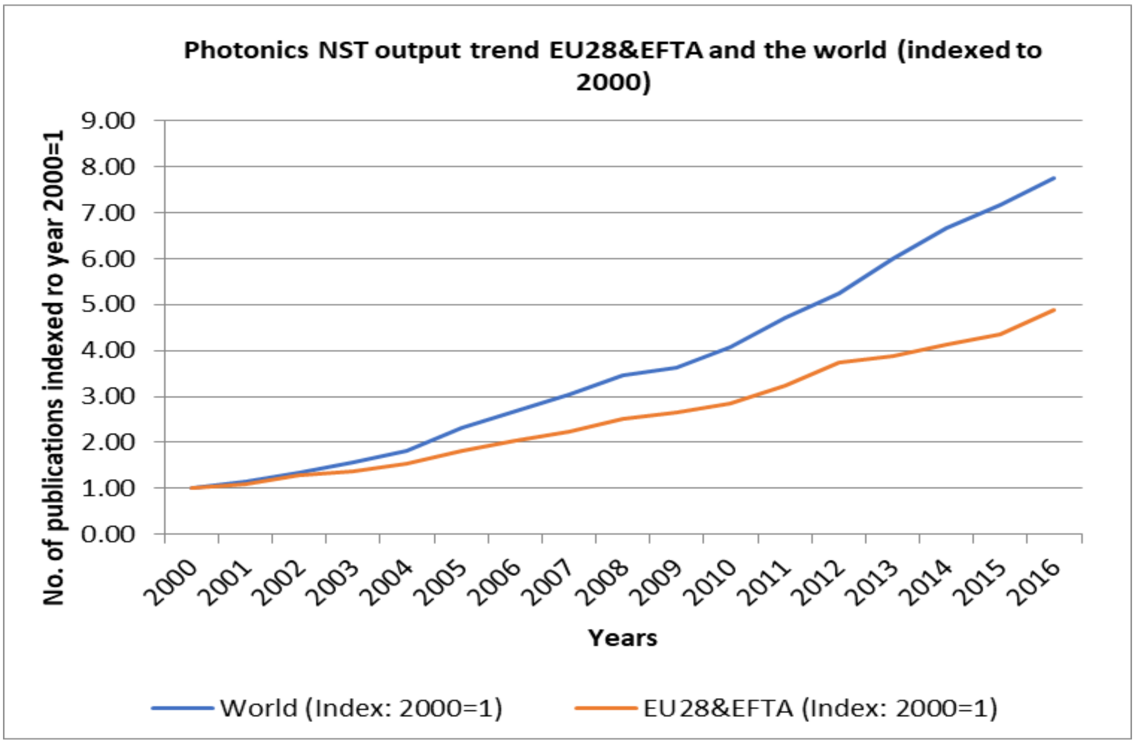

Figure A1.18. Output trend for nanotechnology and photonics in EU28&EFTA and the world

The most prolific region in NST for photonics is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub
Asia	56,012

EU28&EFTA	36,215
North America	29,711
Middle East	4,862
South & Central America	2,250
Oceania	2,767
Africa	1,485

Table A1.22. Number of publications by region for photonics and nanotechnology (2000-2016)

In 2016, the most prolific countries in NST for photonics were China and the USA followed on a distance by Germany, India, South Korea and the UK.

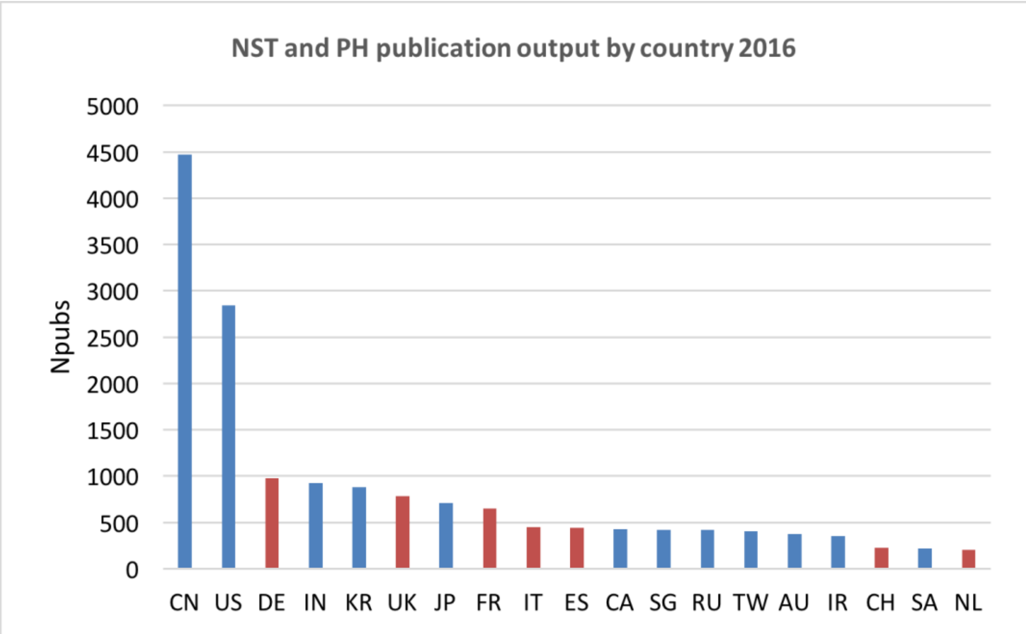

Figure A1.19. Publication output by country in photonics and nanotechnology (2016)

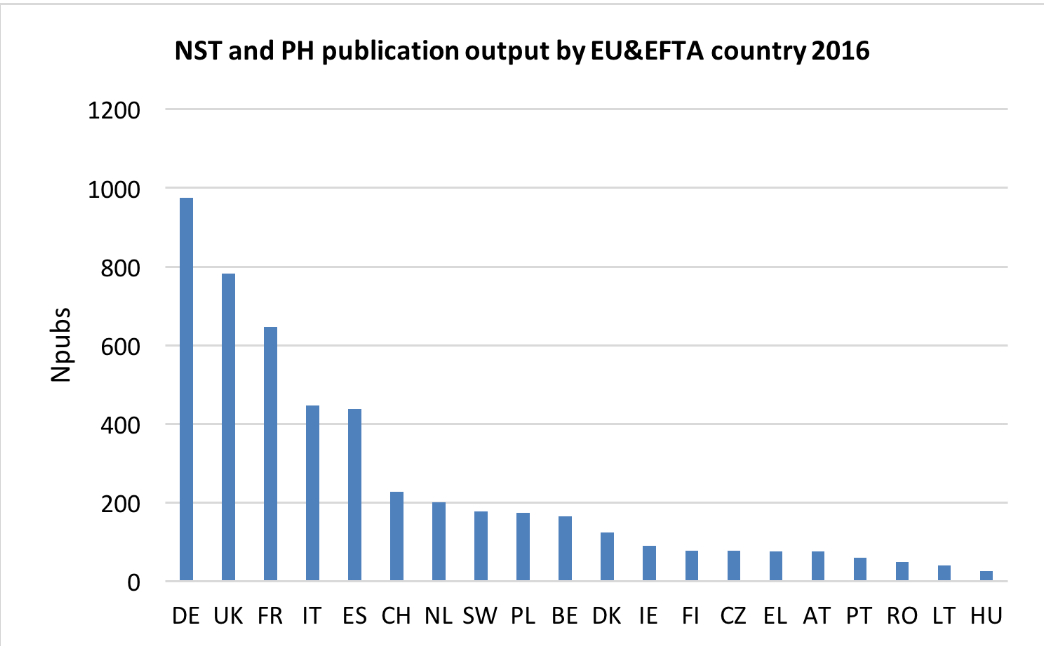

Figure A1.20. Publication output by EU&EFTA country in photonics and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST photonics are higher education institutions, research and technology organisations and industry. The most active organisations in NST for photonics publications in 2016 are shown in the table below. The higher education organisations contributing to the most nanotechnology photonics publications globally in 2016 were the Chinese Academy of Sciences, CNRS, Russian Academy of Sciences, Nanyang University Technology, Nanjing University and Jilin University.

Within EU28&EFTA, the CNRS, CNR, University of Cambridge, Max Planck, EPFL as the most active organisations (more than 100 publications).

Institution	Country	Npub
Chinese Academy of Sciences	CN	819
Centre National de la Recherche Scientifique	FR	254
Russian Academy of Science	RU	228
Nanyang Technological University	SG	227
Nanjing University	CN	188
Jilin University	CN	185
Zhejiang University	CN	161
Peking University	CN	156
Consiglio Nazionale delle Ricerche	IT	154
University of Cambridge	UK	140
Massachusetts Institute Technology	US	131
Soochow University	CN	130
National University of Singapore	SG	130
Huazhong University of Science and Technology	CN	125
Southeast University	CN	122
Max Planck Society	DE	118
University of Science and Technology of China	CN	114
Harbin Institute of Technology	CN	110
Agency for Science, Technology and Research	SG	109
Ecole PolyTechnique Federale de Lausanne	CH	103
Northwestern University	US	102
Stanford University	US	98
Tsinghua University	CN	97

Institution	Country	Npub
Imperial College London	UK	96
Fudan University	CN	96

Table A1.23. Publication output in photonics and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
Centre National de la Recherche Scientifique	FR	254
Consiglio Nazionale delle Ricerche	IT	154
University of Cambridge	UK	140
Max Planck Society	DE	118
Ecole Polytechnique Federale de Lausanne	CH	103
Imperial College London	UK	96
University of Paris XI - Paris-Sud	FR	87
Spanish National Research Council	ES	87
Istituto Italiano di Tecnologia	IT	80
Commissariat a l'Energie Atomique	FR	76
University of Oxford	UK	74
Technical University of Denmark	DK	73
Karlsruhe Institute of Technology	DE	69
Communauté Université Grenoble-Alpes	FR	68
ETH Zurich	CH	65
University of Southampton	UK	64
Eindhoven University of Technology	NL	53
Polish Academy of Sciences	PL	52
Ikerbasque - Basque Foundation for Research	ES	52
Catalan Institution for Research and Advanced Studies	ES	51
University of Strasbourg	FR	50
Ghent University	BE	50
Julius Maximilian University of Würzburg	DE	47
University of Manchester	UK	45

Table A1.24. Publication output in photonics and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for photonics (2016) are shown in the table below. The companies contributing to the most nanotechnology photonics publications globally in 2016 were Samsung, IBM, NTT , Thales, and Hewlett Packard, as shown in the table of the top publishing companies worldwide. The numbers of publications are very low, however.

Company	Country	Npub
Samsung Electronics	KR	24
IBM Corporation	US	15
NTT Advanced Technologies Corporation	JP	13
Thales Research & Technology	FR	8
Hewlett Packard Corporation	US	7
LG Chemicals Ltd	KR	6
Intel Corporation	US	5
OEwaves Inc	US	5
IBM Corporation	CH	5
Luceda Photonics	BE	5

Table A1.25. Publication output in photonics and nanotechnology by companies (2016)

ENVIRONMENT (EV)

Around 2.3 million publications globally were identified[67] from the Web of Science as being related to nanoscience and Technology (NST)[68] between 2000 and 2016. Of these 66,000 (2%) were related to environment and nanotechnology. Looking at the global numbers of publications over time[69], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications rose by 5% in environment, from 10% to 15%.

	Sector in all science	Sector in NST	% NST
2000	10,911	1,101	10%
2001	11,681	1,248	11%
2002	12,573	1,382	11%
2003	14,471	1,602	11%
2004	15,780	1,766	11%
2005	17,255	2,028	12%

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

[68] 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.

[69] See tables in Annex: Publication data

	Sector in all science	Sector in NST	% NST
2006	19,759	2,323	12%
2007	22,380	2,523	11%
2008	25,916	3,023	12%
2009	29,469	3,514	12%
2010	32,257	3,813	12%
2011	37,305	4,653	12%
2012	41,566	5,274	13%
2013	47,473	6,208	13%
2014	51,526	7,270	14%
2015	57,096	8,571	15%
2016	63,362	9,801	15%

Table A1.26. Publication output in environment and in environment and nanotechnology (NST) globally over time (2000-2016)

For environment, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from under 500 in year 2000 to over 2,500 in 2016 but the proportion dropped from 43% to 26% relative to global output in the same timeframe (see figure below).

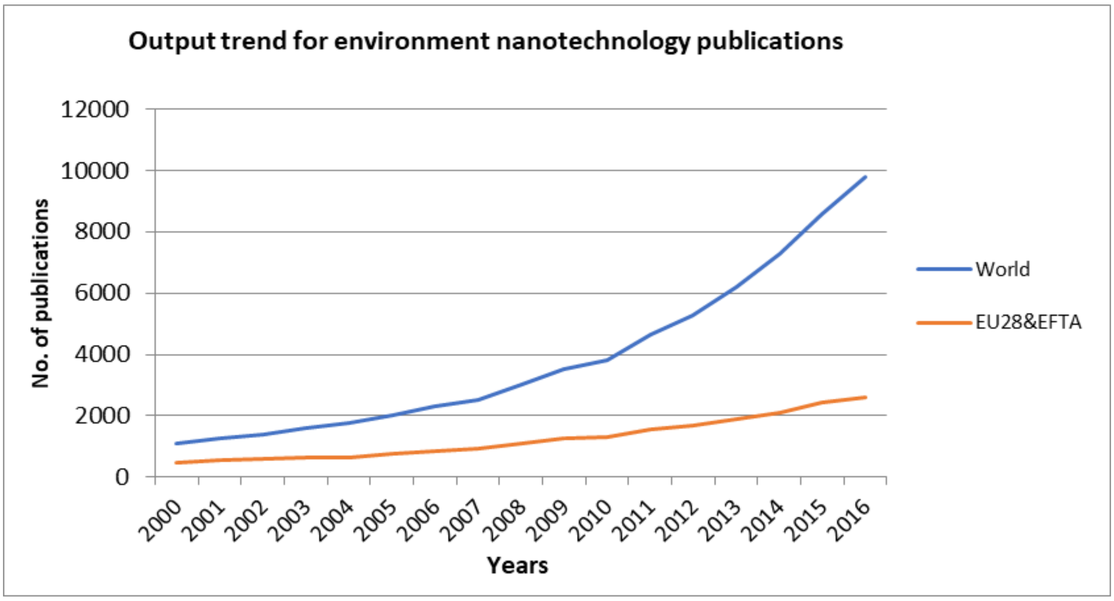

Figure A1.21. Environment nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

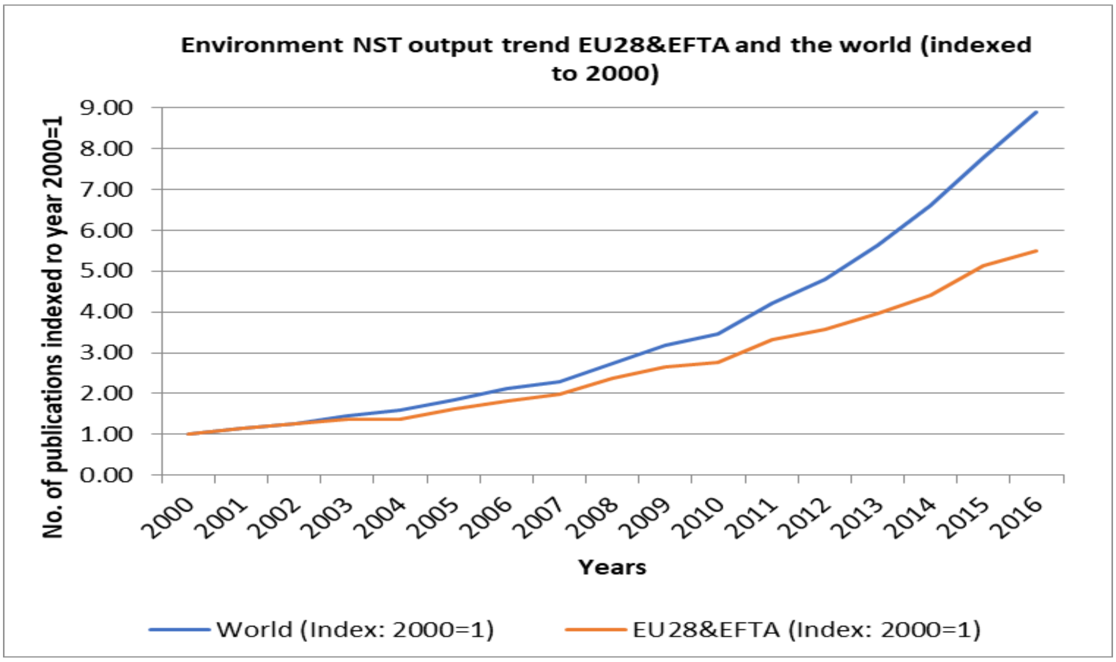

Figure A1.22. Output trend for nanotechnology and environment in EU28&EFTA and the world

The most prolific region in NST for environment is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub
Asia	28,683
EU28&EFTA	21,595
North America	14,915
Middle East	5,591
South & Central America	2,830
Oceania	2,415
Africa	1,944

Figure A1.23. Number of publications by region for environment and nanotechnology (2000-2016)

In 2016, the most prolific countries in NST for environment were China, followed on a distance by USA and India. The other countries at some distance from these.

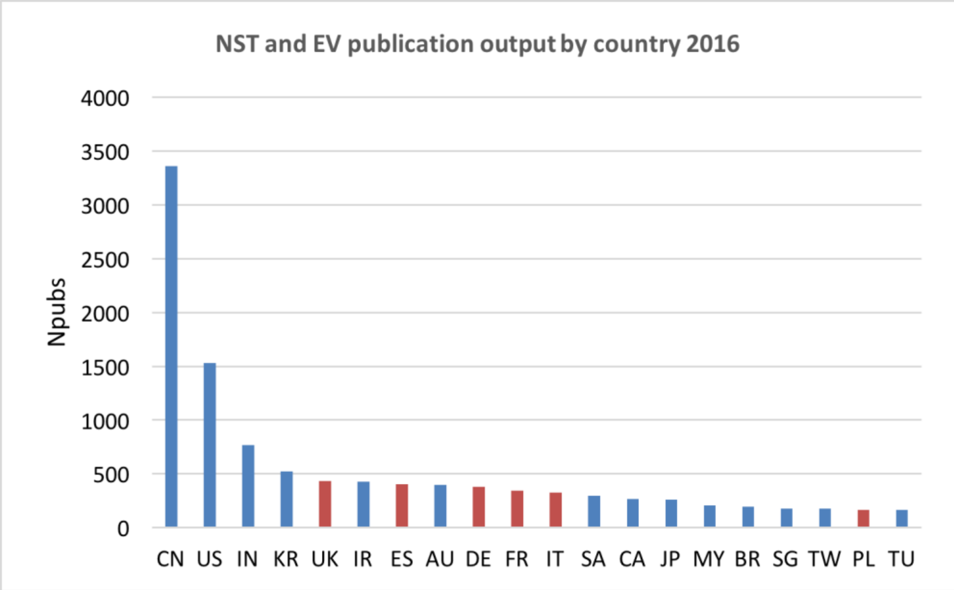

Figure A1.24. Publication output by country in environment and nanotechnology (2016)

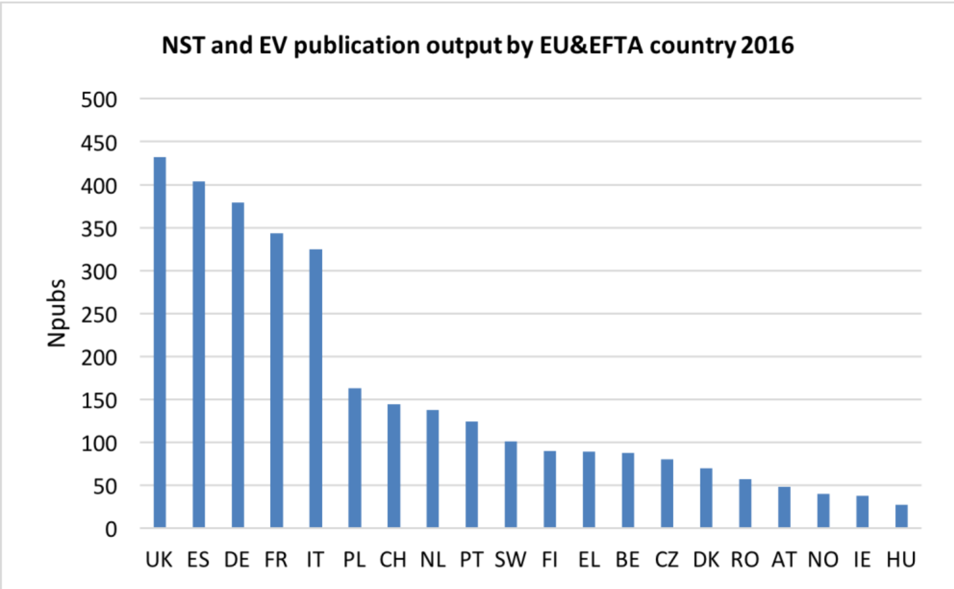

Figure A1.25. Publication output by EU&EFTA country in environment and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST environment are higher education institutions, research and technology organisations and industry. The most active organisations in NST for environment publications in 2016 are shown in the table below. The higher education organisations contributing to the most nanotechnology environment publications globally in 2016 were the Chinese Academy of Sciences, Tsinghua University, CNRS, Tongji University and Harbin institute of Technology (all of them with more than 90 publications).

Within Europe, the CNRS, CNR, CSIC and University of Aveiro (Portugal) and Imperial College London are the most active organisations.

Institution	Country	Npub
Chinese Academy of Sciences	CN	578
Tsinghua University	CN	150
Centre National de la Recherche Scientifique	FR	97

Institution	Country	Npub
Tongji University	CN	91
Harbin Institute of Technology	CN	91
National University of Singapore	SG	82
Zhejiang University	CN	81
King Abdul-Aziz University	SA	78
Nanjing University	CN	74
Nanyang Technological University	SG	73
King Saud University	SA	71
Peking University	CN	71
Council for Scientific and Industrial Research	IN	70
King Abdullah University of Science and Technology	SA	66
Tianjin University	CN	64
Jiangsu University	CN	61
China University of Geosciences	CN	61
University of Malaya	MY	60
Universiti Teknologi Malaysia	MY	58
Islamic Azad University	IR	57
University of Technology, Sydney	AU	57
Hunan University	CN	54
Sichuan University	CN	53
Massachusetts Institute Technology	US	52
Beijing University of Chemical Technology	CN	52

Table A1.27. Publication output in environment and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
Centre National de la Recherche Scientifique	FR	97
Consiglio Nazionale delle Ricerche	IT	50
Spanish National Research Council	ES	46
University of Aveiro	PT	46
Imperial College London	UK	45

Institution	Country	Npub
Karlsruhe Institute of Technology	DE	38
Commissariat a l'Energie Atomique	FR	37
Technical University of Denmark	DK	36
ETH Zurich	CH	35
Delft University of Technology	NL	32
University of Manchester	UK	31
University of Birmingham	UK	30
Complutense University	ES	29
Katholieke Universiteit Leuven	BE	29
Max Planck Society	DE	28
Université Paul Sabatier	FR	26
EMPA Swiss Federal Laboratories for Materials Science and Technology	CH	26
University of Porto	PT	26
Aix-Marseille University	FR	26
University of Lisbon	PT	26
RWTH Aachen University	DE	25
Ghent University	BE	25
Paul Scherrer Institute	CH	24
University of Barcelona	ES	24

Table A1.28. Publication output in environment and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for environment (2016) are shown in the table below. The companies contributing to the most nanotechnology environment publications globally in 2016 were BASF, SINOPEC and IBM, as shown in the table of the top publishing companies worldwide.

Company	Country	Npub
BASF	DE	10
Sinopec	CN	6
IBM Corporation	US	6
Toyota Motor Co Ltd	JP	4

Company	Country	Npub
GS E&C	KR	3
Toray Industries	JP	3
Grundfos Holding AS	DK	3
PerkinElmer Inc.	CA	3
Novartis Institutes for BioMedical Research	CH	3
Guangzhou Hexin Analytical Instrument Co. Ltd.	CN	3

Table A1.29. Publication output in environment and nanotechnology by companies (2016)

TRANSPORT (TR)

Around 2.3 million publications globally were identified[70] from the Web of Science as being related to nanoscience and Technology (NST)[71] between 2000 and 2016. Of these 24,000 (0.9%) were related to transport and nanotechnology. Looking at the global numbers of publications over time[72], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications stays stable in transport at 16% in transport.

	Sector in all science	Sector in NST	% NST
2000	10,418	609	6%
2001	11,591	707	6%
2002	12,093	751	6%
2003	13,506	852	6%
2004	15,044	941	6%
2005	16,278	1,054	6%
2006	17,922	1,171	7%
2007	19,072	1,351	7%
2008	21,019	1,359	6%
2009	23,053	1,483	6%
2010	23,820	1,496	6%
2011	26,635	1,683	6%
2012	28,463	1,761	6%

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

[71] 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.

[72] See tables in Annex: Publication data

	Sector in all science	Sector in NST	% NST
2013	31,657	1,926	6%
2014	34,221	2,105	6%
2015	36,399	2,283	6%
2016	39,086	2,487	6%

Table A1.30. Publication output in transport and in transport and nanotechnology (NST) globally over time (2000-2016)

For transport, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from under 300 in year 2000 to over 850 in 2016 but the proportion dropped from 47% to 34% relative to global output in the same timeframe (see figure below).

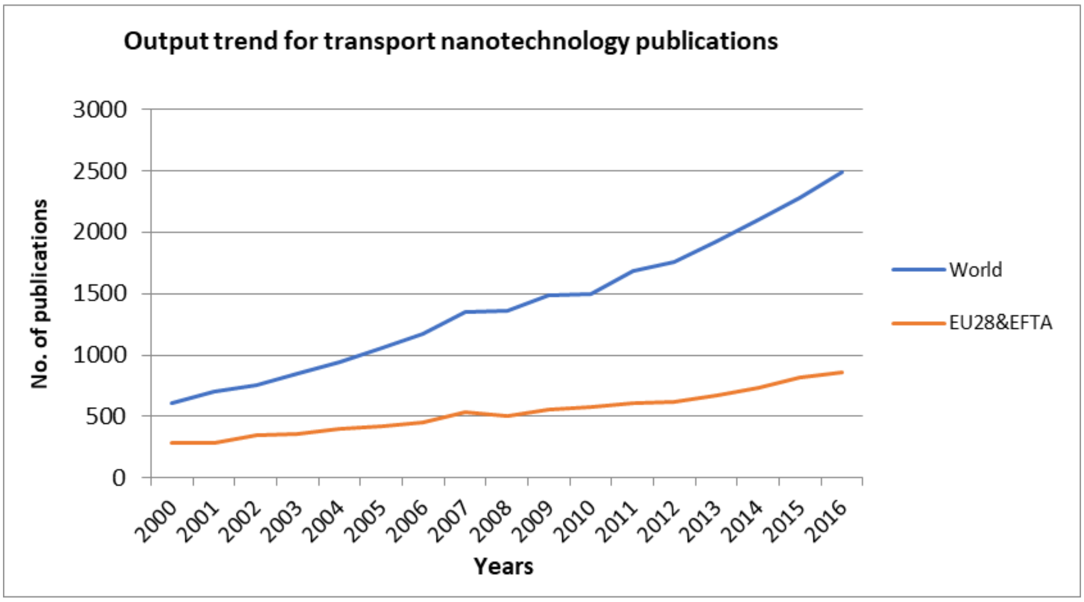

Figure A1.26. Transport nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

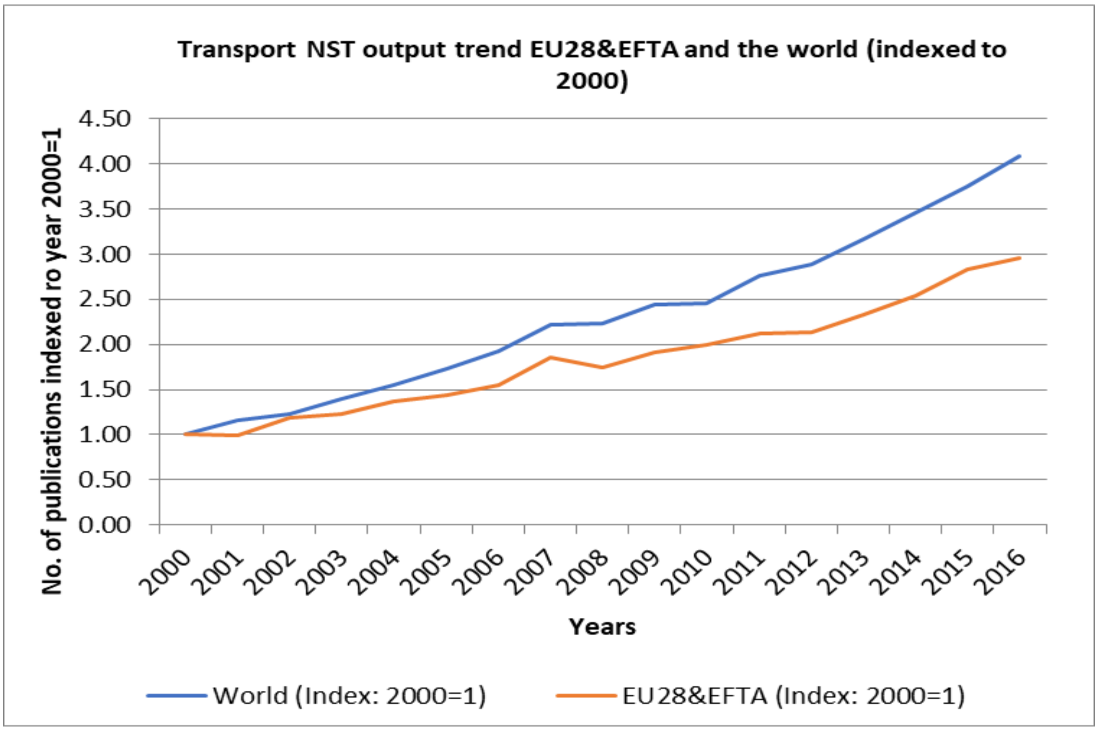

Figure A1.27. Output trend for nanotechnology and transport in EU28&EFTA and the world

The most prolific region in NST for transport is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub
Asia	8,767
EU28&EFTA	9,090
North America	6,353
Middle East	1,345
South & Central America	1,023
Oceania	464
Africa	365

Table A1.31. Number of publications by region for transport and nanotechnology (2000-2016)

In 2016, the most prolific countries in NST for transport were China and the USA followed on a distance by Germany, India and the United Kingdom.

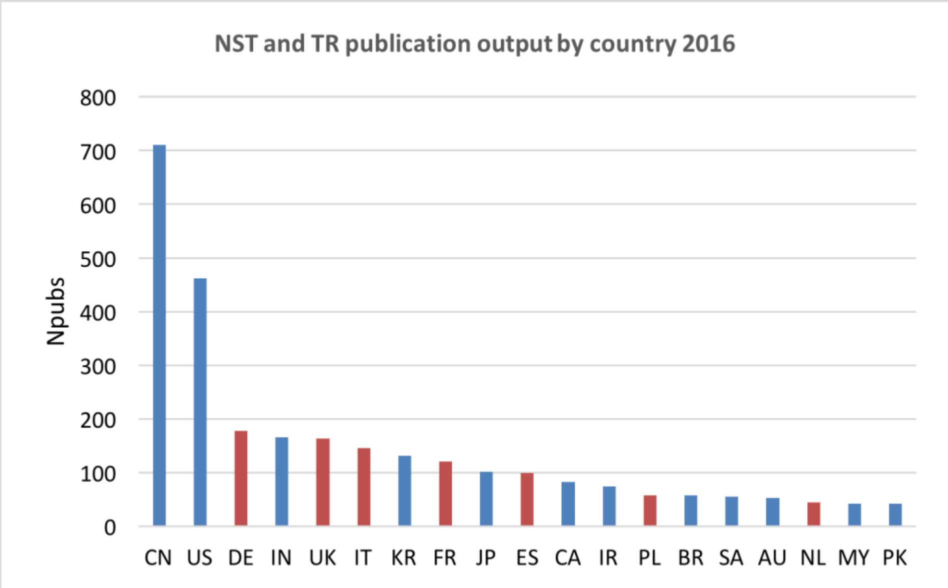

Figure A1.28. Publication output by country in transport and nanotechnology (2016)

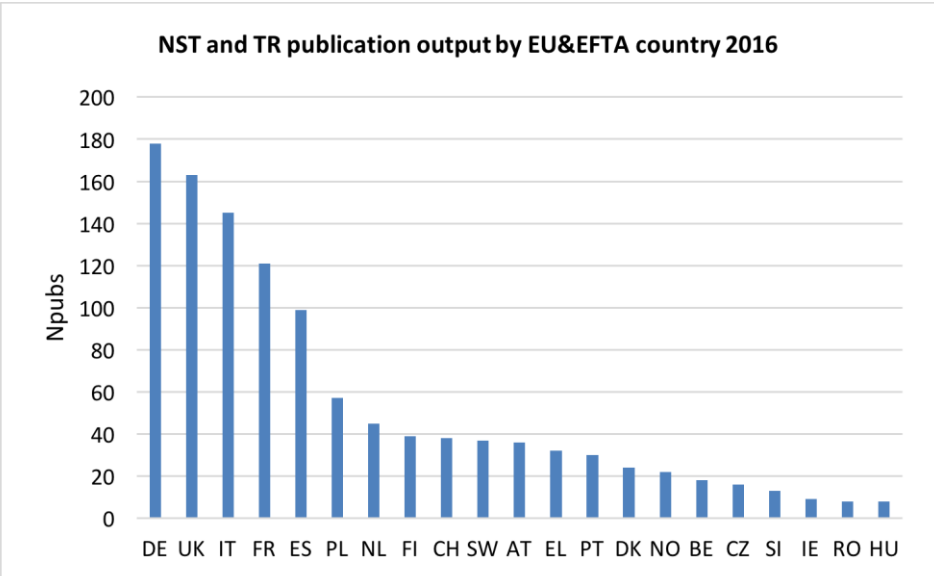

Figure A1.29. Publication output by EU&EFTA country in transport and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST transport are higher education institutions, research and technology organisations and industry. The most active organisations in NST for transport publications in 2016 are shown in the table below. The higher education organisations contributing to the most nanotechnology transport publications globally in 2016 were the Chinese Academy of Sciences and Tsinghua University (both with more than 40 publications). The others have less than 30 publications each.

Within Europe, the CNRS, CSIC, CNR, University of Birmingham and Max Planck are the most active organisations.

Institution	Country	Npub
Chinese Academy of Sciences	CN	81
Tsinghua University	CN	41
Beihang University	CN	29

Institution	Country	Npub
Tianjin University	CN	27
Beijing University of Chemical Technology	CN	26
CNRS	FR	26
CSIC	ES	25
University of Colorado, Boulder	US	24
NASA	US	24
CNR	IT	24
Northwestern Polytechnical University	CN	22
Georgia Institute of Technology	US	22
Peking University	CN	21
Harbin Institute of Technology	CN	20
King Abdul-Aziz University	SA	20
Wuhan University of Technology	CN	20
National Oceanic and Atmospheric Administration	US	20
University of Birmingham	UK	19
Russian Academy of Science	RU	17
Central South University	CN	16
Max Planck Society	DE	16
Sichuan University	CN	16
Beijing Institute of Technology	CN	15

Table A1.32. Publication output in transport and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
CNRS	FR	26
CSIC	ES	25
CNR	IT	24
University of Birmingham	UK	19
Max Planck Society	DE	16
Forschungszentrum Jülich	DE	14
Politecnico di Torino	IT	14

Institution	Country	Npub
University of Aveiro	PT	14
Finnish Meteorological Institute	FI	13
Karlsruhe Institute of Technology	DE	13
University of Naples Federico II	IT	13
University of Manchester	UK	12
University of Nottingham	UK	12
JRC Ispra	IT	12
Leibniz Institute of Tropospheric Research	DE	12
Technical University of Denmark	DK	11
TNO	NL	11
German Aerospace Centre	DE	11
Polish Academy of Sciences	PL	11
Paul Scherrer Institute	CH	11
Tampere University of Technology	FI	10
Delft University of Technology	NL	10
Imperial College London	UK	10

Table A1.33. Publication output in transport and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for transport (2016) are shown in the table below. The companies contributing to the most nanotechnology transport publications globally in 2016 were Posco, Ford, Hyundai, Sinopec and Toyota, as shown in the table of the top publishing companies worldwide.

Company	Country	Npub
Posco	KR	6
Ford Motor Company	US	5
Hyundai Motor Company	KR	5
Sinopec	CN	5
Toyota Motor Co Ltd	JP	4
PetroChina	CN	3
Samsung Electronics	KR	3
Nippon Kayaku Co. Ltd	JP	3

General Motors	US	3
Toto Ltd.	FR	3
AVL LIST GmbH	AT	3

Table A1.34. Publication output in transport and nanotechnology by companies (2016)

CONSTRUCTION (CN)

Around 2.3 million publications globally were identified[73] from the Web of Science as being related to nanoscience and technology (NST)[74] between 2000 and 2016. Of these 21,000 (0.8%) were related to construction and nanotechnology. Looking at the global numbers of publications over time[75], from 2000 to 2016, the proportion of nanotechnology publications grew in all sectors relative to the total number of publications in that sector, except in transport where it was stable. The proportion of nanotechnology publications rose by 3% in construction, from 15% to 18%.

	Sector in all science	Sector in NST	% NST
2000	3381	506	15%
2001	3506	467	13%
2002	3725	546	15%
2003	4140	633	15%
2004	4700	693	15%
2005	4854	711	15%
2006	5446	855	16%
2007	6446	910	14%
2008	6907	1016	15%
2009	7795	1178	15%
2010	8582	1326	15%
2011	9545	1430	15%
2012	10859	1741	16%
2013	12295	2013	16%
2014	13490	2236	17%
2015	14864	2478	17%
2016	16469	2909	18%

Table A1.35. Publication output in construction and in construction and nanotechnology (NST) globally over time (2000-2016)

For construction, the number of nanoscience and nanotechnology publications in the EU&EFTA countries rose from under 200 in year 2000 to over 1,000 in 2016, the proportion relative to global output having risen from 39% in 2000 to 45% in 2006 before falling back to under 40% since 2012 (see figure below).

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

[74] 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.

[75] See tables in Annex: Publication data

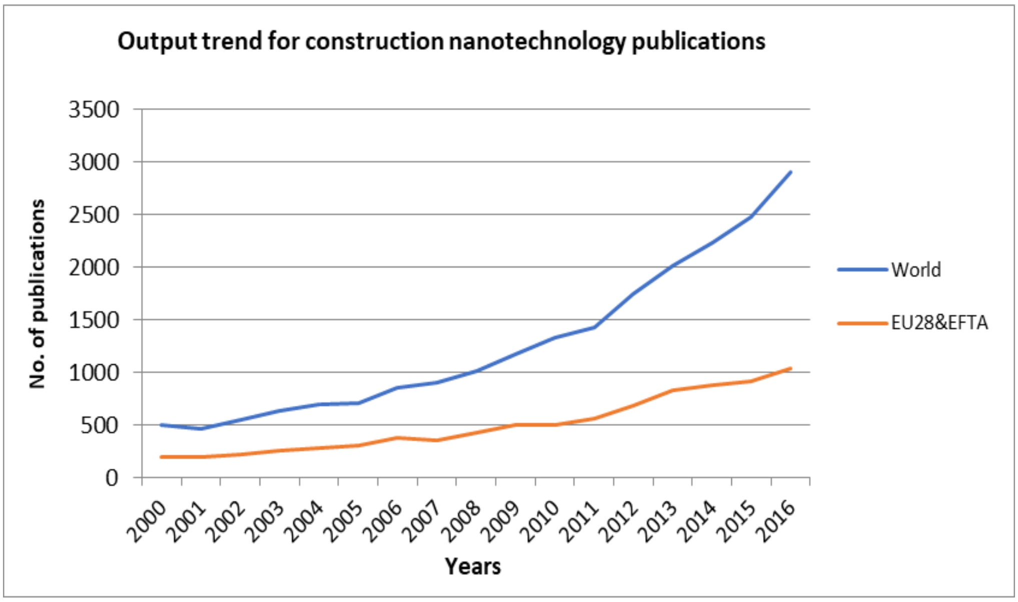

Figure A1.30. Construction nanotechnology publication output by year, worldwide and in the EU and EFTA countries (2000-2016)

The chart below visualises the growth as indexed to 2000 (=1) for EU28&EFTA and the world. As the world has increased the output by four times the output of 2000, EU28&EFTA doubled during the same period.

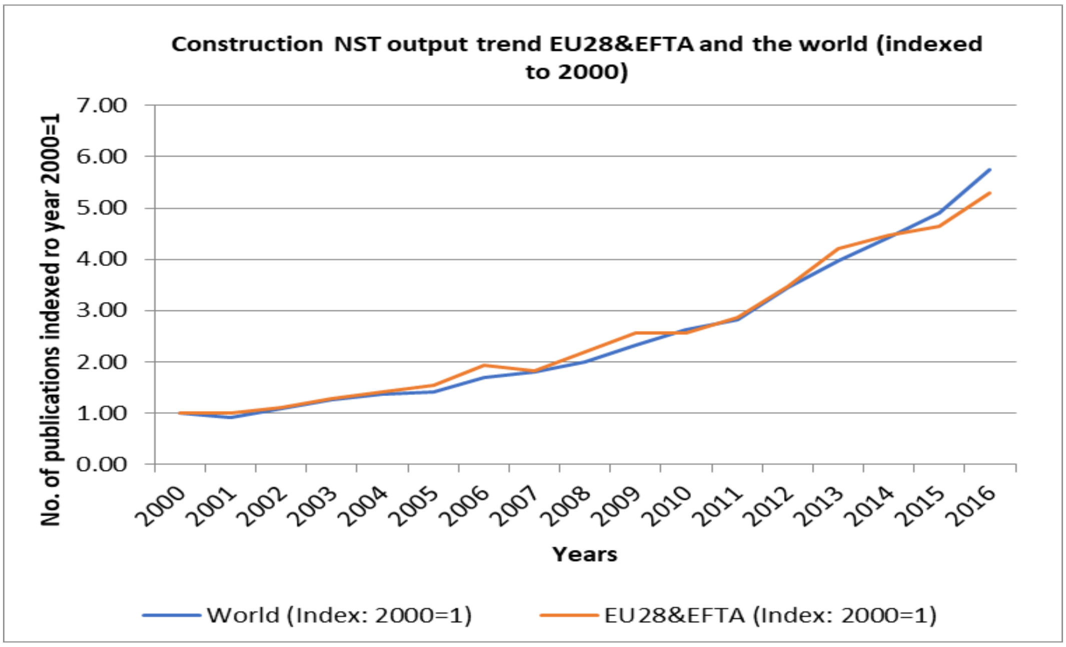

Figure A1.31. Output trend for nanotechnology and construction in EU28&EFTA and the world

The most prolific region in NST for construction is Asia, followed by EU28&EFTA and North America. The other regions have substantially less output, as shown in the table below.

Region	Npub

Asia	7,124
EU28&EFTA	8,651
North America	4,042
Middle East	2,247
South & Central America	1,138
Oceania	877
Africa	880

Table A1.36. Number of publications by region for construction and nanotechnology (2000-2016)

In 2016, the most prolific countries in NST for construction were China and the USA followed on a distance by Spain, the UK, India, South Korea and France.

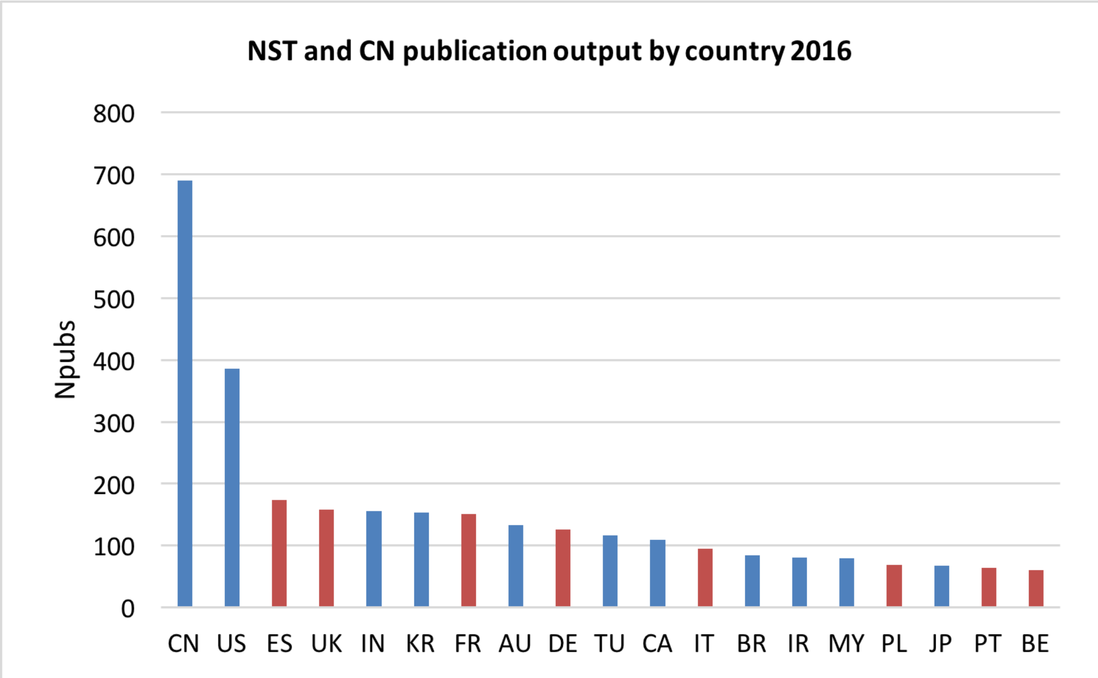

Figure A1.32. Publication output by country in construction and nanotechnology (2016)

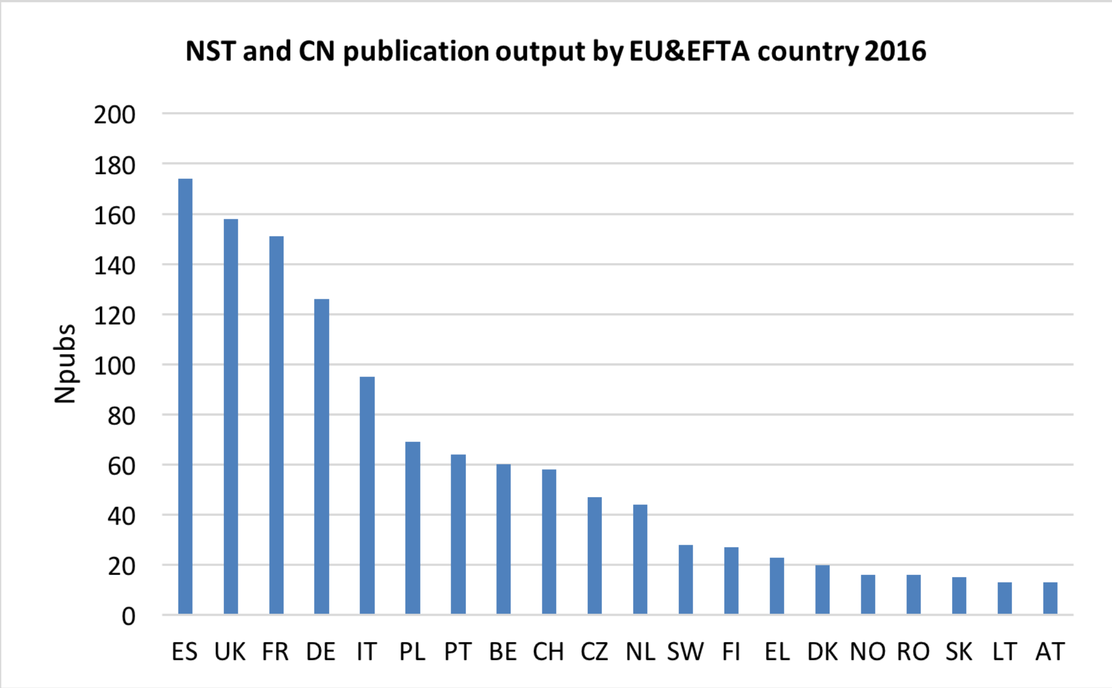

Figure A1.33. Publication output by EU&EFTA country in construction and nanotechnology (2016)

Identified from the publication data, the main players in the R&D landscape of NST construction are higher education institutions, research and technology organisations and industry. The most active organisations in NST for construction publications in 2016 are shown in the table below. The higher education organisations contributing to the most nanotechnology construction publications globally in 2016 were the Wuhan university of Technology, Southeast university, Tongji University, Tsinghua university (all China), and CSIC, Spain (all of them with more than 40 publications).

Within Europe, the CSIC, Ghent university, Delft University of Technology, CNRS and Universitat Politècnica de Catalunya are the most active organisations.

Institution	Country	Npub
Wuhan University of Technology	CN	53
Southeast University	CN	51
Tongji University	CN	46
Spanish National Research Council	ES	43
Tsinghua University	CN	43
University of Malaya	MY	32
Ghent University	BE	29
Harbin Institute of Technology	CN	29
Centre National de la Recherche Scientifique	FR	28
Delft University of Technology	NL	28
Universitat Politècnica de Catalunya	ES	26

Institution	Country	Npub
Chinese Academy of Sciences	CN	26
Curtin University	AU	25
Shenzhen University	CN	25
University of Lisbon	PT	24
Hohai University	CN	23
Hong Kong Polytechnic University	CN	23
Zhejiang University	CN	23
EMPA Swiss Federal Laboratories for Materials Science and Technology	CH	22
China University of Geosciences	CN	20
Czech Technical University, Prague	CZ	20

Table A1.37. Publication output in construction and nanotechnology by higher education institutions (2016)

Institution	Country	Npub
Spanish National Research Council (CSIC)	ES	43
Ghent University	BE	29
Delft University of Technology	NL	28
Centre National de la Recherche Scientifique (CNRS)	FR	28
Universitat Politècnica de Catalunya	ES	26
University of Lisbon	PT	24
EMPA Swiss Federal Laboratories for Materials Science and Technology	CH	22
Czech Technical University, Prague	CZ	20
Ecole Polytechnique Federale de Lausanne	CH	17
ETH Zurich	CH	16
University of Sheffield	UK	16
Brno University of Technology	CZ	14
University of Aveiro	PT	14
AGH University of Science and Technology	PL	13
Katholieke Universiteit Leuven	BE	13
Technical University of Madrid	ES	12

Institution	Country	Npub
Universitat Politècnica de València	ES	12
Cergy-Pontoise University	FR	12
Technische Universität München	DE	11
Université Paul Sabatier	FR	11
University of Aberdeen	UK	11
Silesian University of Technology	PL	11
University of Leeds	UK	11
Spanish National Research Council	ES	43

Table A1.38. Publication output in construction and nanotechnology by higher education institutions in EU&EFTA countries (2016)

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST for construction (2016) are shown in the table below. The amounts are small and hence only a short list. The companies contributing to the most nanotechnology construction publications and at least 3 publications globally in 2016 were Jiangsu Sobute New Mat Co Ltd, Zeobond Pty Ltd, China Three Gorges Corp and Giatec Sci Inc, as shown in the table of the top publishing companies worldwide.

Company	Country	Npub
Sobute New Materials Co. Ltd.	CN	10
Zeobond Pty Ltd	AU	4
China Three Gorges Corporation	CN	3
Giatec Scientific Inc	CA	3

Table A1.39. Publication output in construction and nanotechnology by companies (2016)

The next annex looks at patent data.

ANNEX 2: PATENT DATA BY SECTOR

Introduction

This annex reports patenting activity in nanotechnology by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using a combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (e.g. transport)[76]. 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[77] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[78] that are members of the treaty.

Each sector is considered in turn.

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

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

[78] 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

ICT AND NANOTECHNOLOGY (ICTNT)

Number and evolution over time of ICT nanotechnology patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[79,80] of granted patent and patent applications were found in the period 1993-2013[81]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[82].

In the same period, the number of ICT-related patent families identified among the nanotechnology patents is 7,119, 14% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EPO and USPTO do not sum to 100%. The highest percentage of nanotechnology ICT applications is at the USPTO (92%) while the figures corresponding to PCT (44%) and EPO (35%) are substantially lower.

ICT nanotechnology applications	Patent families	Share of patent families
Total patent families	7119	100%
USPTO applications	6550	92%
PCT applications	3166	44%
EPO applications	2511	35%

Table A2.1. Absolute numbers and percentages of patents on nanotechnology and ICT (1993-2013)

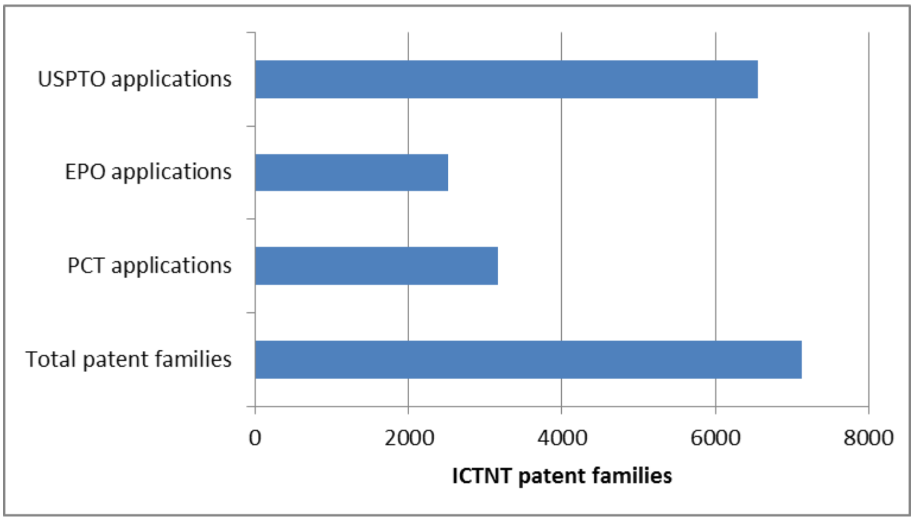

Figure A2.1. Number of nanotechnology and ICT patent families, total and by filing authority (1993-2013)

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

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

[80] 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/.

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

[82] 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.

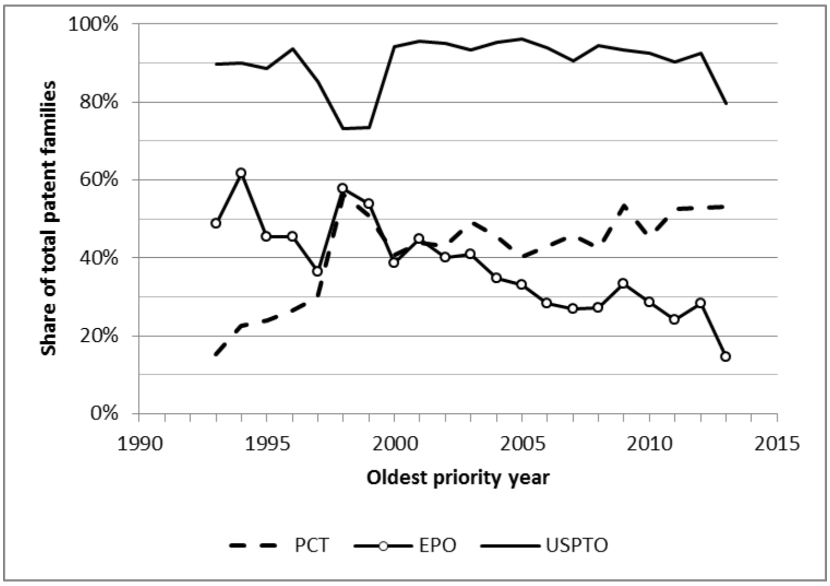

Figure A2.2. Evolution over time of WIPO (PCT), EPO and USPTO ICT nanotechnology patenting (1993-2013)

In the figure above it can be observed that the filings at EPO, USPTO and WIPO follow different patterns. The filings at the USPTO are more or less constant at the 90% level. PCT filings show an increase from 2000 onwards, whereas the EPO filings show at the same time a continuous decrease; the peak in 1998-1999 as an exception to this trend. The decline that is visible from 2013 is caused by the fact that not all data has been added to the patent databases.

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 and these authorities cover 93% of the PCT filings. The United States is by far the most prolific, followed by Japan and Europe (EPO). The patent filings at the EPO (262) are roughly one fifth of those at the USPTO.

Receiving authority	No. of patent families (1993-2013)
USPTO	1419
Japan	640
EPO	262
WIPO	123
Korea	116
United Kingdom	115
Germany	82
France	77
China	57
Canada	50

Table A2.2. Number of nanotechnology and ICT patent families by the top ten PCT receiving authorities (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 7,119 ICT-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in 15% of them while there is participation from the rest of the world in 85% of cases.

	EU28 & EFTA	Rest of World
Number of nanotechnology and ICT patent families	1037	6082
Percentage of nanotechnology and ICT patent families	15%	85%

Table A2.3. Origin of patent applicants, EU28&EFTA and rest of World (1993-2013)

Applicants may file patents with more than one patent authority, e.g. at the USPTO and at the EPO. The table below shows the data for the top ten countries of applicants, as well as indicating the percentage of patent families for each. EU28&EFTA countries are marked in bold. As patents may be filed in more than one patent authority (i.e. PCT, USPTO and EPO applications), the percentages can sum to more than 100%. By far the highest number of patent families is found where the country of the applicant is the United States (2224), followed by Japan already with a lower number of patents (1794). The European countries which account for a higher number of patents are Germany (332), Netherlands (199), United Kingdom (184) and France (179) all of them among the top 10 countries in number of patent families.

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
1	US	2224	62%	99%	41%
2	JP	1794	31%	90%	26%
3	KR	431	21%	94%	22%
4	DE	332	71%	79%	66%
5	NL	199	54%	88%	63%
6	UK	184	86%	80%	61%
7	FR	179	65%	85%	85%
8	TW	125	7%	100%	6%
9	CA	100	70%	100%	43%
10	CN	89	40%	92%	16%

Table A2.4. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Almost all patents by US applicants are filed with the USPTO while around half are filed as PCTs. Only 40% of the patents by US applicants are filed at the EPO. With the exception of France, applicants from the EU28&EFTA countries file less frequently at the EPO than at the USPTO or via the PCT route. Looking at the non-EU28&EFTA and non-US countries of applicants, the filing shows a preference, among the patent authorities considered in this study, for filing at the USPTO.

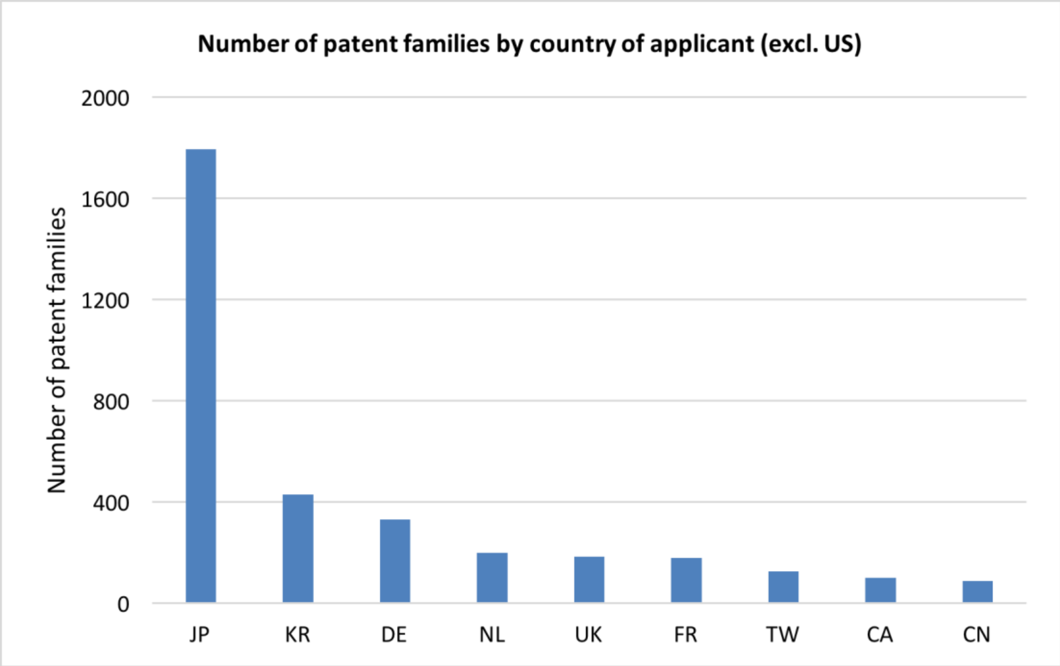

Figure A2.3. Number of patent families by country of applicant for the top ten countries excluding the US (1993-2013)

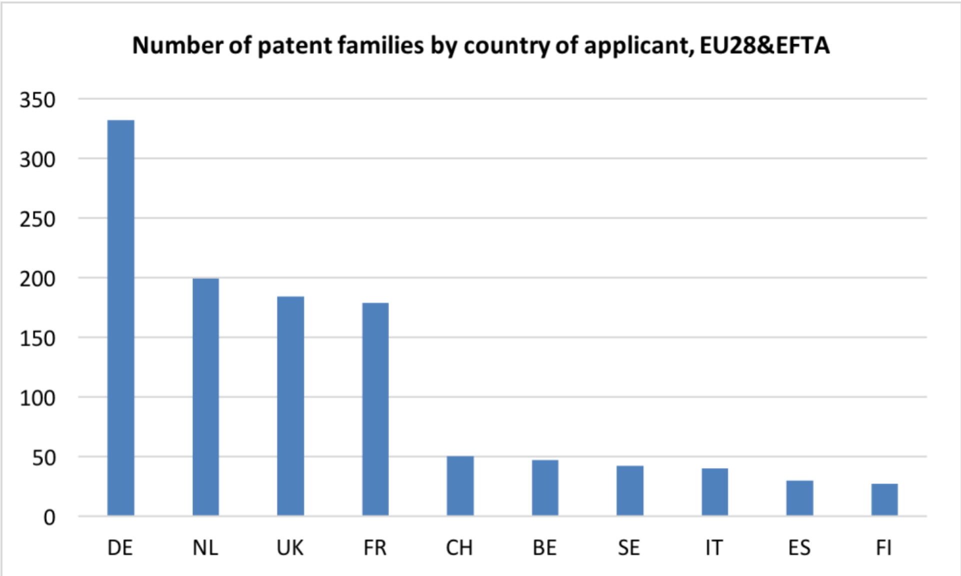

Figure A2.4. Number of patent families by country of applicant for the top ten EU28&EFTA countries (1993-2013)

World rank	Country of applicant	No. of Patent Families	Share of applications		
			PCT	US	EP
4	DE	332	71%	79%	66%
5	NL	199	54%	88%	63%
6	UK	184	86%	80%	61%
7	FR	179	65%	85%	85%
12	CH	50	82%	82%	78%

World rank	Country of applicant	No. of Patent Families	Share of applications		
			PCT	US	EP
13	BE	47	34%	89%	85%
15	SE	42	93%	79%	67%
17	IT	40	60%	75%	68%
18	ES	30	87%	67%	47%
20	FI	27	93%	81%	59%
22	DK	10	100%	80%	60%
23	AT	10	50%	70%	60%
24	IE	8	63%	88%	38%
26	NO	6	100%	83%	83%
27	PL	6	33%	50%	50%
28	PT	5	100%	80%	100%
31	RO	4	75%	75%	75%
33	SI	3	100%	33%	33%
35	GR	3	33%	100%	33%
38	CY	3	100%	100%	100%
41	LU	2	100%	100%	100%
53	CZ	1	0%	100%	100%

Table A2.5. Number of patent families by country of applicant and receiving authority for EU28&EFTA countries (1993-2013)

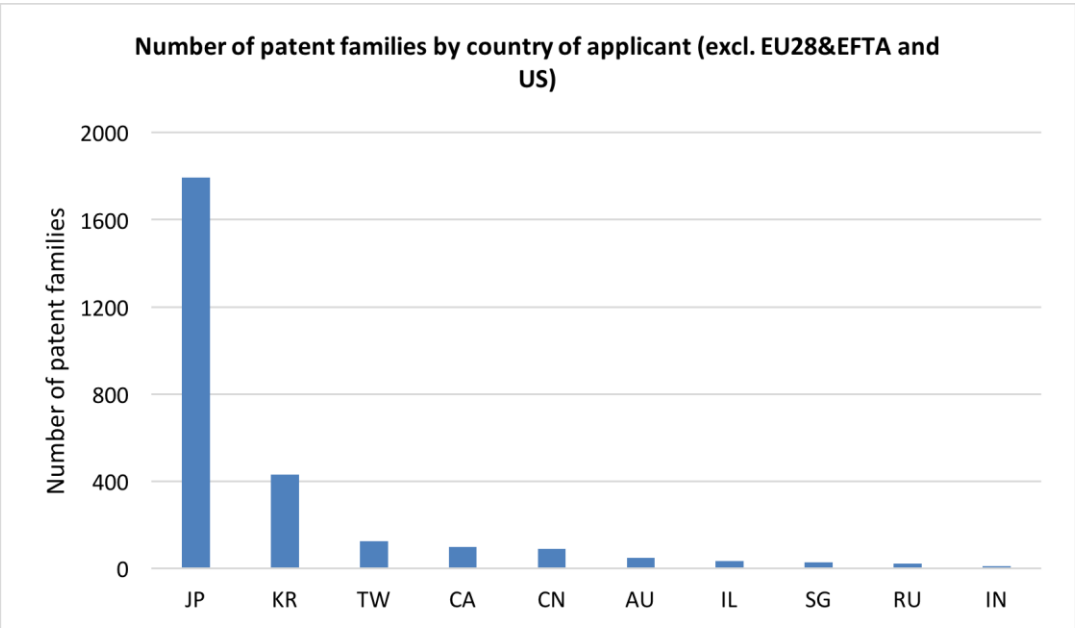

Figure A2.5. Number of patent families by country of applicant for the top ten non-EU28&EFTA, non-US countries (1993-2013)

GRANTED PATENTS

The country from the EU and EFTA performing most strongly in patents granted by the EPO is Germany, followed by France and the Netherlands. These countries, together with the United Kingdom, also have the most patents granted by the USPTO. For all countries, the number of patents granted by the USPTO is substantially larger than by the EPO.

World rank[83]	EU28&EFTA country of applicant	Number of EPO patents granted
4	DE	80
6	FR	62
5	NL	38
9	UK	27
12	BE	9
13	IT	8
15	CH	6
23	AT	3
17	SE	3
18	FI	2
24	NO	2
28	DK	1
29	PT	1
19	ES	1

Table A2.6. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

World rank[84]	EU28&EFTA Country of applicant	Number of USPTO patents granted
4	DE	168
5	NL	118
6	FR	104
9	UK	59
12	BE	27

[83] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

[84] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[84]	EU28&EFTA Country of applicant	Number of USPTO patents granted
13	IT	22
15	CH	20
17	SE	14
18	FI	10
19	ES	7
23	AT	4
25	IE	4
24	NO	4
26	CY	3
28	DK	2
31	PL	2
29	PT	2
32	RO	2
37	CZ	1
39	GR	1
44	LU	1

Table A2.7. Number of USPTO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

The country from the EU and EFTA performing most strongly in patents granted by the EPO or the USPTO is Germany, followed by Netherlands and France. France performs better on patents granted by the EPO and Netherlands shows a better performance on patent granted by the USPTO. For all countries, the number of patents granted by the USPTO is substantially larger than by the EPO.

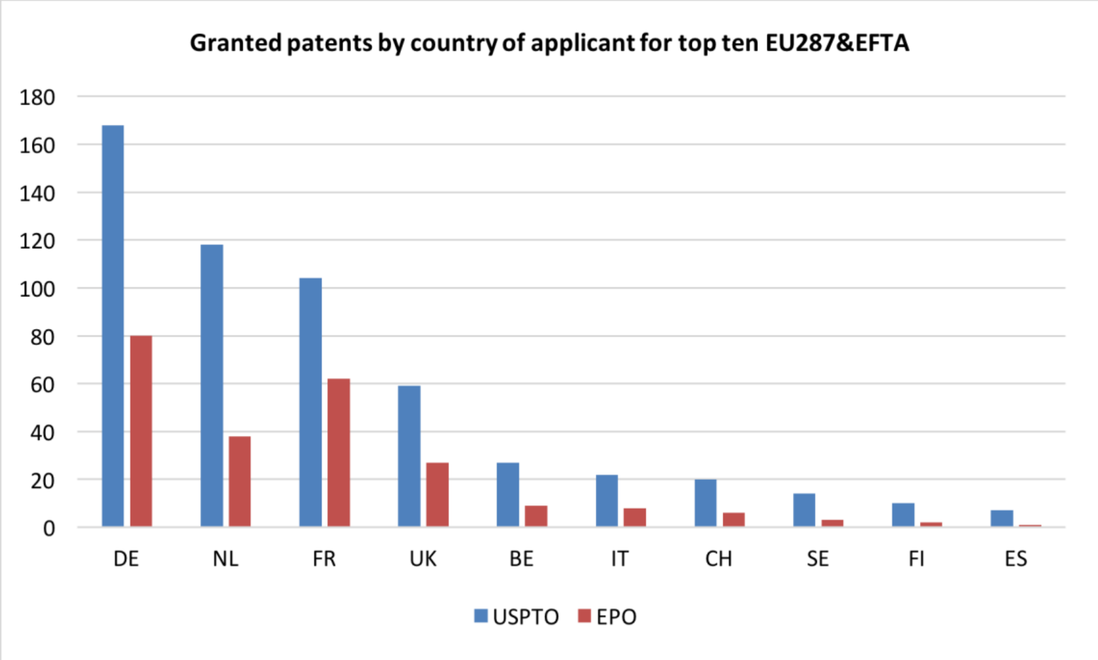

Figure A2.6. Granted patents by country of applicant for top ten EU28&EFTA countries (1993-2013)

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.

INVT	CA	CN	FR	DE	JP	KR	NL	TW	UK	US
APPL										
CA	91	2	2	9	1	0	0	0	5	26
CN	0	81	1	0	4	0	0	4	0	19
FR	2	1	172	8	3	0	5	0	5	22
DE	6	0	15	295	5	1	12	0	15	60
JP	0	5	2	6	1761	4	1	0	19	55
KR	0	8	1	2	6	424	0	0	0	26
NL	1	0	8	14	25	0	94	0	12	78
TW	0	15	1	0	0	0	0	102	0	20
UK	4	0	6	8	5	0	5	2	142	57
US	36	22	25	51	83	24	10	10	34	2089

Table A2.8. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

Among the top ten universities and public research organisations (PROs) with the highest number of patent families (with percentages for PCT, USPTO and EPO applications), six are from outside the United States. Three organisations (CEA and CNRS from France and IMEC from Belgium) are from the EU28&EFTA countries, while only the French organisations are among the top 30 applicants worldwide.

World rank	Country	Organisation	No. of patent families	Share of patent applications		
				PCT	USPTO	EPO
12	US	University of California	69	67%	75%	25%
14	FR	CEA	67	52%	66%	57%
22	US	CalTech	38	50%	97%	16%
23	FR	CNRS	38	68%	45%	68%
25	KR	Elect & Telecommunications Res Institute	36	8%	81%	8%
26	JP	JP Science & Technology Agency	34	71%	82%	56%
35	US	Massachusetts Institute Technology	30	83%	77%	23%
40	BE	IMEC	27	11%	67%	70%
50	TW	Industrial Technology Research Institute	20	0%	100%	0%
54	US	William Marsh Rice University	18	72%	83%	22%

Table A2.9. Number of patent families for top ten universities and PROs (1993-2013)

World rank	Country	Organisation	No. of patent families	Share of patent applications		
				PCT	USPTO	EPO
14	FR	CEA	67	52%	66%	57%
23	FR	CNRS	38	68%	45%	68%
25	KR	Elect & Telecoms Res Inst	36	8%	81%	8%
26	JP	JP Science & Technology Agency	34	71%	82%	56%
40	BE	Imec	27	11%	67%	70%
50	TW	Industrial Technology Research Institute	20	0%	100%	0%
61	KR	KR Institute of Science &	17	18%	82%	24%

World rank	Country	Organisation	No. of patent families	Share of patent applications		
				PCT	USPTO	EPO
		Technology				
68	KR	KR Advanced Institute of Science & Technology	15	7%	47%	13%
71	JP	National Institute of Advanced Ind. Science & Technology	15	0%	73%	33%
73	JP	JP Science & Technology Corp	15	93%	20%	7%

Table A2.10. Number of patent families in the top EU28&EFTA universities and PROs (1993-2013)

GRANTED PATENTS

The table below shows the public research organisations (PROs: higher education organisations or public research organisations) ranked by the highest number of EPO patents granted between 1993 and 2013. Only a few PROs have granted patents by the EPO, and three of them are from the EU28&EFTA countries (from France and Belgium).

Rank	Country	Organisation	EPO	USPTO
1	FR	CEA	17	41
2	FR	CNRS	15	14
3	JP	JP Science & Technology Agency	6	26
4	BE	IMEC	6	11
5	US	William Marsh Rice University	3	13

Table A2.11. Top five universities/research organisations with three or more EPO patents, ordered by decreasing number of EPO patents (1993-2013)

Ranking by the number of USPTO patents granted between 1993 and 2013, nine of the top 12 universities and research organisations are in the US and only two in the EU28&EFTA.

Rank	Country	Organisation	USPTO	EPO
1	FR	CEA	41	17
2	US	University California	41	2
3	US	California Institute Technology	36	2
4	JP	JP Science & Technology Agency	26	6
5	KR	Elect & Telecommunications Res Institute	24	2
6	US	Massachusetts Institute Technology	23	2
7	TW	Industrial Technology Research Institute	16	0

Rank	Country	Organisation	USPTO	EPO
8	FR	CNRS	14	15
9	KR	KR Institute of Science & Technology	14	1
10	US	William Marsh Rice University	13	3

Table A2.12 Top ten universities/research organisations granted USPTO patents, ordered by decreasing number of USPTO patents (1993-2013)

Activity of companies

PATENT APPLICATIONS

The top ten companies with the highest number of patent families (with percentages for PCT, USTO and EPO applications come in majority from Japan. Germany and Netherlands are the only EU28&EFTA countries that feature in this table and are marked in bold. It should be noted that some may be holding companies rather than research companies or manufacturers.

Country	Company	No. of patent families	Share of applications		
			PCT	USPTO	EPO
JP	KK Toshiba	239	5%	97%	7%
KR	Samsung Elect Co Ltd	181	5%	84%	23%
JP	TDK Corp	159	13%	96%	16%
JP	Sony Corp	130	25%	87%	30%
JP	Fujitsu Ltd	122	23%	87%	20%
JP	Hitachi Ltd	121	17%	83%	14%
DE	Infineon Technology AG	82	49%	74%	40%
NL	Hitachi Global Storage Technology	78	0%	90%	21%
JP	Matsushita Elect Ind. Co. Ltd	69	64%	65%	35%
JP	Fujifilm Corp	66	11%	79%	42%

Table A2.13. Number of patent families for top ten companies (1993-2013)

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[85]. The first table shows the top ten when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In the first table, two companies from Netherlands (Philips and NXP) and one company from Germany (Infineon) appear as the main companies in EPO patents.

Interestingly, according to the number of patents granted by the USPTO, there is only

[85] 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.

one US company (IBM) in the top five.

There are five countries Japan, United States, Korea, Germany and the Netherlands populating both tables below.

Country	Company	EPO	USPTO
US	IBM Corp	26	156
KR	Samsung Elect Co Ltd	20	119
DE	Infineon Technology AG	17	57
NL	Kon Philips Elects NV	15	11
JP	Fujitsu Ltd	12	74
US	Hewlett Packard Co	12	18
US	EI Du Pont de Nemours & Co	12	12
US	Hewlett Packard Dev Co Lp	11	65
NL	NXP BV	10	11
JP	Seiko Instruments Inc	10	7

Table A2.14. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

Country	Company	USPTO	EPO
JP	KK Toshiba	200	8
US	IBM Corp	156	26
JP	TDK Corp	128	9
KR	Samsung Elect Co Ltd	119	20
JP	Sony Corp	102	8
JP	Hitachi Ltd	98	8
JP	Fujitsu Ltd	74	12
NL	Hitachi Global Storage Technology	68	8
US	Hewlett Packard Dev Co Lp	65	11
US	Seagate Technology Ltd	64	1

Table A2.15. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

MANUFACTURING AND NANOTECHNOLOGY (MFNT)

Overview

This section looks at the patenting activity in nanotechnology and manufacturing by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (manufacturing, in this case)[86]. 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[87] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[88] that are members of the treaty.

Number and evolution over time of nanotechnology manufacturing patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[89,90] (manufacturing and nanotechnology) of granted patent and patent applications were found in the period 1993-2013[91]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[92].

In the same period, the number of manufacturing-related patent families identified among the nanotechnology patents is 3,222, 6.3% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EPO and USPTO do not sum to 100%. The highest percentage of manufacturing nanotechnology applications is in the USPTO (91%) while the figures corresponding to PCT (54%) and EPO (37%) are considerable lower.

Manufacturing nanotechnology applications	Patent families	Share of patent families
Total patent families	3222	100%

[86] 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.

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

[88] 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

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

[90] 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/.

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

[92] 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.

Manufacturing nanotechnology applications	Patent families	Share of patent families
USPTO applications	2925	91%
PCT applications	1725	54%
EPO applications	1193	37%

Table A2.16. Absolute numbers and percentages of patents on nanotechnology and manufacturing (1993-2013)

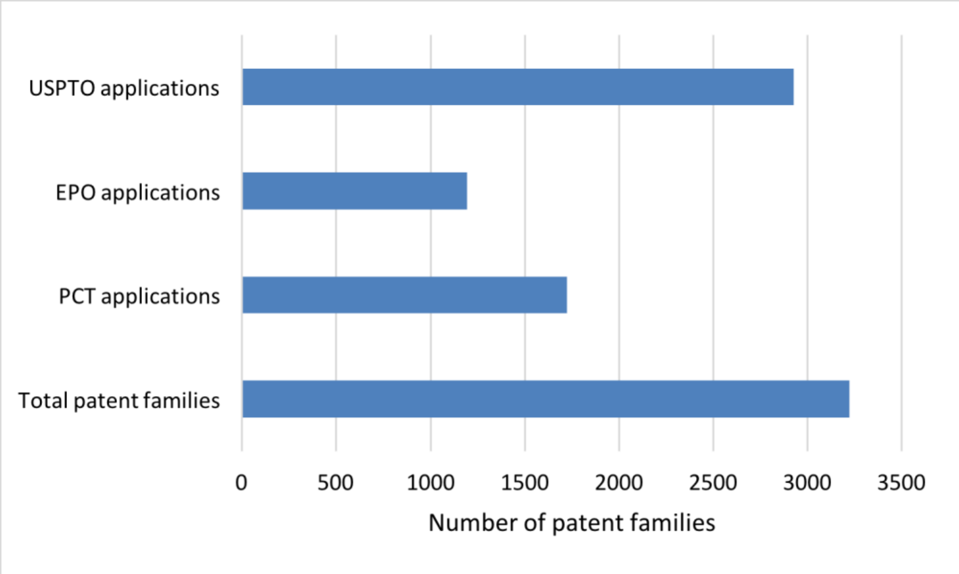

Figure A2.7. Number of manufacturing nanotechnology patent families, total and by filing authority (PCT, EPO, and USPTO) (1993-2013)

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

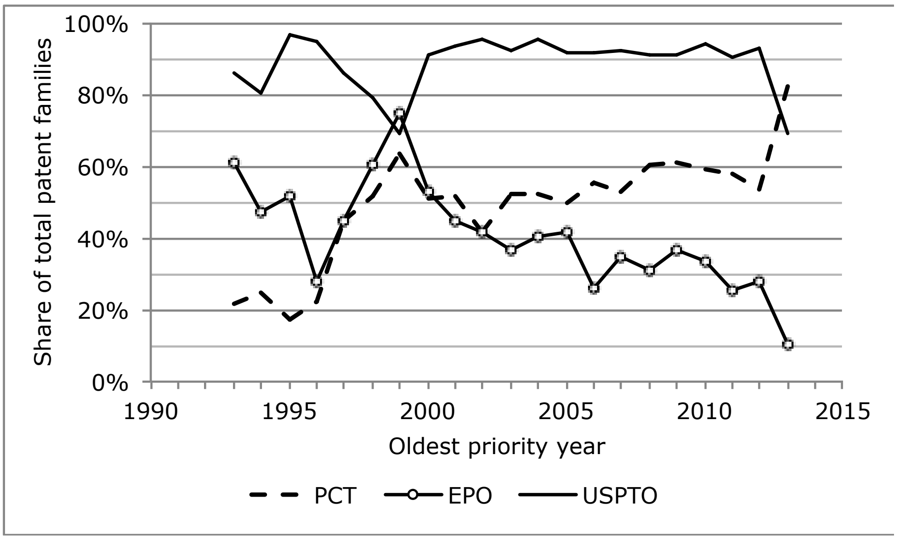

Figure A2.8. Evolution over time of WIPO (PCT), EPO and USPTO manufacturing and nanotechnology patenting (1993-2013)

In this figure, it can be observed that the filings at USPTO are at a more or less constant high level in the period 2000-2013. The filings at the WIPO follow a somewhat similar pattern in the same period; a significant increase in the WIPO and EPO filings is visible in the period 1996-2000, while at the same time the filings at the USPTO decreased. From 2004 onwards, filing at the EPO started to decline for the rest of the period. The decline that is visible from 2013 is caused by the fact that not all data has been added to the patent databases.

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 patent authorities through which PCT applications were filed are shown in the table. The USA is by far the most prolific, followed by Japan and European Patent Office. The filings at the EPO (244)) are less than a third of those at the USPTO and the sum of the figures for the European national patent offices and the EPO is 463 (including but not only those shown in the table), roughly two-thirds of the US filings.

Receiving Authority	No. of Patent Families
USPTO	788
Japan	250
EPO	244
Korea	74
France	66
United Kingdom	50
WIPO	48
Netherlands	32
China	26
Canada	23

Table A2.17. Number of manufacturing nanotechnology patent families by PCT receiving authority, top ten receiving authorities (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 3,222 manufacturing-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in 14%, while there is participation from the rest of the world in 86% of cases.

	EU28 & EFTA	Rest of World
Manufacturing and nanotechnology patent families	463	2759
Percentage manufacturing and nanotechnology patent families	14%	86%

Table A2.18. Origin of patent applicants, EU28&EFTA and rest of World (1993-2013)

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

By far the highest number of patent families is found where the country of the applicant is the US (1314), followed by Japan already with a considerably lower number of patents (768). The European countries which account for a higher number of patents are the

Netherlands (260), Germany (236), France (148) and the United Kingdom (92), all of them among the top 10 countries in number of patent families.

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
1	US	1314	51%	86%	35%
2	JP	768	63%	92%	34%
3	KR	336	37%	89%	25%
4	NL	260	24%	86%	22%
5	DE	236	47%	88%	39%
6	FR	148	58%	75%	63%
7	TW	123	74%	80%	79%
8	CN	104	0%	98%	3%
9	UK	92	37%	68%	13%
10	CA	47	75%	58%	55%

Table A2.19. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Almost all (86%) of the patents by US applicants are filed with the USPTO while roughly 50% are filed as PCTs. Only one third of the patents by US applicants are filed at the EPO. Also among the European applicants the USPTO is the preferred place to file patents.

Looking at the non-EU28&EFTA and non-US countries of applicants, the filing shows a preference, among the patent authorities considered in this study, to filing most at the USPTO, except for Canada.

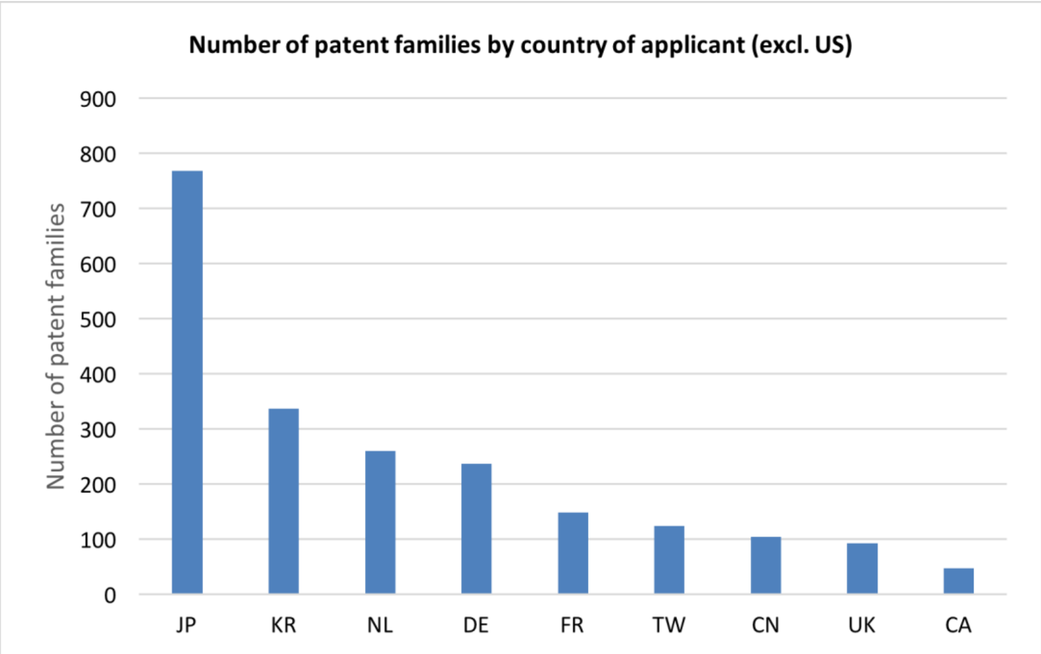

Figure A2.9. Number of patent families by country of applicant, top ten countries excluding the United States (1993-2013)

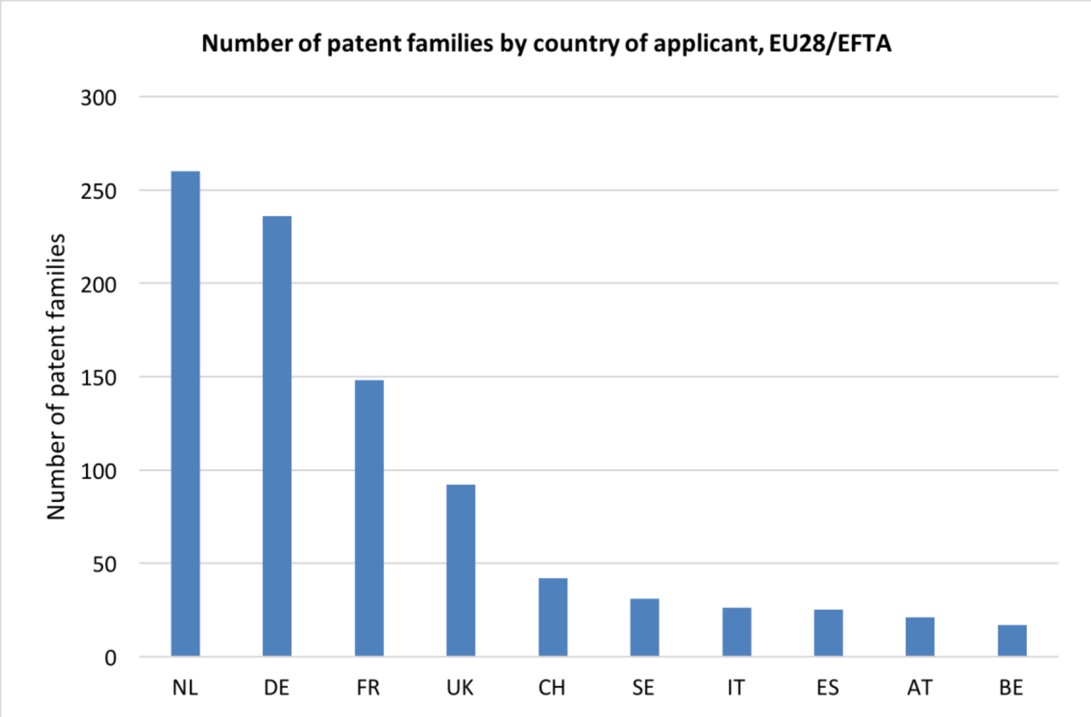

Figure A2.10. Number of patent families by country of applicant for the top ten EU28&EFTA countries (1993-2013)

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
4	NL	260	47%	88%	39%
5	DE	236	58%	75%	63%
6	FR	148	74%	80%	79%
9	UK	92	75%	58%	55%
11	CH	42	69%	71%	62%
12	SE	31	61%	87%	65%
13	IT	26	58%	81%	46%
14	ES	25	84%	56%	40%
18	AT	21	38%	81%	38%
20	BE	17	35%	82%	76%

Table A2.20. Number of patent families by country of applicant and receiving authority for EU28&EFTA applicant countries (1993-2013)

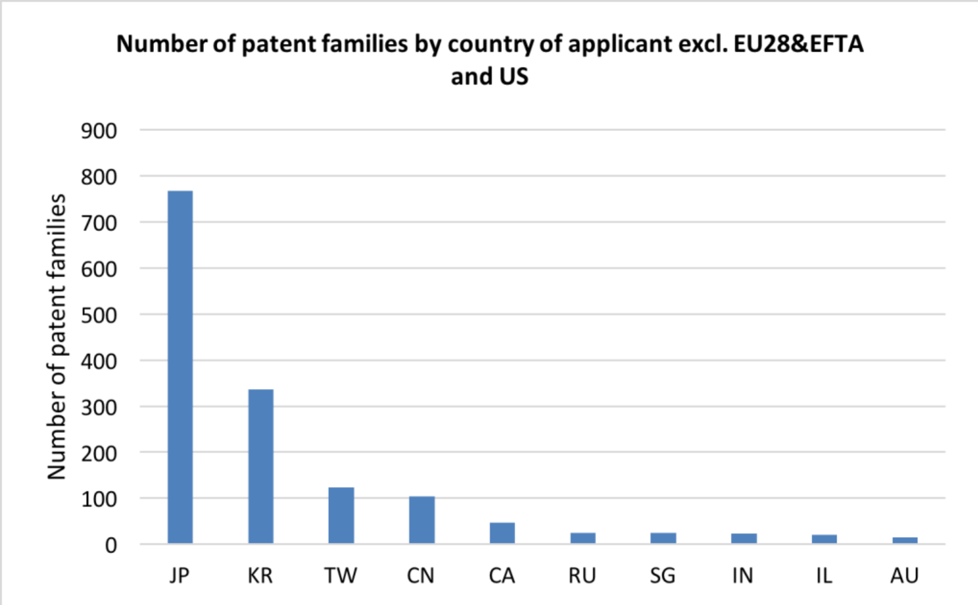

Figure A2.11. Number of patent families by country of applicant for the top ten non-EU28&EFTA, non-US countries (1993-2013)

GRANTED PATENTS

The country from the EU and EFTA performing most strongly in patents granted by the EPO is Germany, followed by the Netherlands, France and the United Kingdom. These four countries also have the most patents granted by the USPTO of the EU28&EFTA countries. In general, for the EU28&EFTA countries, more manufacturing nanotechnology patent are granted by the USPTO than by the EPO.

World rank[93]	EU28&EFTA country of applicant	Number of EPO patents granted
5	DE	55
4	NL	47
6	FR	40
9	UK	23
11	CH	8
12	SE	6
13	AT	4
15	BE	4
14	IT	4
23	FI	3
32	NO	3

[93] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[93]	EU28&EFTA country of applicant	Number of EPO patents granted
21	PL	3
24	DK	1
27	LU	1
19	ES	1

Table A2.21. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

World rank[94]	EU28&EFTA Country of applicant	Number of USPTO patents granted
4	NL	161
5	DE	110
6	FR	74
9	UK	29
11	CH	19
12	SE	14
13	AT	12
14	IT	11
15	BE	8
19	ES	6
21	PL	4
30	CZ	3
24	DK	3
23	FI	3
31	IE	3
27	LU	3
32	NO	1
42	PT	1
43	SK	1

Table A2.22. Number of USPTO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

[94] Ibid

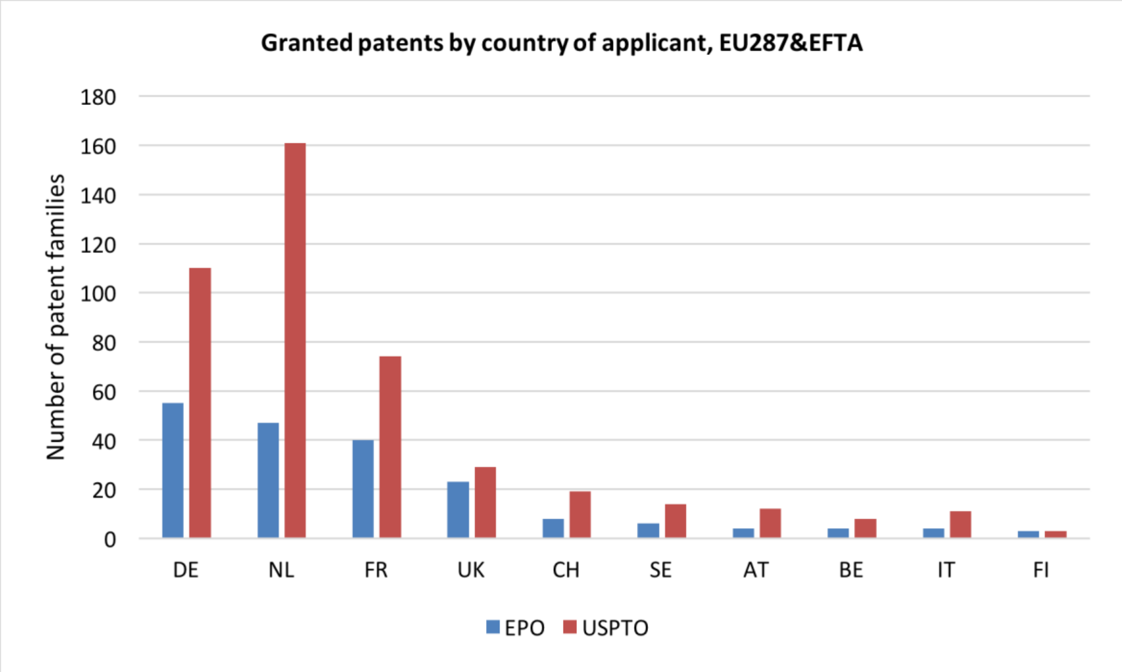

Figure A2.12. Granted patents by country of applicant for top ten EU28&EFTA countries (1993-2013)

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.

INVT	CA	CN	FR	DE	JP	KR	NL	TW	UK	US
APPL										
CA	46	1	5	2	0	0	1	1	1	12
CN	1	101	0	2	6	11	0	8	1	14
FR	5	0	146	3	2	0	3	0	0	5
DE	2	2	4	219	2	2	25	0	6	25
JP	0	6	1	2	733	4	0	0	4	69
KR	0	10	0	2	4	331	0	0	2	27
NL	1	0	5	18	3	1	228	0	3	35
TW	1	31	0	0	0	0	0	97	0	7
UK	1	1	0	4	1	2	3	0	80	23
US	13	14	6	25	54	27	19	8	18	1247

Table A2.23. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

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

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
4	US	University of California	65	72%	80%	23%
12	FR	CEA	42	62%	60%	19%
19	FR	CNRS	33	79%	67%	73%
21	US	University of Texas	31	13%	77%	55%
24	US	Massachusetts Institute Technology	30	83%	77%	20%
26	CN	Tsinghua University	28	7%	93%	4%
27	US	Northwestern University	28	82%	82%	21%
32	JP	National Institute of Advanced Ind. Science and Technology	24	92%	67%	46%
38	TW	Industrial Technology Research Institute	24	0%	100%	0%
36	KR	Elect & Telecommunications Res Institute	21	5%	91%	19%

Table A2.24. Number of patent families for top ten universities and PROs (1993-2013)

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

World rank	Country	Organisation	No. of Patent families	Share of applications		
				PCT	USPTO	EPO
3	FR	CEA[95]	94	48%	55%	9%
17	FR	CNRS[96]	36	72%	61%	69%
78	DE	Fraunhofer[97]	11	73%	36%	82%

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

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

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

100	ES	CSIC[98]	9	78%	22%	44%

Table A2.25. Number of patent families in the top EU28&EFTA universities and PROs (1993-2013)

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted between 1993 and 2013. Only a few PROs have granted patents by the EPO, and three of them are from the EU28&EFTA countries (from France and Germany).

Rank	Country	Organisation	EPO	USPTO
1	US	University of Texas	8	13
2	FR	CNRS	7	16
3	DE	Fraunhofer Gesellschaft	5	1
4	FR	CEA	4	38
5	US	Northwestern University	4	18
6	JP	National Institute of Advanced Ind. Science and Technology	4	13
7	JP	JP Science & Technology Agency	4	6
8	KR	KR Institute of Energy Research	4	3

Table A2.26. Top universities/research organisations with four or more patents granted by the EPO, ordered by number of EPO patents (1993-2013)

Ranking by the number of USPTO patents granted between 1993 and 2013, four of the top ten universities and research organisations are in the United States and only two in the EU28&EFTA.

Rank	Country	Organisation	USPTO	EPO
1	FR	CEA	38	4
2	US	University California	38	3
3	CN	Tsinghua University	22	1
4	US	Northwestern University	18	4
5	US	Massachusetts Institute of Technology	17	2
6	FR	CNRS	16	7
7	KR	Elect & Telecommunications Res Institute	16	2
8	US	University of Texas	13	8
9	JP	National Institute of Advanced Ind. Science and Technology	13	4

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

Rank	Country	Organisation	USPTO	EPO
10	KR	KR Institute of Science & Technology	12	2

Table A2.27. Top ten universities/research organisations with patents granted, ordered by number of USPTO patents (1993-2013)

Activity of companies

PATENT APPLICATIONS

The top ten companies with the highest number of patent families (with percentages for PCT, USPTO and EPO applications), belong to four different countries. The Netherlands is the only EU28 countries that features in the table, marked in bold. It should be noted that some may be holding companies rather than research companies or manufacturers.

World rank[99]	Country	Company	No. of patent families	Share of applications		
				PCT	USPTO	EPO
1	NL	ASML Netherlands BV	125	30%	90%	18%
2	US	Molecular Imprints Inc	109	87%	94%	33%
3	KR	Samsung Elect Co Ltd	82	1%	84%	18%
5	US	IBM Corp	63	51%	97%	38%
6	JP	Nuflare Technology Inc	59	0%	100%	0%
8	NL	Mapper Lithography IP BV	55	91%	80%	69%
9	JP	Canon KK	52	6%	100%	25%
10	JP	Asahi Glass Co Ltd	43	98%	84%	21%
13	JP	KK Toshiba	38	5%	100%	3%
18	US	Applied Materials Inc	33	30%	90%	18%

Table A2.28. Number of patent families for top ten companies (1993-2013)

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[100]. The first table shows the top ten when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In the first table, three companies from Netherlands (Mapper Lithography, ASML and Philips) appear.

Rank	Country	Company	EPO	USPTO
1	US	IBM Corp	12	44
2	NL	Mapper Lithography IP BV	12	32

[99] The ranking is for all organisations, not only companies

[100] 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.

Rank	Country	Company	EPO	USPTO
3	NL	ASML Netherlands BV	11	81
4	US	Molecular Imprints Inc	10	73
5	JP	Hitachi Ltd	6	21
6	JP	Canon KK	5	37
7	US	Lucent Technology Inc	5	7
8	NL	Kon Philips Elects NV	5	5

Table A2.29. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

Rank	Country	Company	USPTO	EPO
1	NL	ASML Netherlands BV	81	11
2	US	Molecular Imprints Inc	73	10
3	KR	Samsung Elect Co Ltd	54	4
4	JP	Nuflare Technology Inc	50	0
5	US	IBM Corp	44	12
6	JP	Canon KK	37	5
7	JP	KK Toshiba	35	1
8	NL	Mapper Lithography IP BV	32	12
9	JP	Asahi Glass Co Ltd	32	1
10	US	Applied Materials Inc	26	2

Table A2.30. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

Interestingly, according to the number of patents granted by the USPTO, the Dutch company ASML is the company with the most patents granted by the USPTO.

HEALTH AND NANOTECHNOLOGY (HTNT)

Overview

This section looks at the patenting activity in nanotechnology and health by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (health, in this case). 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[101] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the easy filing of patent applications in countries[102] that cooperate in this treaty.

Number and evolution over time of health nanotechnology patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[103,104] of granted patent and patent applications were found in the period 1993-2013[105]. All of these were from the European Patent Office (EPO), US Patent and Trademark Office (USPTO) or the World Intellectual Property Organisation (WIPO)[106].

In the same period, the number of health-related patent families identified among the nanotechnology patents is 3,433, 6.8% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EPO and USPTO do not sum to 100%. The highest percentage of health NT applications is in the USPTO (89%), with a slightly lower percentage for PCT applications (80%) and a considerably lower percentage for EPO applications (58%).

Health nanotechnology applications	Patent families	Share of patent families
Total patent families	3433	100%
USPTO applications	3071	89%
PCT applications	2741	80%

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

[102] 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

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

[104] 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/.

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

[106] 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.

EPO applications	2004	58%

Table A2.31. Absolute numbers and percentages of patents on nanotechnology and health (1993-2013)

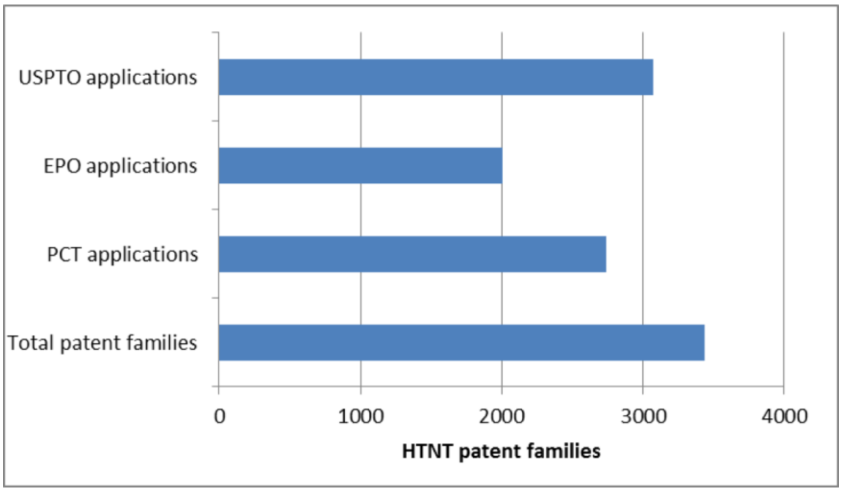

Figure A2.13. Number of nanotechnology and health patent families, total and by filing authority (1993-2013)

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.

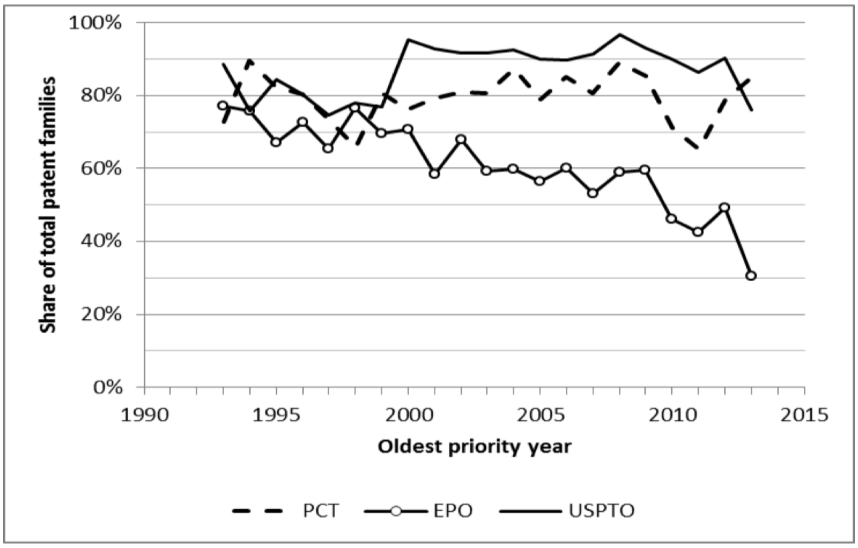

Table A2.32. Evolution over time of WIPO (PCT), EPO and USPTO nanotechnology and health patenting

In this figure, it can be observed that the filings at USPTO and WIPO follow an almost similar pattern. In both cases the share of patent families is almost constant since 2000. The share of total patent families filed at the EPO show a continuous decline since 1994. The decline that is visible from 2013 is caused by the fact that not all data has been added to the patent databases.

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 patent authorities through which PCT applications were filed are shown in the table. The USPTO is by far the most prolific, followed by Japan and Europe (EPO). The number of EPO filings is about one quarter of USPTO filings.

Receiving authority	No. of patent families (1993-2013)

USPTO	1426
EPO	329
Japan	132
WIPO	129
United Kingdom	123
Korea	84
France	57
China	56
Canada	53
Israel	39

Table A2.33. Number of nanotechnology and health patent families by PCT receiving authority, top ten receiving authorities (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 3,433 health-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in 18% of them while there is participation from the rest of the world in 82% of cases.

	EU28 & EFTA	Rest of World
Number of nanotechnology and health patent families	609	2824
Percentage of nanotechnology and health patent families	18%	82%

Table A2.34. Origin of patent applicants, EU28&EFTA and rest of World (1993-2013)

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

By far the highest number of nanotechnology and health patent families is found where the country of the applicant is the US (1865), followed by Germany with significantly less patents (284). Japan (174), United Kingdom (168) and France (161) populate positions 3 to 5 with comparable numbers of patent families. Germany, United Kingdom and France are EU28&EFTA among the top ten countries in number of patent families.

	Country of applicant	No. of Patent Families	Share of applications		
			PCT	USPTO	EPO
1	US	1865	70%	82%	56%
2	DE	284	67%	91%	51%

	Country of applicant	No. of Patent Families	Share of applications		
			PCT	USPTO	EPO
3	JP	174	74%	71%	75%
4	UK	168	79%	77%	61%
5	FR	161	77%	74%	72%
6	KR	149	73%	80%	82%
7	CA	118	60%	78%	36%
8	CN	93	60%	90%	47%
9	IL	87	72%	76%	40%
10	IN	80	69%	85%	47%

Table A2.35. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Most of the nanotechnology and health patents by US applicants – 82% – are filed with the USPTO while roughly 70% are filed as PCT application. Only 56% of the patents filed by applicants from the United States are filed at the EPO. Among the European applicants, applicants from Germany have a preference for the USPTO and use the EPO less.

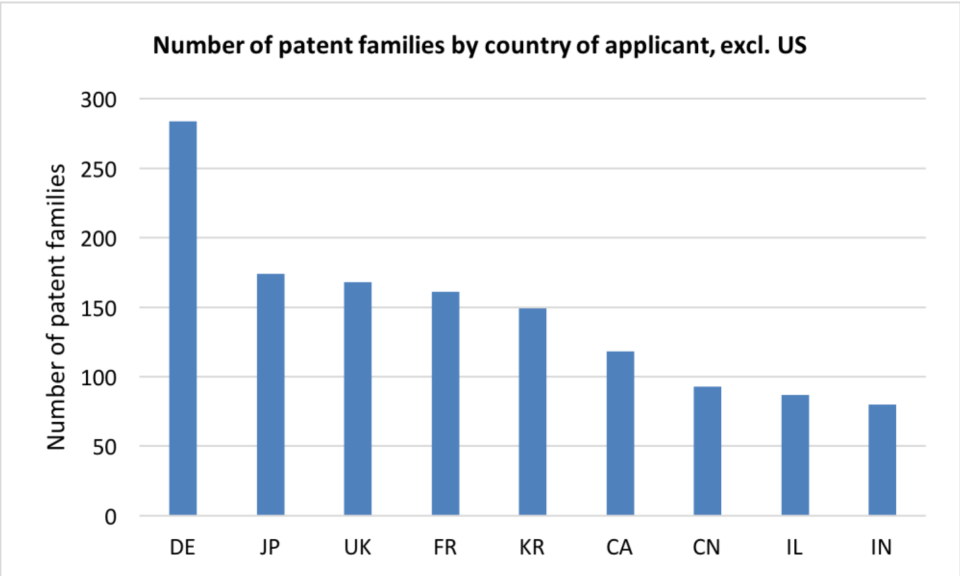

Figure A2.14. Number of patent families by country of applicant, top ten countries excluding United States (1993-2013)

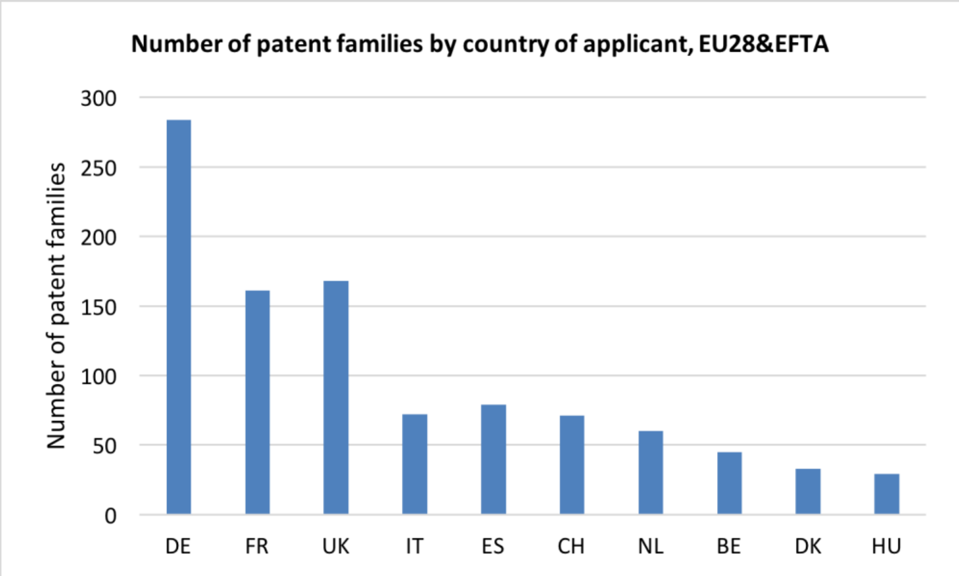

Figure A2.15. Number of patent families by country of applicant for the top ten EU28&EFTA countries (1993-2013)

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
2	DE	284	74%	71%	75%
4	UK	168	77%	74%	72%
5	FR	161	73%	80%	82%
11	ES	79	87%	66%	67%
12	IT	72	81%	58%	75%
13	CH	71	73%	75%	72%
14	NL	60	75%	75%	77%
16	BE	45	84%	82%	76%
20	DK	33	79%	64%	70%
22	HU	29	76%	66%	55%
23	SE	27	78%	67%	70%
25	IE	17	65%	65%	41%
26	NO	14	93%	79%	79%
27	PT	13	54%	46%	77%
29	FI	11	73%	73%	73%
31	AT	8	63%	75%	100%
32	CZ	7	86%	71%	71%
33	PL	7	86%	57%	29%

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
34	SL	7	100%	71%	57%
36	GR	5	80%	100%	80%
37	IS	5	40%	80%	80%
44	HR	2	50%	100%	50%
45	BG	2	100%	50%	100%
47	SK	2	100%	50%	50%
48	RO	2	100%	100%	50%
55	LV	1	100%	100%	100%
63	CY	1	100%	100%	0%
67	EE	1	100%	100%	100%

Table A2.36. Number of patent families by country of applicant and receiving authority for EU28&EFTA countries (1993-2013)

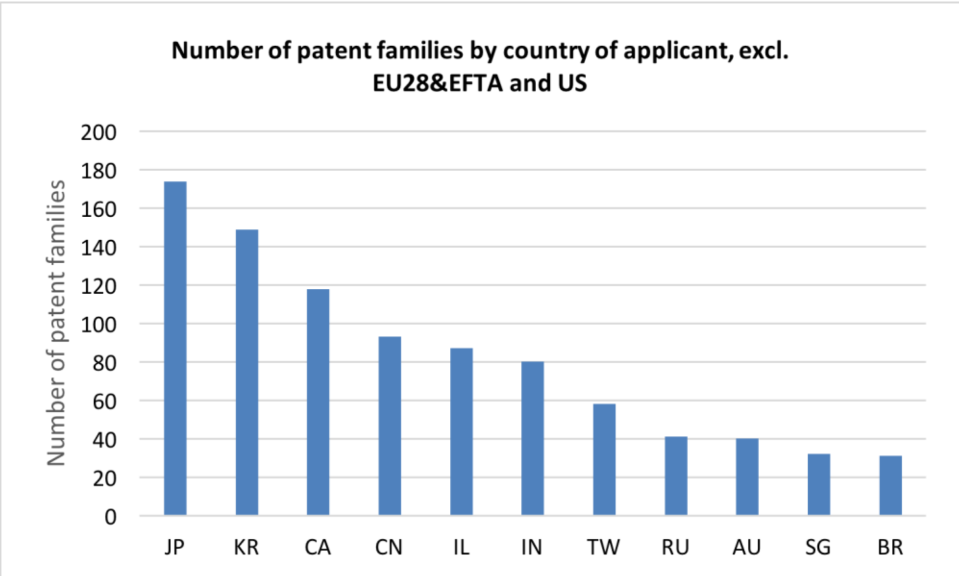

Figure A2.16. Number of patent families by country of applicant, top ten non-EU28&EFTA, non-US applicants (1993-2013)

GRANTED PATENTS

The country from the EU28&EFTA performing most strongly in nanotechnology and health patents granted by the EPO is Germany, followed by France. Also, these two countries, together with the United Kingdom, have the most patents granted by the USPTO.

World rank[107]	EU28&EFTA Country of applicant	Number of EPO patents granted

[107] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[107]	EU28&EFTA Country of applicant	Number of EPO patents granted
2	DE	93
4	FR	71
5	UK	51
7	CH	34
12	IT	28
14	NL	25
16	BE	22
13	ES	19
18	SE	18
19	IE	12
20	DK	10
23	HU	9
26	AT	6
28	FI	6
33	NO	5
41	CR	3
29	PT	3
30	GR	2
35	SL	2
36	HR	1
37	IS	1
55	LU	1
43	SK	1

Table A2.37. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

World rank[108]	EU28&EFTA country of applicant	Number of USPTO patents granted
2	DE	90
4	FR	68

108 Ibid

World rank[108]	EU28&EFTA country of applicant	Number of USPTO patents granted
5	UK	64
7	CH	42
12	IT	27
13	ES	26
14	NL	25
16	BE	21
19	IE	13
18	SE	13
20	DK	10
23	HU	7
26	AT	6
28	FI	3
30	GR	3
29	PT	3
36	HR	2
37	IS	2
33	NO	2
39	PL	2
35	SL	2
41	CZ	1
49	LV	1
43	SK	1

Table A2.38. Number of USPTO patents granted for countries, by county of applicant (1993-2013)

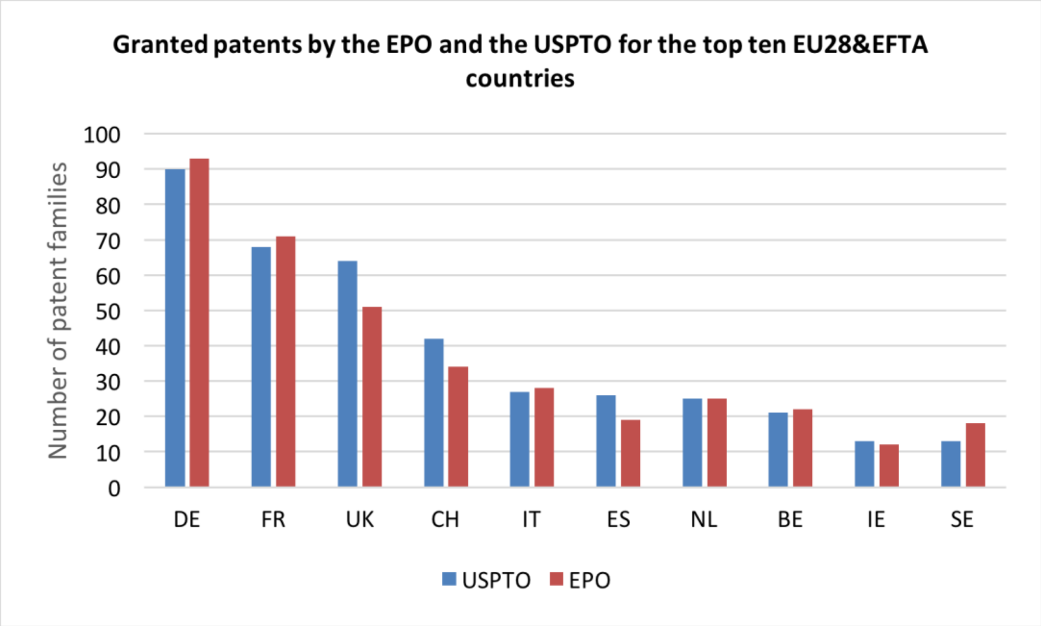

Figure A2.17. Granted patents by country of applicant for the top ten EU28&EFTA countries (1993-2013)

In both cases, the top five countries Germany, France, United Kingdom, Switzerland and Italy are the same and also in the same order.

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.

INVT	CA	CN	FR	DE	IN	IS	IT	JP	KR	NL	ES	CH	UK	US
APPL														
CA	118	4	1	3	0	3	0	0	2	1	1	0	7	55
CN	3	93	0	1	0	1	1	2	4	0	1	0	0	23
FR	1	0	161	4	2	2	6	2	0	2	6	11	7	14
DE	3	1	5	284	2	3	3	4	3	12	3	23	6	37
JP	0	2	2	1	1	1	2	174	0	0	0	0	0	28
KR	2	4	0	3	2	0	0	0	149	0	0	0	0	30
NL	1	1	5	20	1	0	0	0	0	60	3	4	7	21
CH	4	1	16	29	3	1	5	0	2	1	3	71	3	36
UK	7	2	8	6	3	1	2	0	0	2	9	3	168	46
US	49	23	17	49	15	30	10	24	29	15	9	21	40	1865

Table A2.39. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

Among the top ten universities and public research organisations (PROs) with the highest number of patent families (with percentages for PCT, USPTO and EPO applications), nine are in the United States. The EU28&EFTA countries are represented by one organisation from France (CNRS). The World ranking shown is for all types of organisations (not only universities and PROs).

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
1	US	University of California	73	81%	82%	38%
4	US	University of Texas	66	56%	56%	25%
5	US	MIT	50	94%	76%	42%
7	US	University of Michigan	28	71%	89%	39%
10	FR	CNRS	23	91%	52%	78%
12	US	Northwestern University	21	81%	81%	24%
14	US	Johns Hopkins University	19	74%	74%	37%
15	US	University of Texas	17	100%	0%	0%
16	US	William Marsh Rice University	16	75%	69%	13%
18	US	Emory University	16	94%	69%	44%
20	SG	Agency for Science Technology & Research	15	87%	53%	33%

Table A2.40. Number of patent families for top ten universities and PROs (1993-2013)

The table below shows the top performing universities and PROs for patent families in EU28&EFTA countries. Only one organisation from France is among the top 30 applicants worldwide (the ranking being shown in the first column).

World rank	Country	Organisation	No. of Patent families	PCT	USPTO	EPO
10	FR	CNRS	23	91%	52%	78%
61	ES	CSIC	9	89%	67%	78%
62	ES	Univ. de Santiago de Compostela	9	100%	44%	44%
68	FR	CEA	9	67%	33%	56%
99	UK	ISIS Innovation Ltd	7	100%	57%	57%

Table A2.41. Number of patent families of the top five EU28&EFTA universities and PROs (1993-2013)

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted between 1993 and 2013. Only a few PROs have granted patents by the EPO, and two of them are from the EU28&EFTA countries (from France and Spain).

World Rank	Country	Organisation	EPO	USPTO
3	FR	CNRS	8	7
13	US	MIT	4	19
17	US	Scripps Research Institute	4	4
21	US	University of California	3	33
22	US	University of Michigan	3	17
25	ES	CSIC	3	4
30	IN	Council of Scientific & Industrial Research	3	1

Table A2.42. Universities/research organisations granted patents, top seven based on granted EPO patents (1993-2013)

Ranking by the number of USPTO patents granted between 1993 and 2013, ten of the top 12 universities and research organisations are in the US and only one in the EU28&EFTA.

World Rank	Country	Organisation	USPTO	EPO
3	US	University of California	33	3
4	US	University of Texas	26	1
7	US	MIT	19	4
8	US	University of Michigan	17	3
10	US	Northwestern University	13	2
14	US	University of Illinois	9	1
15	US	University of Florida Research Foundation Inc.	9	1
17	US	California Institute Technology	8	1
19	US	William Marsh Rice University	8	0
20	FR	CNRS	7	8
21	US	Emory University	7	1
22	TW	Industrial Technology Research Institute	7	1

Table A2.43. Universities/research organisations with seven or more patents granted by USPTO (1993-2013)

Activity of companies[109]

PATENT APPLICATIONS

The top ten companies with the highest number of patent families (with percentages for PCT, USPTO and EPO applications), belong to six different countries. Two companies from Netherlands and France are in second and third places in this table, with one company from Ireland and one from the United Kingdom also. It should be noted that some may be holding companies rather than research companies or manufacturers.

World rank	Country	Company	No. of patent families	Share of applications		
				PCT	USPTO	EPO
2	US	Immunomedics Inc.	55	64%	87%	60%
9	NL	Kon Philips Elects NV	24	96%	63%	88%
11	FR	L'Oréal	21	10%	57%	95%
13	US	IBC Pharmaceuticals Inc.	20	20%	95%	20%
17	US	Nanosystems Llc	16	88%	25%	19%
24	US	Abraxis Bioscience Llc	14	50%	79%	36%
26	IE	Elan Pharma Int. Ltd	14	43%	29%	79%
28	US	Boston Scientific Scimed Inc.	14	79%	79%	14%
32	BB	Boston Scientific Ltd	13	31%	0%	100%
39	US	Cerulean Pharma Inc.	12	58%	92%	8%
40	US	Neorx Corp	12	92%	42%	58%
41	UK	MidaTech Ltd	12	58%	50%	58%

Table A2.44. Number of patent families for top twelve companies (1993-2013)

GRANTED PATENTS

The top companies that have five or more patents that have been granted patents by the EPO and/or USPTO are shown in the tables below[110]. The first table below shows the figures for the companies with five or more patents granted by the EPO, sorted by EPO patent numbers. The second table below contains the data for the companies with five or more granted USPTO patents, with one from France and one from Germany. In both tables, Immunomedics Inc. and L'Oréal are in the top three.

Country	Company	EPO	USPTO
FR	L'Oréal	20	11

[109] In some cases, the companies may be holding companies.

[110] 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.

US	Immunomedics Inc.	19	39
BB	Boston Scientific Ltd	8	0
US	Pfizer Inc.	6	5
IE	Elan Pharma Int. Ltd	6	4
DE	Hexal AG	6	2
UK	Cancer Research Campaign Technology Ltd	5	4
IT	Chiesi Farma Spa	5	4
FR	Guerbet Sa	5	4
BE	Janssen Pharmaceutica NV	5	4
CH	Novartis AG	5	2

Table A2.45. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

Country	Company	USPTO	EPO
US	Immunomedics Inc.	39	19
US	IBC Pharmaceuticals Inc.	14	1
FR	L'Oréal	11	20
US	Boston Scientific Scimed Inc.	8	0
US	Procter & Gamble Co.	7	2
US	Nano Systems Llc	7	0
US	Theravance Inc.	6	3
CA	Nucryst Pharmaceuticals Corp.	6	1
US	Pfizer Inc.	5	6
JP	Ono Pharma Co. Ltd	5	3
US	Cydex Pharmaceuticals Inc.	5	2
DE	Merck Patent GmbH	5	2

Table A2.46. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

ENERGY AND NANOTECHNOLOGY (ENNT)

Overview

This section looks at the patenting activity in nanotechnology and energy (ENNT) by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (energy, in this case)[111]. 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[112] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[113] that are members of the treaty.

Number and evolution over time of energy nanotechnology patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[114,115] of granted patent and patent applications were found in the period 1993-2013[116]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[117].

In the same period, the number of energy-related patent families identified among the nanotechnology patents is 2,068, 3.6% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EPO and USPTO do not sum to 100%. The highest percentage of energy and nanotechnology applications is at the USPTO (90%) while the numbers for ENNT patent filings at the EPO (41%) or using the PCT route are considerably lower.

Energy and nanotechnology applications	Patent families	Share of patent families
Total patent families	2068	100%
USPTO applications	1851	90%

[111] 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.

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

[113] 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

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

[115] 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/.

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

[117] 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.

PCT applications	1330	64%
EPO applications	846	41%

Table A2.47. Absolute numbers and percentages of patents on nanotechnology and energy (1993-2013)

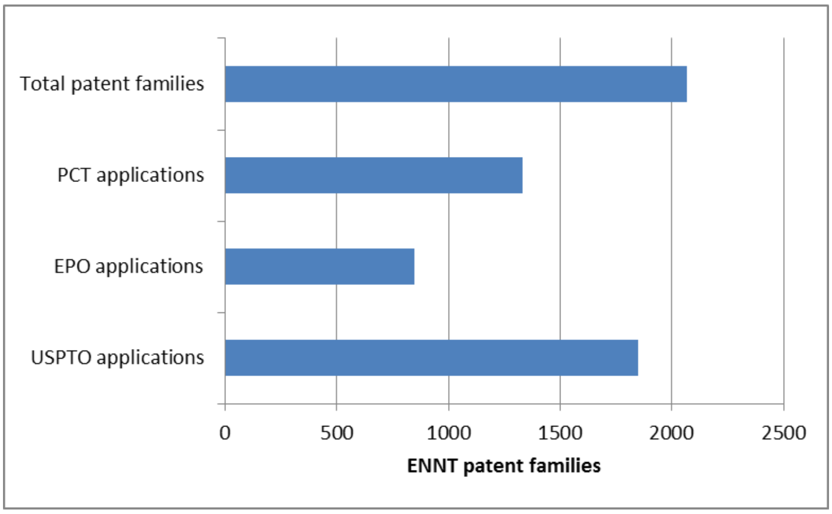

Figure A2.18. Number of nanotechnology and energy patent families, total and by filing authority (PCT, EPO, and USPTO) (1993-2013)

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.

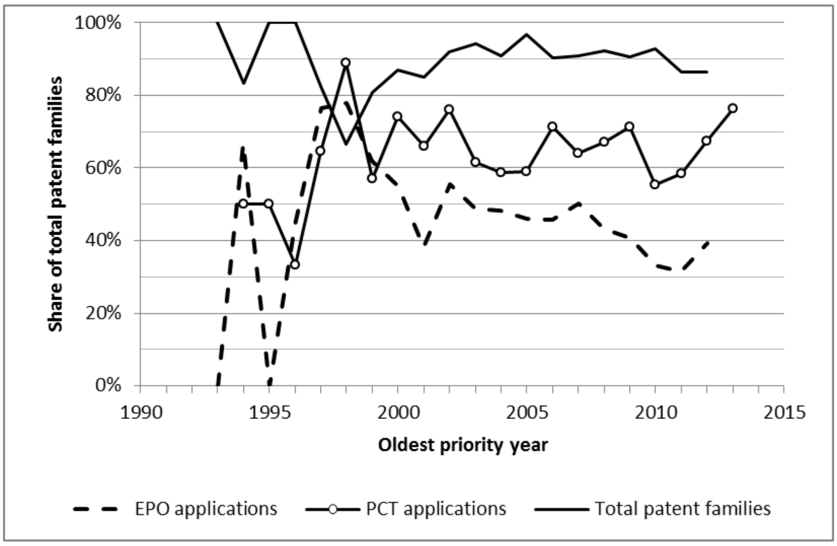

Figure A2.19. Evolution over time of WIPO (PCT), EPO and USPTO energy nanotechnology patenting

In this figure, it can be observed that the filings at USPTO are on a more or less constant level in the period 2000-2012. Filings at the WIPO and the EPO are on a lower level compared to the filings at the USPTO. In contrast with filings at the USPTO and the WIPO the filings at the EPO started to decline in 1997 and this trend continued until 2011 when signs of a reverse of this trend might be visible. The number of PCT filings increases since 2010.

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 patent authorities through which PCT applications were filed are shown in the table. The USA is by far the most prolific, followed by Japan and Europe (EPO). The EPO filings (128) are about one quarter of USPTO filings.

Receiving authority	No. of patent families
USPTO	594
Japan	218
EPO	128
Korea	87
WIPO	57
France	38
China	36
United Kingdom	34
Germany	24
Canada	22

Table A2.48. Number of energy nanotechnology patent families by the PCT receiving authority, top ten receiving authorities (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 2068 energy-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in 21% of the patent families. In 79% of the patent families no participation of an EU28 or EFTA applicant could be determined.

	EU28 & EFTA	Rest of World
Number of nanotechnology and energy patent families	433	1635
Percentage of nanotechnology and energy patent families	21%	79%

Table A2.49. Origin of patent applicants, EU28&EFTA and rest of World (1993-2013)

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

By far the highest number of patent families is found where the of the applicant country is the United States (960), followed by Japan (340) and Korea (301) already with a considerably lower number of patents. The European countries that account for the highest numbers of patent applications from European countries are Germany (171), France (89), the United Kingdom (74) and Austria (30), all of them among the top ten countries in number of patent families.

World rank	Country of applicant	No. of Patent Families	Share of applications		
			PCT	USPTO	EPO

World rank	Country of applicant	No. of Patent Families	Share of applications		
			PCT	USPTO	EPO
1	US	960	65%	92%	37%
2	JP	340	69%	82%	39%
3	KR	301	32%	89%	25%
4	DE	171	80%	68%	73%
5	CN	95	59%	71%	27%
6	TW	94	0%	99%	5%
7	FR	89	82%	73%	74%
8	UK	74	84%	73%	57%
9	CA	57	60%	79%	30%
10	AT	30	53%	80%	57%

Table A2.50. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Almost all (92%) of patents by US applicants are filed with the USPTO while 65% are filed as PCTs. Slightly more than one third of the patents by US applicants are filed at the EPO.

Among the European applicants, the differences in the percentage of filings among the different patent authorities are not large. Germany, France and the United Kingdom show a preference for the PCT route while Austria files a higher percentage at the USPTO.

Looking at the non-EU28&EFTA and non-US countries of applicants, the filing shows a preference, among the patent authorities considered in this study, to filing mostly at the USPTO.

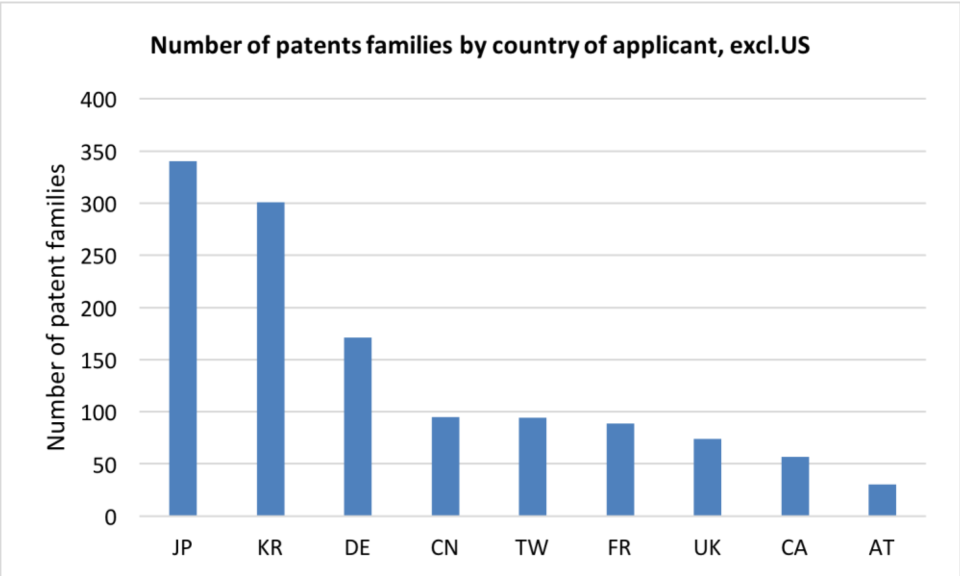

Figure A2.20. Number of patent families by country of applicant, top ten countries excluding the United States (1993-2013)

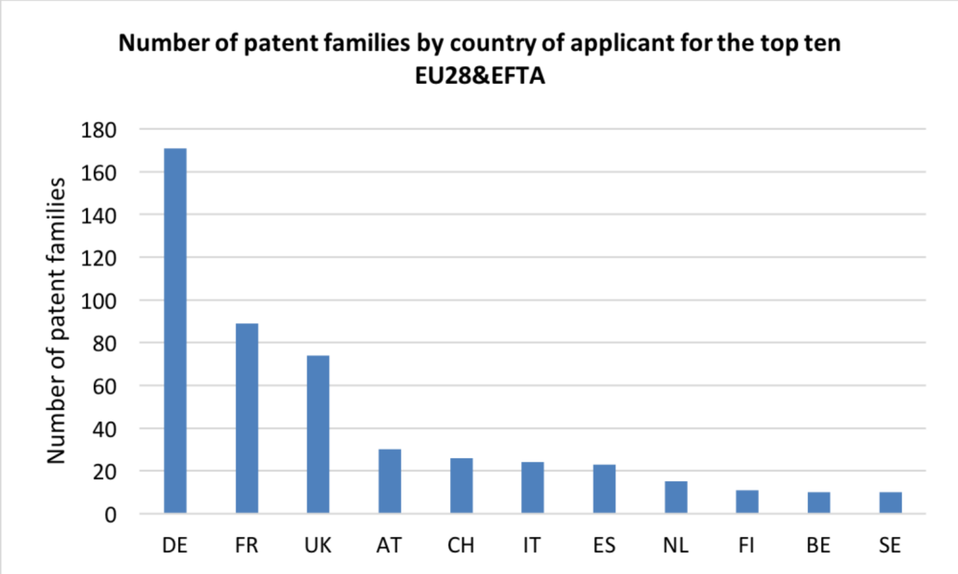

Figure A2.21. Number of patent families by country of applicant, top EU28&EFTA countries (1993-2013)

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
4	DE	171	80%	68%	73%
7	FR	89	82%	73%	74%
8	UK	74	84%	73%	57%
10	AT	30	53%	80%	57%
11	CH	26	62%	46%	65%
12	IT	24	79%	58%	71%
13	ES	23	74%	65%	61%
16	NL	15	80%	80%	80%
20	FI	11	91%	64%	55%
21	BE	10	70%	60%	80%
22	SE	10	90%	70%	70%
25	DK	5	100%	20%	20%
27	NO	4	75%	50%	50%
29	PT	4	75%	50%	50%
30	RO	4	0%	100%	50%
34	GR	3	100%	100%	33%
38	IE	2	50%	50%	100%
40	LU	2	50%	100%	50%

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
41	PL	2	50%	50%	100%
53	CZ	1	100%	0%	0%
59	HU	1	0%	100%	0%
62	LT	1	0%	0%	100%

Table A2.51. Number of patent families by country of applicant and receiving authority for EU28&EFTA countries (1993-2013)

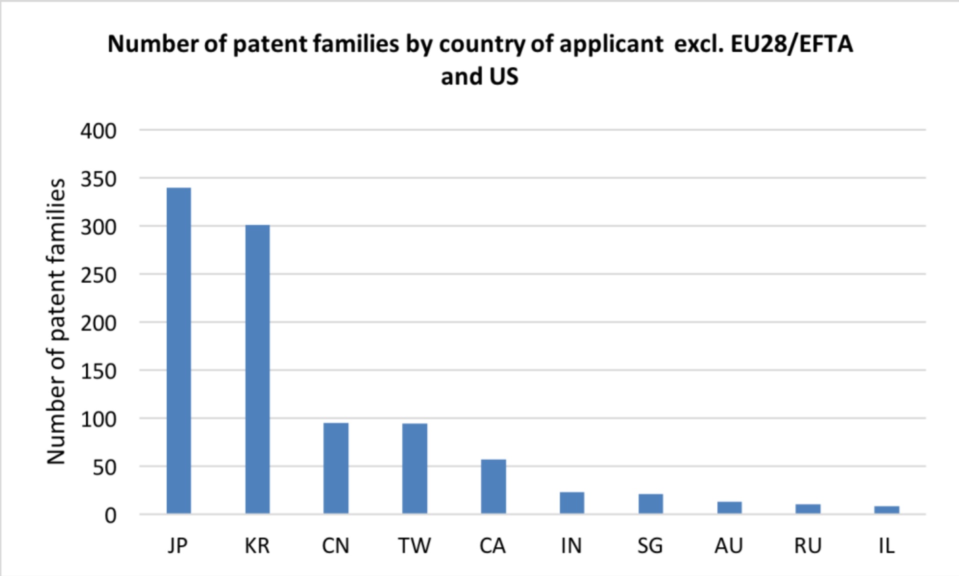

Figure A2.22. Number of patent families by country of applicant for the top ten non-EU28&EFTA, non-US countries (1993-2013)

GRANTED PATENTS

The country from the EU and EFTA performing most strongly in patents granted by the EPO is Germany, followed by France. These two countries also have the most patents granted by the USPTO. For all EU28&EFTA countries, the number of patents granted by the USPTO is greater than those granted by the EPO, as shown in the tables below.

World rank[118]	EU28&EFTA country of applicant	Number of EPO patents granted
5	DE	34
7	FR	26
9	UK	9
10	AT	8
11	IT	7
16	CH	4
29	BE	3

[118] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[118]	EU28&EFTA country of applicant	Number of EPO patents granted
44	DK	1
45	FI	1
21	NL	1
31	NO	1
46	PL	1
17	RO	1
14	SE	1

Table A2.52. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

World rank[119]	EU28&EFTA country of applicant	Number of USPTO patents granted
5	DE	47
7	FR	29
9	UK	18
10	AT	13
11	IT	8
12	ES	7
14	SE	5
16	CH	4
17	RO	4
21	NL	3
27	GR	2
29	BE	1
31	NO	1
39	HU	1
40	IE	1

Table A2.53. Number of USPTO patents granted for countries, by county of applicant (1993-2013)

[119] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

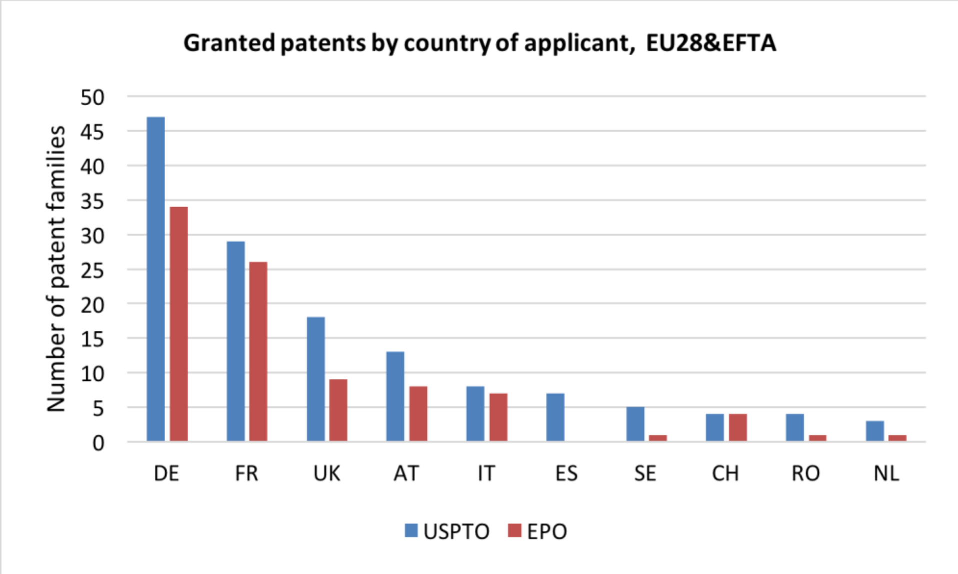

Figure A2.23. Granted patents by country of applicant for the EU28&EFTA countries (1993-2013)

In both cases, the top five countries Germany, France, United Kingdom, Austria and Italy are the same and are in the same order.

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.

INVT	AT	CA	CN	FR	DE	JP	KR	NL	TW	UK	US
APPL											
AT	29	0	0	0	9	0	1	0	0	15	29
CA	0	55	1	3	0	0	4	0	1	15	0
CN	0	1	89	0	6	4	6	1	1	25	0
FR	0	2	0	84	6	0	0	0	0	15	0
DE	12	0	2	7	136	1	0	0	14	36	12
JP	0	0	4	0	1	326	6	0	6	20	0
KR	1	4	6	0	0	7	299	0	1	20	1
NL	0	0	14	0	0	0	0	80	0	7	0
TW	0	1	1	0	2	0	1	0	70	8	0
UK	24	17	23	14	33	21	20	6	10	920	24
US	29	0	0	0	9	0	1	0	0	15	29

Table A2.54. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

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

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
2	US	University of California	57	63%	86%	25%
3	US	Massachusetts Institute of Technology	32	91%	75%	25%
8	KR	KR Institute of Science & Technology	24	17%	79%	4%
9	US	University of Michigan	23	83%	70%	61%
10	FR	CNRS[120]	22	82%	68%	95%
14	FR	CEA & aux energies alternatives	18	78%	0%	0%
15	US	Princeton University	16	81%	81%	75%
17	KR	Elect & Telecommunications Res Institute	15	13%	93%	7%
18	KR	KR Advanced Institute of Science & Technology	15	13%	67%	13%
19	CN	Tsinghua University	14	14%	86%	0%

Table A2.55. Number of patent families for top ten universities and PROs (1993-2013)

The top universities and PROS from EU28&EFTA countries are shown in the table below. Only the French organisations are among the top 30 applicants worldwide (the ranking being shown in the first column).

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
10	FR	CNRS[9]	22	82%	68%	95%
14	FR	CEA & Aux Energies Alternatives[121]	18	78%	0%	0%
53	DE	Max Planck Gesellschaft	8	63%	50%	63%
75	FR	CEA	7	86%	57%	29%

[120] Centre National de la Recherche Scientifique

[121] CEA & Aux Energies alternatives and CEA, are strongly related organisations but probably not fully identical and therefore the information for these two organisations is not merged.

141	DE	Technische Universitaet Dresden	5	80%	40%	40%
146	ES	CSIC	5	100%	40%	0%

Table A2.56. Number of patent families in the top six EU28&EFTA universities and PROs (1993-2013)

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted in the period 1993-2013. Only a few PROs have granted patents by the EPO, and four of them are from the EU28&EFTA countries (from France, Switzerland, Germany and Belgium).

World Rank	Country	Organisation	EPO	USPTO
1	FR	CNRS[9]	7	9
2	US	Wake Forest University Health Sciences	4	1
3	US	Princeton University	2	10
4	JP	JP Science & Technology Agency	2	6
5	JP	National Institute of Advanced Ind. Science and Technology	2	3
6	CH	Ecole PolyTechnique Federale De Lausanne EPFL	2	2
7	DE	Fraunhofer Gesellschaft	2	1
8	BE	IMEC	2	1
9	US	Massachusetts Institute Technology	1	17
10	US	University of Michigan	1	8

Table A2.57. Universities/research organisations granted patents, ordered by descending number of patents granted by the EPO

Ranking by the number of USPTO patents granted between 1993 and 2013, six of the top ten universities and research organisations are from the United States and only one from a EU28&EFTA country (CNRS, FR).

World Rank	Country	Organisation	USPTO	EPO
1	US	University of California	26	0
2	US	Massachusetts Institute Technology	17	1
3	TW	Industrial Technology Research Institute	13	0
4	US	Princeton University	10	2
5	FR	CNRS	9	7
6	KR	Kr Institute of Science & Technology	9	0
7	CN	Tsinghua University	9	0

8	US	University of Michigan	8	1
9	US	Boston College	7	0
10	US	University of Florida Research Foundation Inc	7	0

Table A2.58. Universities/research organisations granted patents, ordered in descending order of the number of patents granted by the USPTO

Activity of companies

PATENT APPLICATIONS

The top ten companies with the highest number of patent families (with percentages for PCT, USPTO and EPO applications), belong to four different countries. Germany is the only EU28&EFTA country that features in this table. It should be noted that some of the companies may in reality be holding companies rather than research companies or manufacturers.

World rank	Country	Company	No. of patent families	Share of applications		
				PCT	USPTO	EPO
1	KR	Samsung Elect Co Ltd	68	1%	94%	9%
4	US	Konarka Technology Inc	28	75%	50%	43%
5	DE	Merck Patent GmbH	27	59%	89%	89%
6	DE	BASF	24	71%	71%	63%
7	JP	Fujifilm Corp	24	83%	58%	17%
12	JP	Sony Corp	20	60%	80%	20%
13	JP	Toyota Jidosha KK	18	78%	61%	44%
16	JP	Sumitomo Chem Co Ltd	16	100%	63%	31%
22	US	E I Du Pont de Nemours & Co	12	42%	100%	42%
23=	US	Honeywell Int. Inc	11	27%	91%	64%
23=	US	Plextronics Inc	11	91%	36%	55%

Table A2.59. Number of patent families for top ten companies (1993-2013)

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[122]. 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 on the basis of the USPTO patents. Two companies from Germany appear in the top ten for EPO patents, in first and fourth places.

Country	Company	EPO	USPTO

[122] 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.

DE	Merck Patent GmbH	10	9
JP	Toyota Jidosha Kk	6	7
KR	Samsung Elect Co Ltd	4	32
DE	BASF	4	6
US	Honeywell Int. Inc	3	8
US	E Ink Corp	3	3
US	Konarka Technology Inc	2	12
JP	Sony Corp	2	10
US	3M Innovative Properties Co	2	4
JP	Showa Denko KK	2	4

Table A2.60. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

Country	Company	USPTO	EPO
KR	Samsung Elect Co Ltd	32	4
US	Konarka Technology Inc	12	2
US	E I Du Pont de Nemours & Co	11	1
JP	Sony Corp	10	2
KR	Samsung SDI Co Ltd	10	0
DE	Merck Patent GmbH	9	10
TW	Hon Hai Precision Ind. Co Ltd	9	0
TW	Nanosolar Inc	9	0
US	Honeywell Int. Inc	8	3
JP	Toyota Jidosha Kk	7	6
US	IBM Corp	7	1
JP	Honda Motor Co Ltd	7	0

Table A2.61. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

Companies from five countries populate the top of the table of companies ranked by USPTO patent numbers. One EU28&EFTA company (Merck Patent GmbH from Germany) ranks in sixth place.

PHOTONICS AND NANOTECHNOLOGY (PHNT)

Overview

This section looks at the patenting activity in nanotechnology and photonics by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (photonics, in this case). 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[123] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the easy filing of patent applications in countries[124] that cooperate in this treaty.

Number and evolution over time of nanotechnology photonics patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[125,126] (PTNT) of granted patent and patent applications were found in the period 1993-2013[127]. All of these publications were published by the European Patent Office (EPO), US Patent and Trademark Office (USPTO) or the World Intellectual Property Organisation (WIPO)[128].
[129]

In the same period, the number of photonics-related patent families identified among the nanotechnology patents is 2,037, 4% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EPO and USPTO do not sum to 100%. The highest percentage of nanotechnology photonic applications is in the USPTO (91%) while the figures corresponding to PCT (59%) and EPO (40%) are considerably lower.

Photonics and nanotechnology applications	Patent families	Share of patent families
Total patent families	2037	100%

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

[124] 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

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

[126] 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/.

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

[128] 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.

[129] Patent publications published by the EPO are called 'EP'-documents, those published by the USPTO 'US'-documents and the ones published by the WIPO 'PCT'-documents or 'WO'-documents.

Photonics and nanotechnology applications	Patent families	Share of patent families
USPTO applications	1846	91%
PCT applications	1201	59%
EPO applications	805	40%

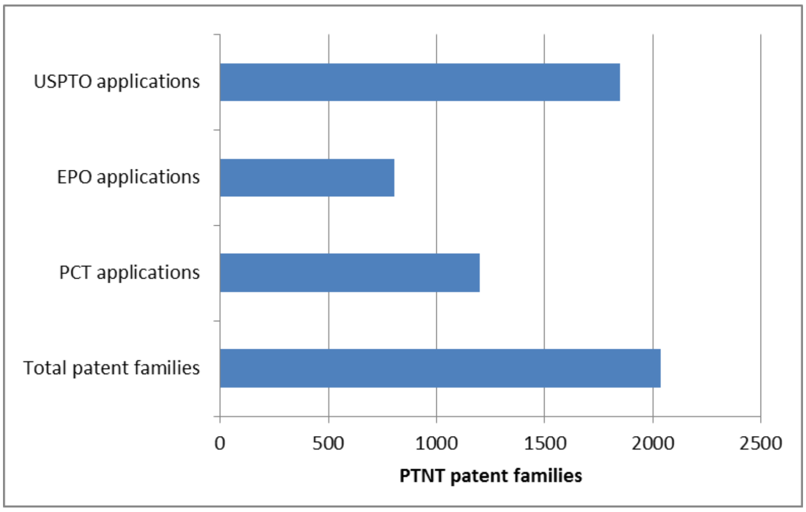

Table A2.62. Absolute numbers and percentages of patents on nanotechnology and photonics (1993-2013)

Figure A2. 24. Number of nanotechnology and photonics patent families, total and by filing authority (1993-2013)

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.

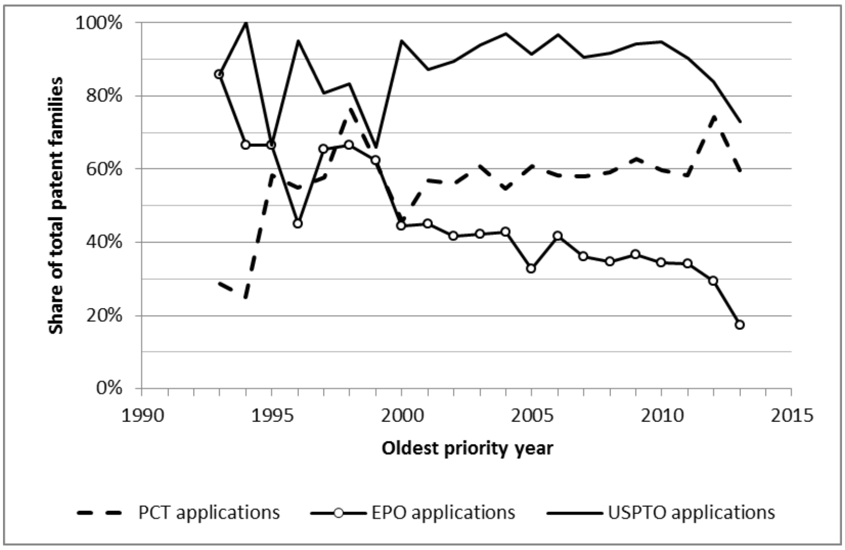

Figure A2.25. Evolution over time of WIPO (PCT), EPO and USPTO nanotechnology and photonics patenting (1993-2013)

In this figure, it can be observed that the share of the total number of filings at USPTO and WIPO in the period 2000-2011 is more or less constant, while the share of filings at the EPO show a decline since about the year 2000. The decline that is visible from 2013 is caused by the fact that not all data has been added to the patent databases.

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 patent authorities through which PCT applications were filed are shown in the table, each of them with ten or more filings. The

USA is by far the most prolific with 544 patent families, followed by Japan and Europe (EPO). The number of filings at the EPO is just 101, less than one fifth of those at the USPTO.

Receiving authority	No. of patent families (1993-2013)
United States	544
Japan	172
European Patent Office (EPO)	101
United Kingdom	87
International Bureau (WIPO)	46
South Korea	44
France	36
Canada	36
Germany	29
China	19
Denmark	15
Spain	12
Israel	12
Singapore	10

Table A2.63. Number of nanotechnology photonics patent families by PCT receiving authority, top ten receiving authorities (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 2,037 photonics-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in 23% of them while there is participation from the rest of the world in 77% of cases.

	EU28 & EFTA	Rest of World
Number of PTNT patent families	282	924
Percentage of PTNT patent families	23%	77%

Table A2. 64. Origin of patent applicants[130], EU28&EFTA and rest of World (1993-2013)

Applicants may file patents with more than one patent authority, e.g. at the USPTO and at the EPO. The table below shows the data for the top ten countries of applicants, as well as indicating the percentage of patent families for each. EU28 and EFTA countries are indicated by bold typeface. As patents may be filed in more than one patent authority the percentages can sum to more than 100%. By far the highest number of patent families is found where the country of the applicant is the US (921), followed by Japan

[130] The numbers are based on the domiciles of the applicants in so far as they are known

already with a considerably lower number of patents (474). The EU28&EFTA countries that account for a higher number of patents are Germany (160), United Kingdom (144), France (110), and Netherlands (40), all of them among the top 10 countries in number of patent families.

	Country of applicant	No. of Patent Families	PCT	USPTO	EPO
1	US	921	62%	93%	32%
2	JP	474	41%	89%	35%
3	DE	160	69%	68%	65%
4	UK	144	74%	68%	49%
5	KR	143	33%	89%	27%
6	FR	110	64%	71%	77%
7	CA	80	60%	81%	40%
8	TW	58	2%	97%	5%
9	CH	45	51%	76%	13%
10	NL	40	70%	73%	75%

Table A2.65. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Applicants from the United States and Japan file most of their applications at the USPTO, PCT filings come in second place and EPO last. European applicants file almost equally at the WIPO (PCT), USPTO and the EPO, except for the United Kingdowm which files less at the EPO. Looking at the non-EU28&EFTA and non-US countries of applicants, the filing shows a preference, among the patent authorities considered in this study, to file mostly at the USPTO.

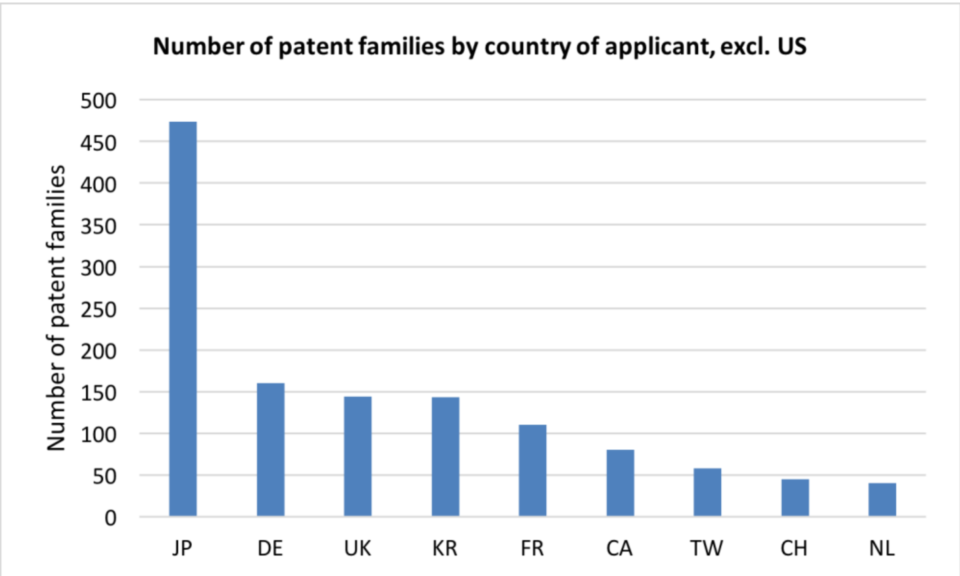

Figure A2.26. Number of patent families by country of applicant, top ten countries, excluding the United States (1993-2013)

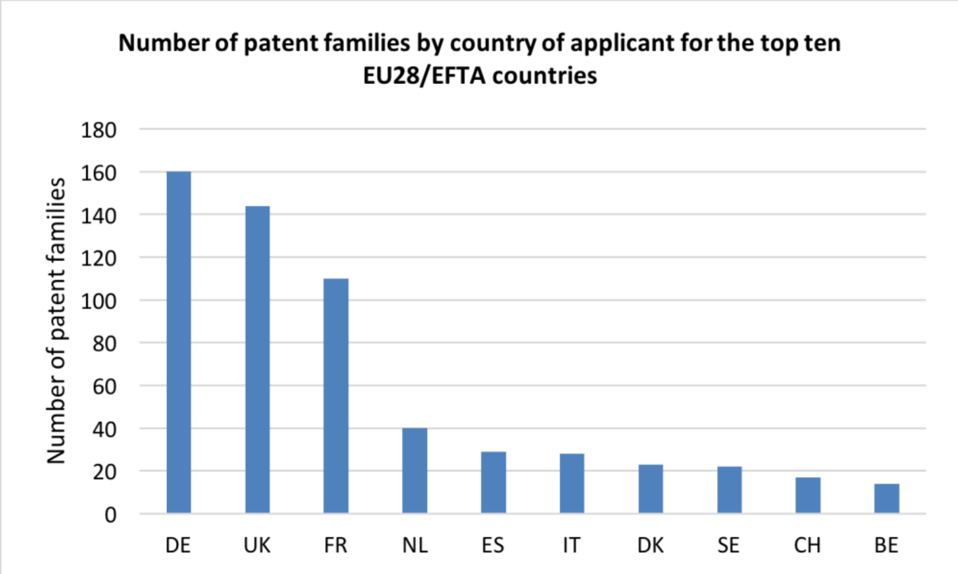

Figure A2.27. Number of patent families by country of applicant for the top ten EU28&EFTA countries (1993-2013)

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
3	DE	160	69%	68%	65%
4	UK	144	74%	68%	49%
6	FR	110	64%	71%	77%
10	NL	40	70%	73%	75%
12	ES	29	69%	62%	41%
13	IT	28	64%	64%	82%
14	DK	23	70%	61%	57%
15	SE	22	64%	64%	36%
18	CH	17	53%	65%	59%
19	BE	14	36%	100%	71%
21	FI	8	100%	63%	38%
22	NO	8	75%	75%	63%
24	GR	6	50%	50%	17%
25	IR	6	50%	50%	33%
26	AT	5	20%	100%	40%
29	PT	4	100%	50%	100%
30	RO	4	25%	75%	25%
36	HU	2	0%	100%	0%

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
45	CR	1	0%	100%	0%
47	LT	1	0%	0%	0%
50	PL	1	100%	100%	100%

Table A2.66. Number of patent family by country of applicant and receiving authority for all EU28&EFTA countries (1993-2013)

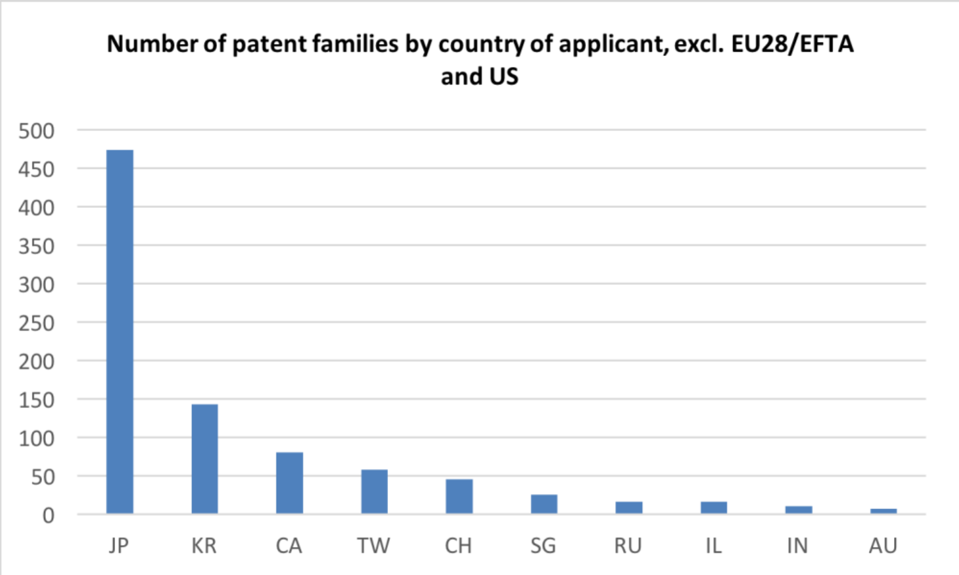

Figure A2.28. Number of patent families by country of applicant for the top ten non-EU28&EFTA, non-US applicants (1993-2013)

GRANTED PATENTS

The EU28&EFTA with the highest number of EPO patents is the Germany, France and the United Kingdom. Also, these three countries have the most patents granted by the USPTO.

World rank[131]	EU28&EFTA Country of applicant	Number of EPO patents granted
5	DE	39
6	FR	33
4	UK	27
10	IT	9
14	DK	7
11	NL	6
13	SE	5
18	CH	4

[131] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[131]	EU28&EFTA Country of applicant	Number of EPO patents granted
15	ES	3
17	BE	2
23	IR	2
21	NO	2
24	RO	1

Table A2.67. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

World rank[132]	EU28&EFTA country of applicant	Number of USPTO patents granted
4	UK	75
5	DE	62
6	FR	55
11	NL	15
10	IT	13
17	BE	11
15	ES	11
14	DK	10
13	SE	9
18	CH	6
21	NO	4
27	AT	3
22	FI	3
26	GR	2
24	RO	2
23	IR	2
33	HU	1
42	PO	1
43	SL	1
4	NL	161

[132] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[132]	EU28&EFTA country of applicant	Number of USPTO patents granted
5	DE	110

Table A2.68. Number of USPTO patents granted for countries, by county of applicant (1993-2013)

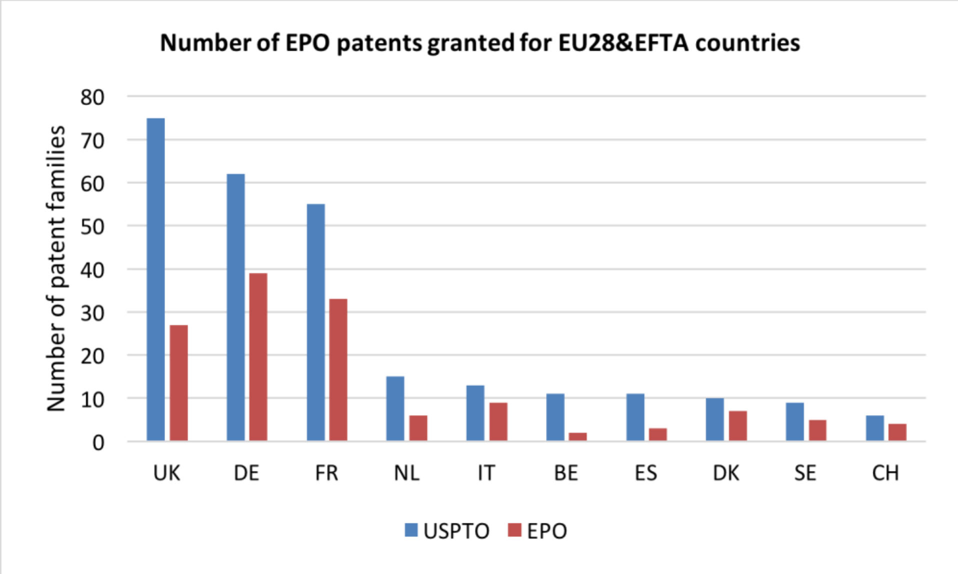

Figure A2.29. Granted patents by country of applicant for the top ten EU28&EFTA countries (1993-2013)

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.

INVT	CA	CN	FR	DE	JP	KR	NL	ES	UK	US
APPL										
CA	77	2	3	8	1	1	0	11	3	18
CN	1	44	1	2	1	5	0	0	1	7
FR	3	1	105	4	2	1	3	4	2	19
DE	8	2	3	156	3	0	6	3	9	17
JP	1	1	3	4	441	7	1	0	27	32
KR	0	5	1	1	7	139	0	0	0	17
NL	0	0	3	9	1	0	31	2	0	11
TW	0	8	0	0	0	0	0	0	2	7
UK	5	0	3	11	8	0	1	2	132	27
US	21	7	21	20	25	16	9	4	31	884

Table A2.69. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

Among the top ten universities and public research organisations (PROs) (with percentages for PCT, USTO and EPO applications), seven are from the United States. The EU28 or EFTA is represented by one organisation from France.

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
2	US	University of California	59	71%	85%	25%
3	US	Massachusetts Institute of Technology	53	94%	94%	15%
8	JP	University of Tokyo	29	48%	50%	5%
9	US	CAITech	27	66%	86%	41%
10	FR	CNRS	27	63%	85%	11%
14	US	University of Michigan	23	85%	48%	78%
17	KR	Elect & Telecommunications Res Inst.	17	71%	85%	25%
20	US	Harvard College	17	94%	94%	15%
22	US	Princeton University	17	66%	86%	41%
24	US	Leland Stanford Junior University	16	63%	85%	11%

Table A2.70. Number of patent families for top ten universities and PROs (1993-2013)

The table below shows the top performing universities and PROs for patent families in EU28&EFTA countries. Only the three[10] organisations from France, one from Germany and one from Belgium are among the top fifty applicants worldwide (the ranking being shown in the first column).

World rank	Country	Organisation	No. of Patent families	PCT	USPTO	EPO
10	FR	CNRS	27	85%	48%	78%
29	FR	CEA	13	54%	62%	15%
34	FR	CEA & aux energies alternatives	12	100%	0%	0%
35	DE	Fraunhofer Gesellschaft	12	58%	25%	75%
40	BE	IMEC	11	36%	100%	64%

Table A2.71. Number of patent families in the top EU28&EFTA universities and PROs (1993-2013) [133]

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted between 1993 and 2013, all of the top five being EU28 countries.

Rank	Country	Organisation	EPO	USPTO
1	FR	CNRS	12	9
2	DE	Fraunhofer Gesellschaft	4	1
3	UK	University of Glasgow	2	2
4	BE	IMEC	2	1
5	UK	University College Cardiff Consultants Ltd	2	1

Table A2.72. Top universities/research organisations granted EPO patents, ordered by EPO patents

The table below shows the PROs ranked by the highest number of USPTO patents granted between 1993 and 2013, none of the top ten being EU28 countries.

Rank	Country	Organisation	USPTO	EP
1	US	Massachusetts Institute of Technology	44	2
2	US	University of California	35	3
3	JP	University of Tokyo	25	4
4	US	California Institute of Technology	18	1
5	US	Princeton University	13	4
6	KR	Elect & Telecommunications Res Inst.	13	1
7	US	Leland Stanford Junior University	11	0
8	JP	JP Science & Tech Agency	10	5
9	US	University of Michigan	10	1
10	US	University of Delaware	10	0

Table A2.73. Top ten universities/research organisations with USPTO patents granted, ordered by USPTO patents granted

Activity of companies

PATENT APPLICATIONS

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

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[133] No disambiguation was done for the applicants and 'CEA' and 'CEA & Aux Energie alternatives' might therefore refer to the same organisation.

	Country	Company	No. of patent families	PCT	US	EP
1	JP	Canon KK	70	24%	100%	29%
2	KR	Samsung Elect Co Ltd	47	4%	89%	21%
3	JP	NEC Corp	34	62%	65%	21%
4	US	Hewlett Packard Dev Co Lp	33	97%	85%	48%
5	JP	KK Toshiba	26	15%	88%	15%
6	DE	Osram Opto Semiconductors GmbH	25	64%	84%	72%
7	JP	Hitachi Ltd	21	29%	76%	19%
8	NL	Kon Philips Elects NV	17	94%	35%	100%
9	JP	Matsushita Elect Ind. Co Ltd	17	24%	94%	35%
10	JP	TDK Corp	17	65%	88%	41%

Table A2.74. Number of patent families for top ten companies (1993-2013)

GRANTED PATENTS

The companies with at least seven patents granted by the EPO are presented in table below; companies with ten or more patents granted by the USPTO are shown in the second table below.[134]. The first table shows the top ten when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In the first table, one company each from Germany (Osram Opto Semiconductors GmbH), the Netherlands (Koninklijke Philips Electronics NV), France (Thales) and the United Kingdom (Mesophotonics) appear as the main EU companies in EPO patents.

World rank	Country	Company	EPO	USPTO
1	JP	Canon KK	20	70
12	DE	Osram Opto Semiconductors GmbH	18	21
18	NL	Koninklijke Philips Electronics NV	17	6
6	US	Hewlett Packard Dev Co	16	28
33	FR	Thales	12	7
32	JP	Sumitomo Elect Ind. Ltd	11	12
4	KR	Samsung Elect Co Ltd	10	42
37	US	Lucent Tech Inc	8	11

[134] 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.

World rank	Country	Company	EPO	USPTO
57	US	3m Innovative Properties Co	7	7
36	JP	Fujifilm Corp	7	10
42	UK	Mesophotonics Ltd	7	9
5	JP	NEC Corp	7	22
21	JP	TDK Corp	7	15

Table A2.75. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

World rank	Country	Company	USPTO	EPO
1	JP	Canon KK	70	17
4	KR	Samsung Elect Co Ltd	47	2
6	US	Hewlett Packard Dev Co	33	32
11	JP	KK Toshiba	26	4
5	JP	NEC Corp	34	21
12	DE	Osram Opto Semiconductors GmbH	25	16
15	JP	Hitachi Ltd	21	6
19	JP	Matsushita Elect Ind. Co Ltd	17	4
21	JP	TDK Corp	17	11
25	JP	Nippon Sheet Glass Co Ltd	15	8

Table A2.76. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

Interestingly, for patents granted by the USPTO most are Japanese companies. There is one US company in the top five. There are companies from four countries populating this table Japan, United States, Korea and Germany.

ENVIRONMENT AND NANOTECHNOLOGY (EVNT)

Overview

This section looks at the patenting activity in nanotechnology and environment by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for EV nanotechnology i.e. B82 and those related to the sector under consideration (environment, in this case)[135]. 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[136] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[137] that are members of the treaty.

Number and evolution over time of enviroment and nanotechnology patent families

Using the above methodology, 50,780 (simple) environment and nanotechnology patent families[138,139] (EVNT) of granted patent and patent applications were found in the period 1993-2013[140]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[141].

In the same period, the number of environment-related patent families identified among the EV nanotechnology patents is 531, 1.0% of all environment and nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EP and USA do not sum to 100%. The highest percentage of environment and nanotechnology applications is in the USA (89%) while the figures corresponding to PCT (70%) and EPO (48%) are considerably lower.

Environment and nanotechnology applications	Patent families	Share of patent families
Total patent families	531	100%

[135] 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.

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

[137] 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

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

[139] 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/.

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

[141] 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.

Environment and nanotechnology applications	Patent families	Share of patent families
USPTO applications	473	89%
PCT applications	370	70%
EPO applications	256	48%

Table A2.77. Absolute numbers and percentages of patents on environment and nanotechnology (1993-2013)

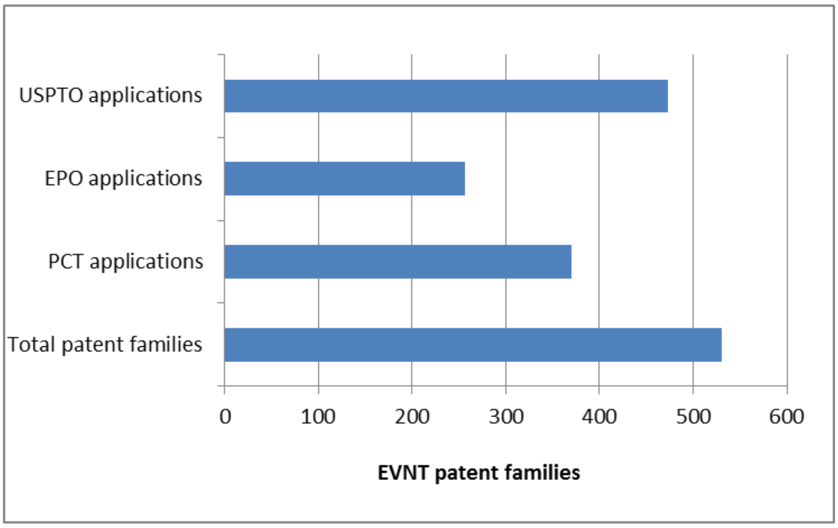

Figure A2.30. Number of environment and nanotechnology patent families, total and by filing authority (1993-2013)

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.

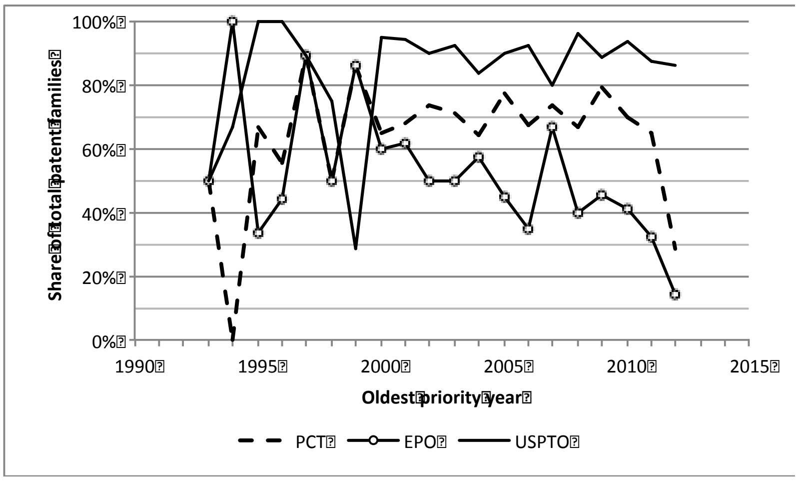

Figure A2.31. Evolution over time of WIPO (PCT), EPO and USPTO environment EV nanotechnology patenting

In this figure, it can be observed that the filings at USPTO and WIPO follow a somewhat similar pattern, albeit that the PCT applications are at a lower level. The number of EPO filings evolve at an even lower level and are seen to decline. The decline that is visible from 2013 is caused by the fact that not all data has been added to the patent databases.

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 patent authorities through which PCT applications were filed are shown in the table, each of them with four or more filings. The

USPTO is by far the most prolific in terms of filing of applications, followed by the Japan Patent Office and the EPO.

Receiving Authority	No. of Patent Families (1993-2013)
United States (USPTO)	180
Japan	47
European Patent Office (EPO)	38
World Intellectual Property Organisation (WIPO)	17
France	12
Korea	12
Israel	10
United Kingdom	10
China	7
Singapore	5

Table A2.78. Number of environment and nanotechnology patent families by top ten PCT receiving authority (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 551 environment-related EV nanotechnology patent families, there is at least one EU28 or EFTA applicant in 14% of them while there is participation from the rest of the World in 86% of cases.

	EU28 & EFTA	Rest of World
Number of environment NT patent families	76	455
Percentage of environment NT patent families	14%	86%

Table A2.79. Origin of patent applicants, EU28&EFTA and rest of World (1993-2013)

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

By far the highest number of patent families is found where the country of the applicant is the US (247), followed by Japan with a considerably lower number of patents (80). The European countries that account for the most patents are Germany (30), France (22), Spain (15) and UK (15), all of them among the top 10 countries in number of patent families.

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
1	US	247	73%	89%	50%

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
2	JP	80	77%	98%	41%
3	KR	36	66%	88%	54%
4	DE	30	33%	89%	33%
5	FR	22	80%	67%	80%
6	CN	19	86%	91%	91%
7	ES	15	68%	84%	42%
8	UK	15	80%	80%	73%
9	TW	12	93%	67%	67%
10=	IL	11	0%	100%	17%
10=	CA	11	100%	91%	82%

Table A2.80. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Most of the patents by US applicants (89%) are filed with the USPTO while three quarters are filed as PCTs. Only half of the patents by US applicants are filed at the EPO.

Among the European applicants, all file more than two-thirds at the USPTO and most in the top ten (except Germany) file more than two-thirds at the EPO. Germany has low filing (33%) at both EPO and via the PCT route.

Looking at the non-EU28&EFTA and non-US countries of applicants, the filing shows a preference, among the patent authorities considered in this study, for many (except Taiwan and Canada) to file most at the USPTO.

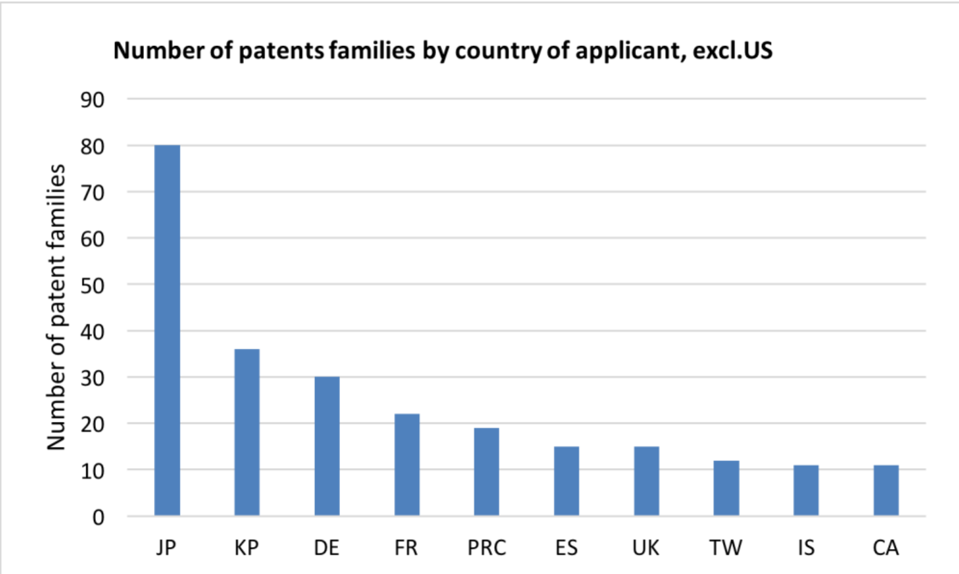

Figure A2.32. Number of patents families by country of applicant for the top ten countries, excluding the United States (1993-2013)

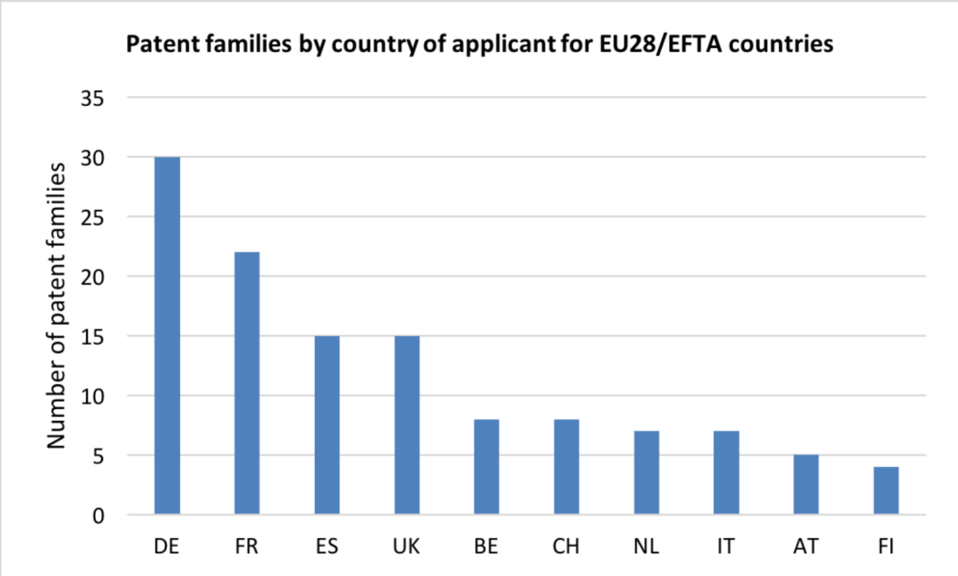

Figure A2.33. Number of patents families by country of applicant for the top ten EU28&EFTA countries (1993-2013)

World rank	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
4	DE	30	80%	67%	80%
5	FR	22	86%	91%	91%
7	ES	15	80%	80%	73%
8	UK	15	93%	67%	67%
13	BE	8	100%	75%	88%
14	CH	8	88%	75%	50%
15	NL	7	100%	100%	100%
16	IT	7	71%	57%	43%
18	AT	5	60%	60%	100%
19	FI	4	100%	75%	100%
20	IE	4	75%	50%	50%
25	PL	2	100%	100%	100%
26	SE	2	100%	100%	100%
30	PT	1	100%	0%	0%
32	NO	1	100%	0%	100%
35	CZ	1	0%	0%	100%
36	DK	1	100%	100%	100%

Table A2.81. Number of patent families by country of applicant and receiving authority for EU28&EFTA countries (1993-2013)

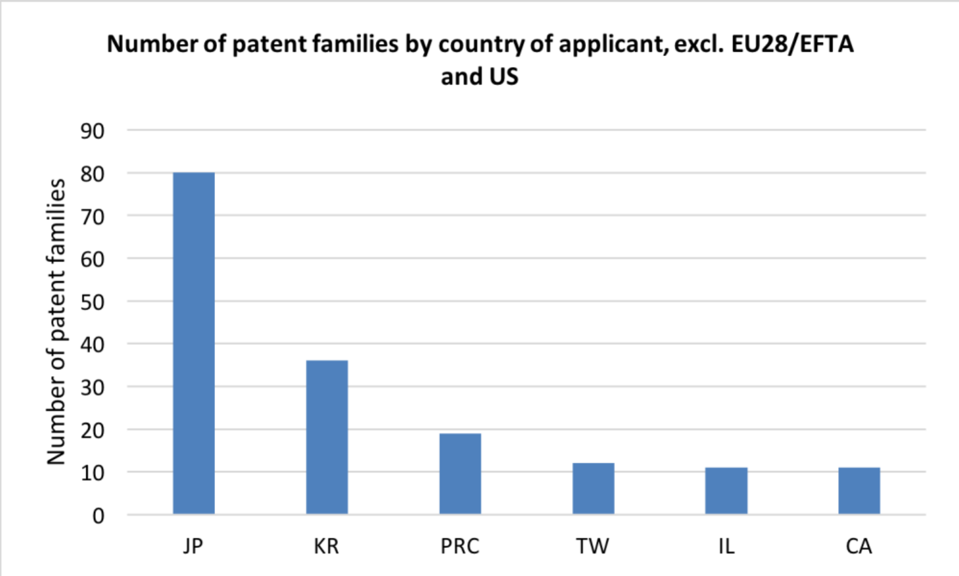

Figure A2.34. Number of patent families by country of applicant for non-EU28&EFTA, non-US countries with two or more patent families (1993-2013)

GRANTED PATENTS

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

World rank[142]	EU28&EFTA country of applicant	Number of EPO patents granted
3	DE	12
5	FR	4
13	AT	2
11	BE	1
31	FI	1
19	IE	1
14	IT	1
32	NO	1
6	ES	1
20	SE	1
15	CH	1

Table A2.82. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

World rank[143]	EU28&EFTA country of applicant	Number of USPTO patents granted

[142] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

[143] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[143]	EU28&EFTA country of applicant	Number of USPTO patents granted
3	DE	13
5	FR	10
6	ES	10
10	UK	5
11	BE	4
13	AT	2
14	IT	2
15	CH	2
17	NL	2
19	IE	1
20	SE	1
21	DK	1
27	PL	1

Table A2.83. Number of USPTO patents granted for countries, by county of applicant (1993-2013)

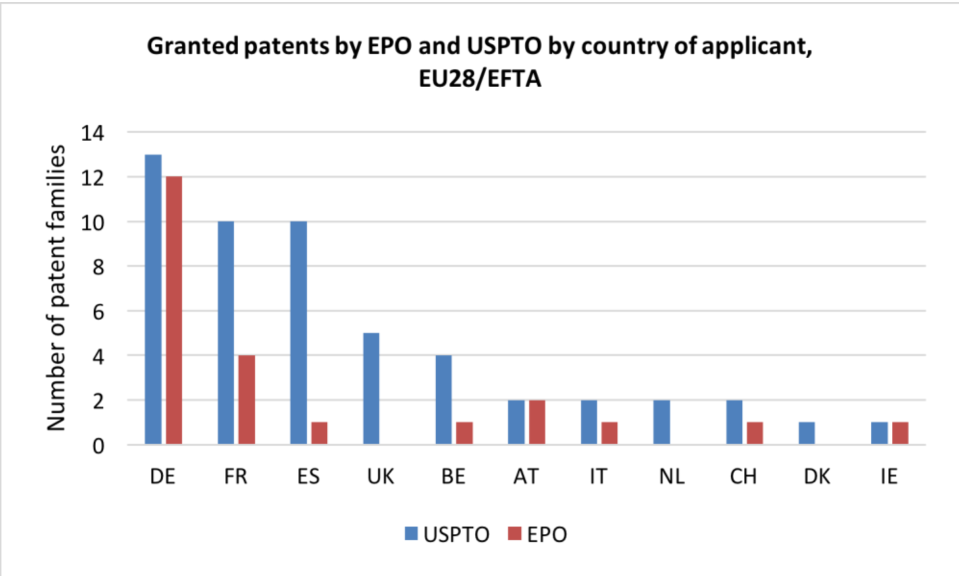

Figure A2.35. Granted patents by EPO and USPTO by country of applicant for the EU28&EFTA countries (1993-2013)

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.

INVT	FR	DE	UK	IS	JP	PRC	KR	ES	TW	US
APPL										

INVT	FR	DE	UK	IS	JP	PRC	KR	ES	TW	US
APPL										
FR	22	1	1	0	0	0	0	0	0	1
DE	1	30	0	0	1	1	0	0	0	4
UK	1	0	13	0	1	0	0	0	0	4
IS	0	0	0	11	0	0	0	0	0	0
JP	0	1	1	0	78	0	1	0	0	6
KR	0	2	0	0	0	19	3	0	0	3
ES	0	0	0	0	1	3	36	0	0	0
TW	0	0	0	0	0	0	0	15	0	0
US	2	5	6	1	4	5	1	0	0	239

Table A2.84. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

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

Looking at the top 15 performing universities and PROs for patent families, five out of 15 are from outside the US, two being from the EU28 or EFTA (from France and Spain). The table below shows the universities and PROs in the top 40 by number of patent families (of all types of organisations).

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
3	ES	Universidad De Sevilla	9	67%	89%	67%
4	US	University of California	8	75%	50%	13%
6	FR	CNRS[144]	7	57%	86%	57%
10	US	University of Arkansas	5	40%	100%	40%
11	KR	Korea Institute of Science & Technology (Kist)	5	0%	80%	20%
15	US	Idaho Research Foundation Inc	4	50%	75%	25%
18	US	Rice University	4	25%	75%	0%
19	KR	Gwangju Institute of Science & Technology	4	0%	50%	0%
25	IL	Technion R&D Foundation Ltd	3	67%	67%	33%
29	US	Auburn University	3	33%	67%	0%
32	US	Stevens Institute of Technology	3	67%	100%	0%
33	US	Massachusetts Institute of Tech	3	67%	67%	0%
37	US	U Chicago Argonne Llc	3	0%	100%	0%
38	US	Michigan State University	3	67%	67%	33%
39	US	Washington State University	3	33%	100%	33%

Table A2. 85. Number of patent families for top ten universities and PROs (1993-2013)

The table below shows the top performing universities and PROs for patent families in EU28&EFTA countries. Only French and Spanish organisations are among the top 30

[144] Centre National de la Recherche Scientifique

applicants worldwide (the ranking being shown in the first column).

World rank	Country	Organisation	No. of Patent families	Share of applications		
				PCT	USPTO	EPO
3	ES	Universidad de Sevilla	9	67%	89%	67%
6	FR	CNRS[9]	6	57%	86%	57%
44	ES	CSIC	2	100%	50%	50%
50	FR	CEA	2	50%	100%	50%

Table A2.86. Number of patent families in the top EU28&EFTA universities and PROs (1993-2013)

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted between 1993 and 2013. Only a few PROs have granted patents by the EPO, and two of them are from the EU28&EFTA countries (from Germany and Spain).

Rank	Country	Organisation	EPO	USPTO
1	ES	Universidad De Sevilla	1	0
2	US	University of Arkansas	1	8
3	IN	Indian Institute of Tech	1	0
4	US	Rensselaer Polytechnic Institute	1	1
5	US	The Trustees of Princeton University	1	3
6	KR	Elect & Telecommunications Res Inst	1	1

Table A2.87. Universities/research organisations granted patents, by decreasing number of EPO patents (1993-2013)

Ranking by the number of USPTO patents granted between 1993 and 2013, nine of the top 12 universities and research organisations are in the US and only two (Universidad De Sevilla and CNRS) in the EU28&EFTA.

Rank	Country	Organisation	USPTO	EPO
1	ES	Universidad De Sevilla	8	1
2	US	University of Arkansas	4	1
3	FR	CNRS	3	0
4	KR	Korea Institute of Science & Technology (KIST)	3	0
5	US	Stevens Institute of Technology	3	0
6	US	Uchicago Argonne Llc	3	0
7	US	University of California	3	0
8	US	Auburn University	2	0

Rank	Country	Organisation	USPTO	EPO
9	US	Brown University	2	0
10	IN	Council of Scientific & Industrial Research	2	0
11	US	Kansas State University Research Foundation	2	0
12	US	New Jersey Institute of Technology	2	0

Table A2.88. Universities/research organisations granted patents, by decreasing number of USPTO patents (1993-2013)

Activity of companies

PATENT APPLICATIONS

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

	Country	Company	No. of patent families	Share of applications		
				PCT	USPTO	EPO
1	KR	Samsung SDI	10	0%	80%	40%
2	JP	Toyota	9	78%	67%	89%
3	FR	Rhodia	8	75%	50%	88%
4	DE	Bayer Ag	6	83%	17%	17%
5	DE	Lanxess Deutschland GmbH	5	0%	80%	80%
6	DE	BASF	5	40%	40%	40%
7	JP	Toda Kogyo Corp	5	0%	100%	80%
8	US	Kx Tech Llc	5	20%	40%	100%
9	US	Lawrence Livermore National Security Llc	5	40%	80%	0%
10	US	Empire Tech Dev Llc	4	100%	75%	25%
11	US	Perry Equipment Corp	4	100%	75%	50%
12	JP	Sharp KK	4	25%	75%	0%
13	JP	Honda Motor Co Ltd	4	25%	50%	25%
14	JP	Nissan Motor Co Ltd	4	50%	75%	50%
15	JP	Phild Co Ltd	4	100%	50%	75%
16	JP	Showa Denko KK	4	50%	50%	25%

Table A2.89. Number of patent families for top sixteen companies, with at least 4 patent families (1993-2013)

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[145]. The first table shows the top ten when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In both tables, one company from France (Rhodia) and another from Germany (Lanxess) appear as the main companies, as well as BASF (DE) for EPO patents and Umicore (BE) for USPTO patents.

Country	Company	EPO	USPTO
DE	Lanxess Deutschland GmbH	4	4
FR	Rhodia	4	4
KR	Samsung SDI	3	7
JP	Toyota	3	4
US	Kx Tech Llc	3	2
JP	Phild Co Ltd	3	2
US	3M	2	3
JP	Toda Kogyo Corp	2	3
JP	GSI Creos Corp	2	2
DE	BASF	2	1
US	Seldon Tech Llc	2	1

Table A2.90. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

Country	Company	USPTO	EPO
KR	Samsung SDI	7	3
DE	Lanxess Deutschland GmbH	4	4
FR	Rhodia	4	4
JP	Toyota	4	3
US	Lawrence Livermore National Security Llc	4	0
US	3M	3	2
JP	Toda Kogyo Corp	3	2
US	Hyperion Catalysis Int. Inc	3	1
US	Inframat Corp	3	0
JP	Nissan Motor Co Ltd	3	0

[145] 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.

US	Perry Equipment Corp	3	0
JP	Toshiba	3	0
DE	Umicore	3	0

Table A2.91. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

Interestingly, according to the number of patents granted by the USPTO, there is only one US company in the top five. There are five countries populating the table, Korea, Germany, the US, Japan and France.

TRANSPORT AND NANOTECHNOLOGY (TRNT)

Overview

This section looks at the patenting activity in nanotechnology and transport by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (transport, in this case)[146]. 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[147] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[148] that are members of the treaty.

Number and evolution over time of nanotechnology transport patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[149,150] of granted patent and patent applications were found in the period 1993-2013[151]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[152].

In the same period, the number of transport-related patent families identified among the nanotechnology patents is 329, 0.6% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EP and USA do not sum to 100%. The highest percentage of transport nanotechnology applications is in the USA (95%) while the figures corresponding to PCT (64%) and EPO (65%) are considerably lower.

Transport and nanotechnology applications	Absolute number	Share of patent families
Total patent families	329	100%

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

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

[148] 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

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

[150] 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/.

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

[152] 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.

Transport and nanotechnology applications	Absolute number	Share of patent families
USPTO applications	312	95%
EPO applications	215	65%
PCT applications	211	64%

Table A2.92. Absolute numbers and percentages of patents on nanotechnology and transport (1993-2013)

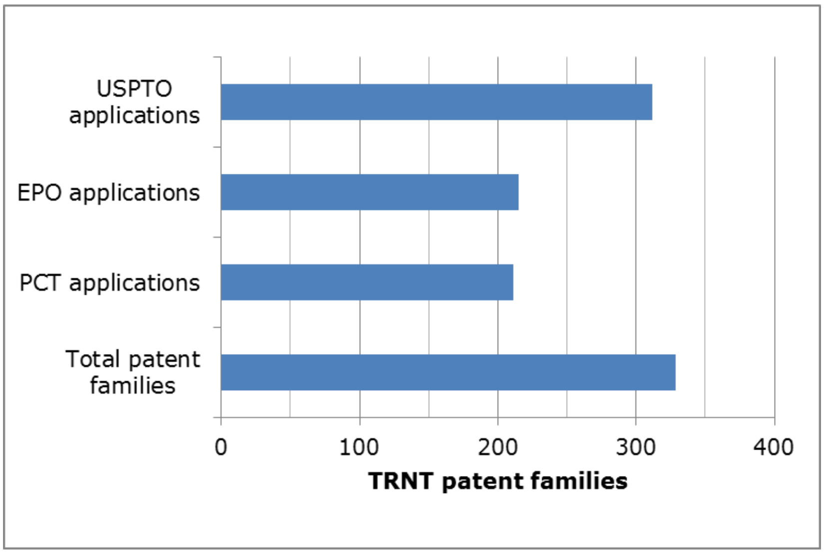

Figure A2.36. Number of transport and nanotechnology patent families, total and by filing authority (1993-2013)

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.

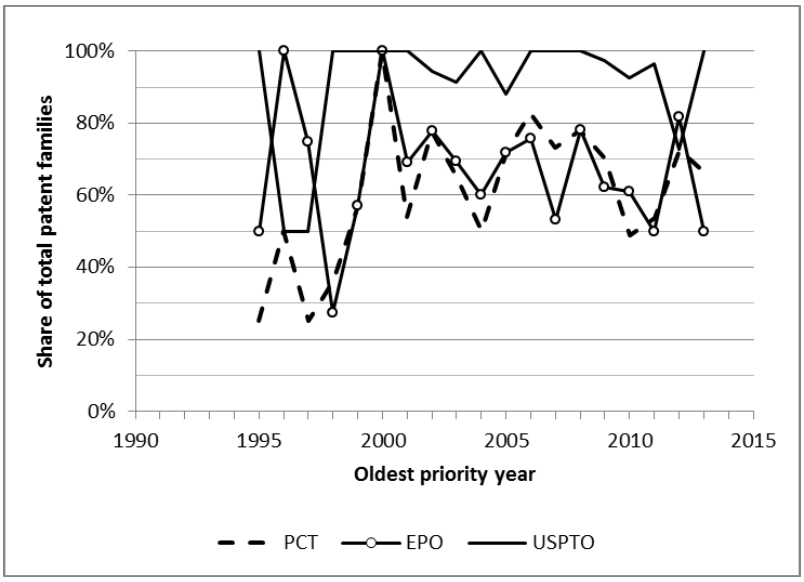

Figure A2.37. Evolution over time of WIPO (PCT), EPO and USPTO transport nanotechnology patenting (1993-2013)

In this figure, it can be observed that the filings at EPO and WIPO follow a similar pattern and the values are comparable. The share of patent filings at the USPTO is significant bigger with values in the 90-100% range for the period 1998-2011. It should be noted that the numbers of patents are low which may increase the appearance of fluctuations in the statistics. Any decline that is visible from 2013 is caused by the fact that not all data has been added to the patent databases.

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 patent authorities through which PCT applications were filed are shown in the table, each of them with two or more filings. The United States is by far the most prolific with 97 patent families, followed by Japan (34) and EPO (30).

Rank	Receiving authority	No. of patent families
1	USPTO	97
2	Japan	34
3	EPO	30
4	Korea	9
5	Sweden	7
6	France	6
7	China	5
8	United Kingdom	4
9	WIPO	4
10	Canada	2
11	Netherlands	2
12	Spain	2

Table A2.93. Number of nanotechnology transport patent families by PCT receiving authority, top receiving authorities (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 329 transport-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in 17% of them while there is participation from the rest of the world in 83% of cases.

	EU28 & EFTA	Rest of World
Number of transport NT patent families	57	272
Percentage of transport NT patent families	17%	83%

Table A2.94. Origin of patent applicants, EU28&EFTA and rest of World (1993-2013)

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

By far the highest number of patent families is found where the country of the applicant is the US (156), followed by Japan already with a considerably lower number of patents

(74). The European countries which account for a higher number of patents are Germany (40), France (24), Switzerland (11), United Kingdom (10) and Sweden (9), all of them among the top 10 countries in number of patent families.

Rank	Country of applicant	No. of Patent Families	Share of applications		
			PCT	USPTO	EPO
1	US	156	66%	92%	58%
2	JP	74	53%	96%	64%
3	DE	40	58%	80%	85%
4	FR	24	79%	96%	88%
5	KR	21	43%	86%	38%
6	CN	12	67%	83%	50%
7	CH	11	100%	82%	100%
8	UK	10	60%	80%	50%
9	SE	9	100%	100%	89%
10	CA	9	33%	100%	56%

Table A2.95. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Most of the patents by US applicants are filed with the USPTO while roughly two-thirds are filed as PCTs and at EPO. Patent applicants from the EU28&EFTA countries shown file between 82% (CH) and 100% (SE) of their transport and nanotechnology patent applications at the USPTO and between 50% (UK) and 100% (CH) at the EPO. PCT application filings by applicants from the EU28&EFTA countries shown range from 58% (DE) to 100% (CH and SE). Patent applicants from Japan, Korea, China and Canada all file more at the USPTO than at the EPO or through the PCT route.

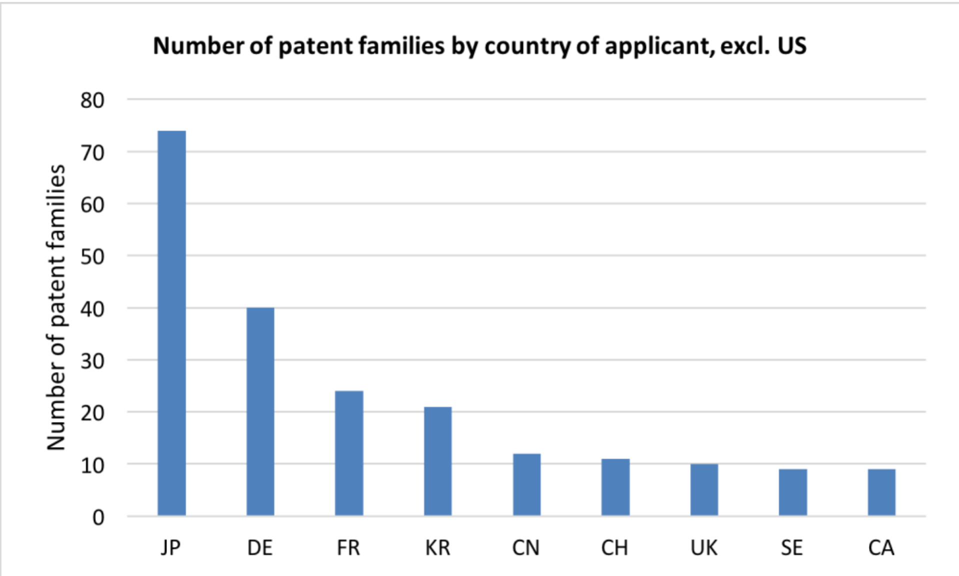

Figure A2.38. Number of patent families by country of applicant for the top ten countries excluding the US (1993-2013)

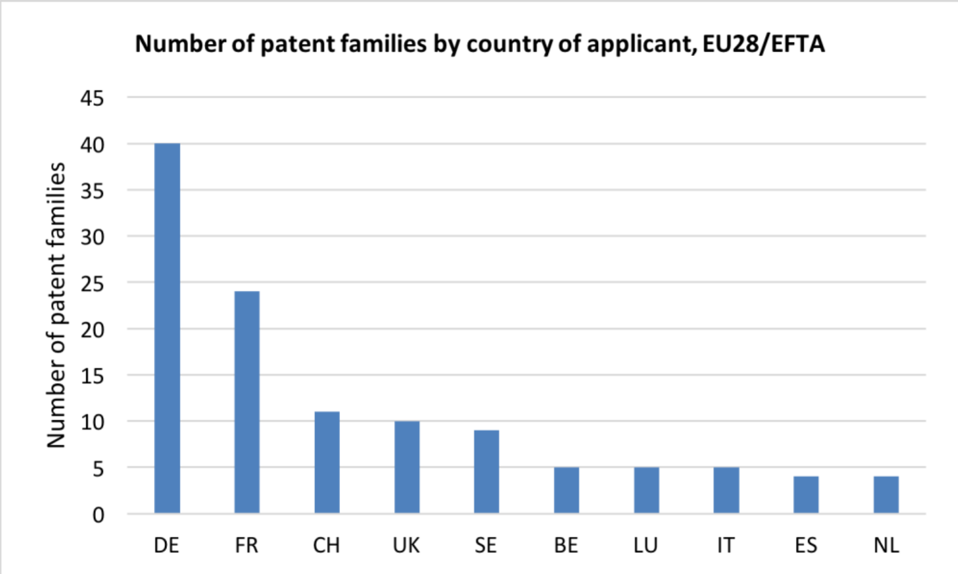

Figure A2.39. Number of patent families by country of applicant for the EU28&EFTA countries (1993-2013)

World rank	Country of applicant	No. of Patent Families	Share of applications		
			PCT	USPTO	EPO
3	DE	40	58%	80%	85%
4	FR	24	79%	96%	88%
7	CH	11	100%	82%	100%
8	UK	10	60%	80%	50%
9	SE	9	100%	100%	89%
12	BE	5	80%	100%	80%
13	LU	5	20%	80%	100%
14	IT	5	40%	80%	60%
15	ES	4	50%	100%	100%
16	NL	4	100%	100%	75%
20	AT	2	50%	100%	50%
21	BG	1	0%	100%	0%
22	FI	1	100%	100%	100%
24	IS	1	100%	100%	100%

Table A2.96. Number of patent families by country of applicant and receiving authority for EU28&EFTA countries (1993-2013)

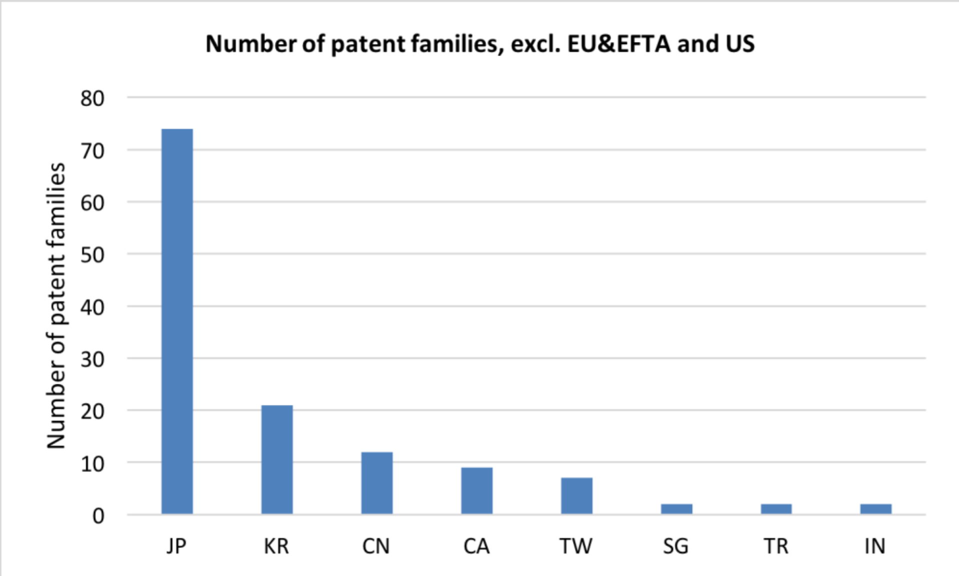

Figure A2.40. Number of patent families for countries with two or more applications for applicants from non-EU28&EFTA, non-US countries (1993-2013)

GRANTED PATENTS

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

World rank[153]	EU28&EFTA Country of applicant	Number of EPO patents granted
3	DE	15
4	FR	8
9	CH	6
15	IT	2
13	NL	2
7	UK	2
18	AT	1
14	BE	1
6	SE	1

Table A2.97. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

EU28&EFTA Country of applicant	Number of USPTO patent granted
DE	24
FR	15
SE	6

[153] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

EU28&EFTA Country of applicant	Number of USPTO patent granted
UK	5
CH	4
NL	3
BE	3
IT	2
ES	2
AT	1
BG	1
FI	1
LI	1

Table A2.98. Number of USPTO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

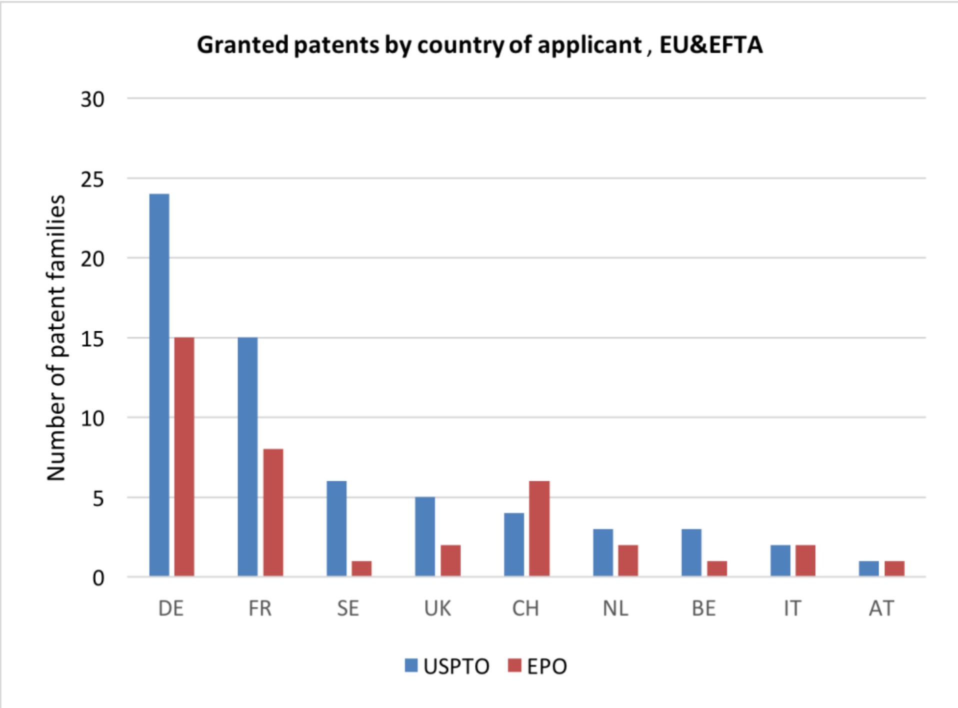

Figure A2.41. Granted patents by country of applicant for EU28&EFTA (1993-2013)

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.

INVT	BE	CA	CN	FR	DE	JP	KR	SE	UK	US
APPL										
BE	5	0	0	5	1	0	0	0	0	0

INVT	BE	CA	CN	FR	DE	JP	KR	SE	UK	US
APPL										
BE	5	0	0	5	1	0	0	0	0	0
CA	0	8	0	0	2	0	0	0	0	3
CN	0	0	11	0	1	1	0	0	0	4
FR	5	0	0	23	2	0	0	0	0	7
DE	1	2	1	2	38	0	0	0	1	5
JP	0	0	1	1	0	69	1	0	1	8
KR	0	0	0	0	0	1	21	0	0	1
SE	0	0	0	0	0	0	0	9	0	1
UK	0	0	0	0	1	0	0	0	10	1
US	0	3	5	6	5	8	1	1	3	141

Table A2.99. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

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

Rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
22	US	Dartmouth College	4	50%	50%	50%
24	US	University of California	3	67%	100%	0%
25	FR	CNRS	3	67%	67%	100%
72	US	Massachusetts Institute of Tech	2	100%	100%	50%
76	US	University of Florida Research Foundation Inc	2	50%	100%	0%
77	US	University of Houston	2	100%	50%	50%
78	US	University of South Florida	2	100%	50%	0%
79	US	William Marsh Rice University	2	50%	100%	0%
80	FR	Ecole Nal Superieure de Chimie de Lille	2	100%	0%	0%

Table A2.100. Number of patent families for top universities and PROs (1993-2013)

The table below shows the top performing universities and PROs for EU28&EFTA countries. Only one French organisation is among the top 30 applicants worldwide (the ranking being shown in the first column).

World rank	Country	Organisation	No. of Patent families	Share of applications		
				PCT	USPTO	EPO
25	FR	CNRS	3	67%	67%	100%
80	FR	Ecole Nal Superieure de Chimie de Lille	2	100%	0%	0%
81	FR	Universite de Bordeaux 1	1	100%	100%	0%
82	FR	Universite Louis Pasteur de Strasbourg	1	100%	0%	100%
83	UK	University of Nottingham	1	100%	100%	0%
155	FR	Armines	1	100%	100%	0%
156	FR	CEA & aux energies alternatives	1	100%	0%	0%

Table A2.101. Number of patent families in the top EU28&EFTA universities and PROs (1993-2013)

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted between 1993 and 2013. Only four PROs have transport patents granted by the EPO, and one of them is from an EU28&EFTA country (Germany).

Rank	Country	Organisation	EPO	USPTO
1	US	Dartmouth College	1	2
2	KR	KR Institute of Science & Tech	1	1
3	JP	Aichi University of Education	1	0
4	DE	Fraunhofer Gesellschaft	1	0

Table A2.102. Universities/research organisations granted patents, ordered by EPO patents (1993-2013)

Ranking by the number of USPTO patents granted between 1993 and 2013, nine of the top 12 universities and research organisations are in the US and only two in the EU28&EFTA.

Rank	Country	Organisation	USPTO	EPO
1	US	Dartmouth College	9	1
2	US	University of California	3	1
4	FR	CNRS	3	0
5	US	University of Florida Research Foundation Inc	3	0
6	US	William Marsh Rice University	3	0

Table A2.103. Universities/research organisations with three or more USPTO patents, ordered by USPTO patents (1993-2013)

Activity of companies

PATENT APPLICATIONS

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

World rank	Country	Company	No. of patent families	Share of applications		
				PCT	USPTO	EPO
1	JP	Bridgestone Corp	9	56%	67%	56%
2	US	PPG Ind. Ohio Inc	8	75%	63%	75%
3	US	Boeing	7	43%	100%	86%
4	US	ExxonMobil Chemical Patents Inc	6	100%	100%	100%
5	SE	Saab Ab	6	100%	17%	100%
13	FR	Cie Gen Des Ets Michelin	5	40%	0%	80%
14	CH	Michelin Recherche et Technique Sa	5	100%	80%	100%
15	JP	Fujifilm Corp	5	20%	100%	80%
16	JP	Sharp KK	5	20%	60%	0%
17	BE	Solvay SA	4	100%	50%	100%
18	US	E I Du Pont de Nemours & Co	4	50%	25%	75%
19	FR	Renault SAS	4	75%	50%	75%

Table A2.104. Number of patent families for top companies (1993-2013)

GRANTED PATENTS

The top companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[154]. The first table shows the top eight when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In the first table, Michelin (FR and CH) and ASML (NL) appear as the main EU27&EFTA companies for EPO patents.

Country	Company	EPO	USPTO
US	Goodyear Tire & Rubber Co	4	2
FR	Cie Gen Des Ets Michelin	4	0

[154] 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.

Country	Company	EPO	USPTO
US	PPG Ind. Ohio Inc	3	4
CH	Michelin Recherche et Technique Sa	3	2
JP	Bridgestone Corp	2	6
US	ExxonMobil Chemical Patents Inc	2	6
NL	ASML Netherlands BV	2	2
JP	Sumitomo Rubber Ind. Ltd	2	2

Table A2.105. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

Country	Company	USPTO	EPO
JP	Bridgestone Corp	6	2
US	ExxonMobil Chemical Patents Inc	6	2
US	Boeing Co	6	1
US	PPG Ind. Ohio Inc	4	3
US	Applied Nanostructured Solutions Llc	3	0
US	Goodyear Tire & Rubber Co	2	4
CH	Michelin Recherche Et Technique Sa	2	3
NL	ASML Netherlands BV	2	2
JP	Sumitomo Rubber Ind. Ltd	2	2
DE	Carl Zeiss SMT GmbH	2	1
JP	Fujifilm Corp	2	1
US	Goodrich Corp	2	1
UK	Hexcel Composites Ltd	2	1
JP	Nissin Kogyo Co Ltd	2	1
FR	Renault SAS	2	1
DE	Robert Bosch GmbH	2	1
JP	Showa Denko Kk	2	1
UK	Airbus Operations Ltd	2	0
DE	Degussa Huls AG	2	0
US	Guardian Ind. Corp	2	0
JP	Kk Toshiba	2	0

Table A2.106. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

CONSTRUCTION AND NANOTECHNOLOGY (CNNT)

Overview

This section looks at the patenting activity in nanotechnology and construction by patent filings and patents granted over the time period 1993-2013 at the leading global patent offices and by country of applicant and country of inventor, and by organisation including companies.

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology i.e. B82 and those related to the sector under consideration (construction, in this case)[155]. 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[156] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[157] that are members of the treaty.

Number and evolution over time of construction nanotechnology patent families

Using the above methodology, 50,780 (simple) nanotechnology patent families[158,159] (CNNT) of granted patent and patent applications were found in the period 1993-2013[160]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[161].

In the same period, the number of construction and nanotechnology patent families identified among the nanotechnology patents is 2,254, 4.4% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EP and USA do not sum to 100%. The highest percentage of construction and nanotechnology applications is filed at the USPTO (92%) while the figures corresponding to PCT (64%) and EPO (54%) are significantly lower.

Construction and nanotechnology applications	Patent families	Share of patent families
Total patent families	2254	100%
USPTO applications	2079	92%

[155] 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.

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

[157] 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

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

[159] 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/.

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

[161] 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.

Construction and nanotechnology applications	Patent families	Share of patent families
PCT applications	1444	64%
EPO applications	1215	54%

Table A2.107. Absolute numbers and percentages of patents on nanotechnology and construction (1993-2013)

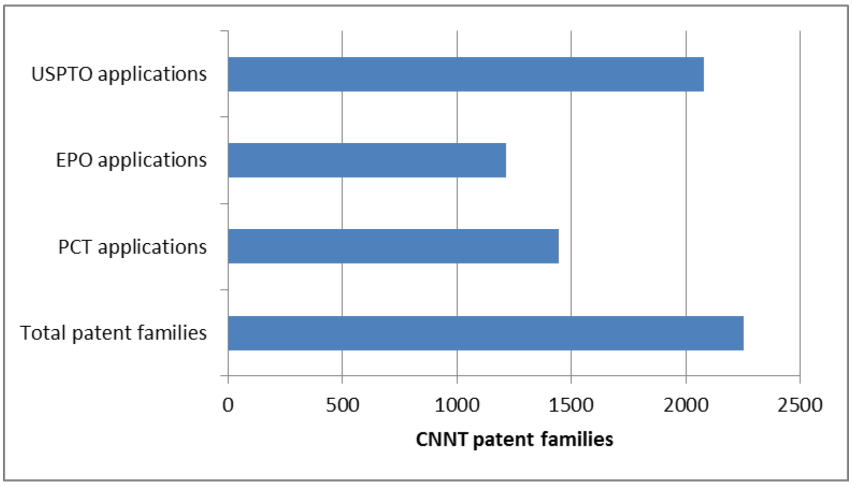

Figure A2.42. Number of construction and nanotechnology patent families, total and by filing authority (1993-2013)

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

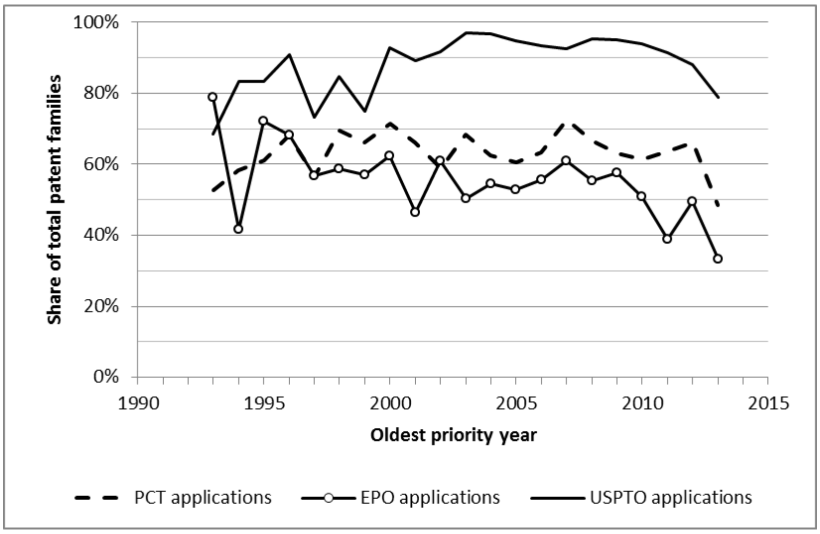

Figure A2.43. Evolution over time of WIPO (PCT), EPO and USPTO construction nanotechnology patenting

In this figure, it can be observed that the filings at EPO, USPTO and WIPO follow a somewhat similar pattern. The level of filings at the USPTO is significantly higher than those at the EPO or the WIPO (PCT). The decline that is visible from 2013 is caused by the fact that not all data has been added to the patent databases.

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 patent authorities through which PCT applications were filed cover 94.6% of the total filings. In the table for each of them the number of filings is shown. The USA is by far the most prolific, followed by Europe (EPO) and Japan. The sum of the figures for the European national patent offices in this table and the EPO is just 367, only over half of the number of US filings, for the countries shown here.

Receiving authority	No. of patent families (1993-2013)
USPTO	610
EPO	259
Japan	233
Korea	48
WIPO	46
France	45
United Kingdom	40
China	26
Germany	23
Canada	14

Table A2.108. Number of construction nanotechnology patent families by the top ten PCT receiving authorities (1993-2013)

Activity by country of applicant

PATENT APPLICATIONS

Within the group of 2,254 construction-related patent families, in 449 (20%) at least one EU28 or EFTA applicant is involved while in the other 1,805 (80%) patent families EU28&EFTA participation could not be determined.

	EU28 & EFTA	Rest of World
Number of CT patent families	449	1805
Percentage of CT patent families	20%	80%

Table A2.109. Origin of patent applicants, EU28&EFTA and rest of World (1993-2013)

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

By far the highest number of patent families is found where the country of the applicant is the US (683), followed by Japan already with a considerably lower number of patents (334). The European countries which account for a higher number of patents are Germany (214), France (63) and the United Kingdom (57), all of them among the top 10 countries in number of patent families.

World	Country of	No. of patent	Share of applications

rank[162]	applicant	families	PCT	USPTO	EPO
1	US	683	73%	99%	51%
2	JP	334	51%	94%	49%
3	DE	214	82%	78%	84%
4	KR	87	34%	95%	29%
5	NL	69	45%	87%	61%
6	FR	63	63%	83%	81%
7	UK	57	86%	77%	70%
8	TW	53	0%	100%	8%
9	CN	41	46%	93%	32%
10=	CA	27	70%	100%	63%
10=	CH	27	85%	93%	96%

Table A2.110. Top ten countries based on filed patent families, by country of applicant and receiving authority (1993-2013)

Almost all of patents by US applicants are filed with the USPTO while roughly three-quarters (73%) are filed as PCTs. Only half of the patents by US applicants are filed at the EPO.

Among the EU applicants, between 77% (UK) and 87% (NL) files at the USPTO, between 86% (UK) and 45% (NL) file by the PCT route (France is also low at 63%), and between 84% (DE) and 61% (NL) file at the EPO.

Looking at the non-EU28&EFTA and non-US countries of applicants, the filing shows a preference, among the patent authorities considered in this study, to filing most at the USPTO.

[162] The world ranking is based on the number of patent applications and in case countries have the same number of applications on the alphabetical order of the name of the country

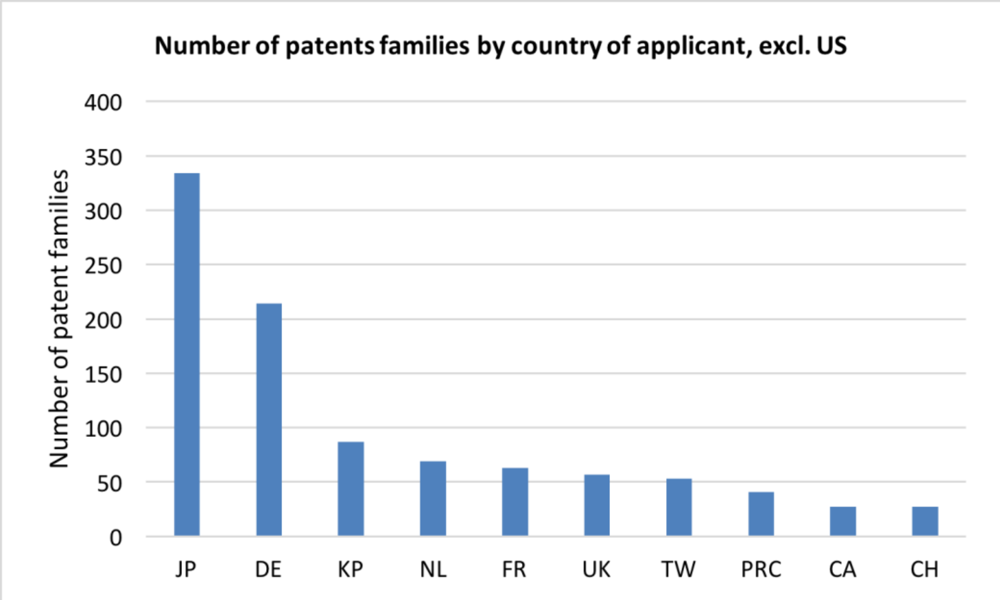

Figure A2.44. Number of patent families by country of applicant, top ten countries excluding United States (1993-2013)

World rank[8]	Country of applicant	No. of patent families	Share of applications		
			PCT	USPTO	EPO
3	DE	214	82%	78%	84%
5	NL	69	45%	87%	61%
6	FR	63	63%	83%	81%
7	UK	57	86%	77%	70%
11	CH	27	85%	93%	96%
12	SE	20	85%	85%	85%
13	IT	18	94%	89%	89%
16	BE	12	92%	83%	83%
17	DK	11	100%	73%	73%
21	FI	8	100%	88%	88%
19	ES	8	100%	75%	100%

Table A2.111. Number of patent families by country of applicant and receiving authority for EU28&EFTA countries (1993-2013)

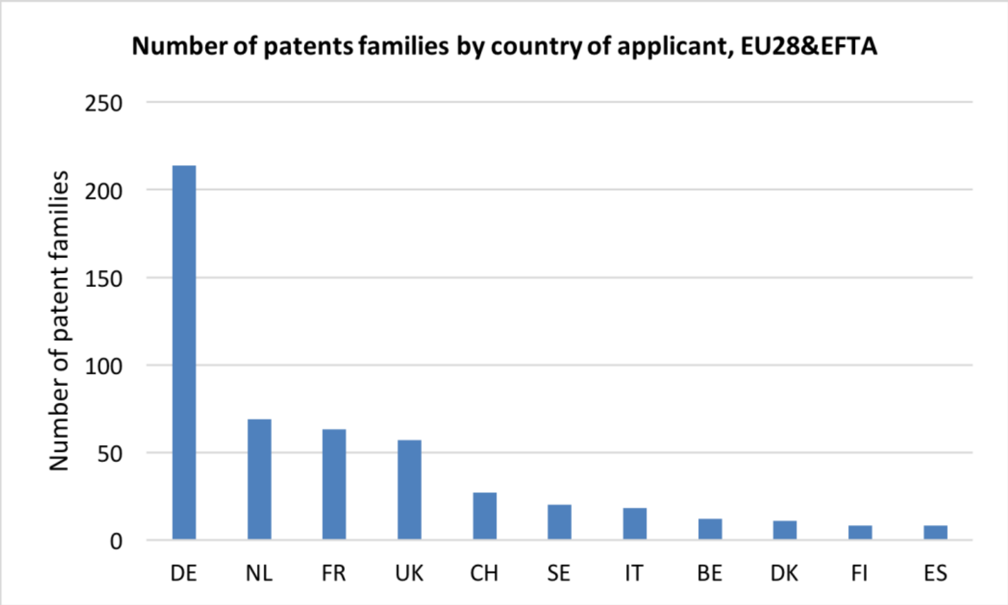

Figure A2.45. Number of patent families by country of applicant for the top ten EU28&EFTA countries (1993-2013)

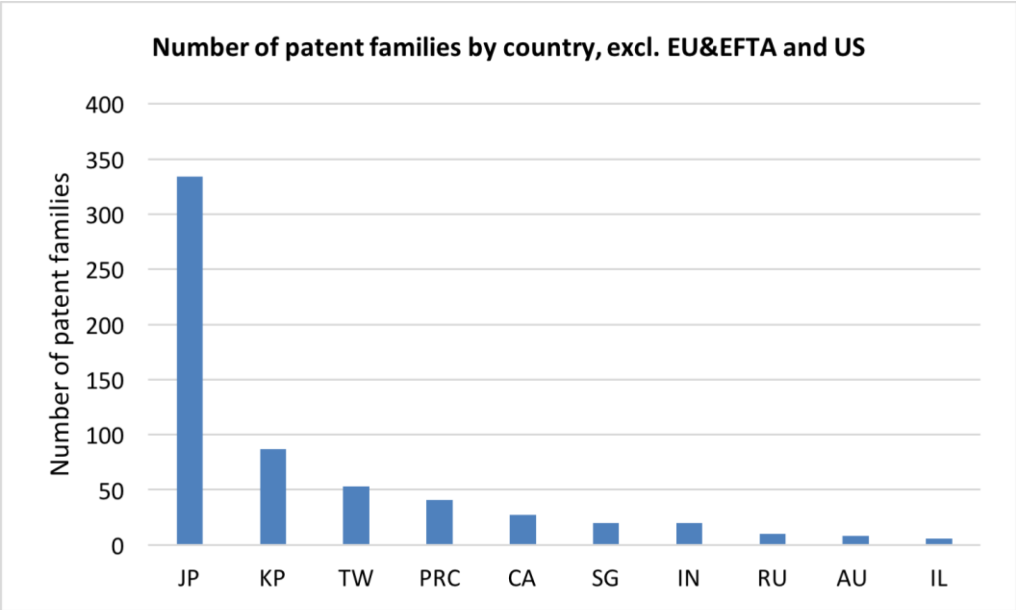

Figure A2.46. Number of patent families by country of applicant, top ten non-EU28&EFTA, non-US applicants (1993-2013)

GRANTED PATENTS

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

World rank[163]	EU28&EFTA country of applicant	Number of EPO patents granted
3	DE	66
7	FR	13
5	NL	13

[163] World rank is based on decreasing number of total patent families granted by the USPTO and, if needed to distinguish, the names of the applicant country in alphabetical order

World rank[163]	EU28&EFTA country of applicant	Number of EPO patents granted
13	SE	8
12	IT	7
11	CH	6
8	UK	6
15	DK	4
22	AT	3
18	FI	3
23	ES	2
16	BE	1
20	IE	1
27	NO	1

Table A2.112. Number of EPO patents granted for EU28&EFTA countries, by country of applicant (1993-2013)

World rank[164]	EU28&EFTA Country of applicant	Number of USPTO patents granted
3	DE	89
5	NL	39
7	FR	30
8	UK	23
11	CH	12
12	IT	11
13	SE	8
16	BE	7
15	DK	6
18	FI	4
20	IE	4
22	AT	2
23	ES	2
35	CZ	1

[164] Ibid

World rank[164]	EU28&EFTA Country of applicant	Number of USPTO patents granted
38	GR	1
39	IS	1
27	NO	1
44	PL	1

Table A2.113. Number of USPTO patents granted for EU28&EFTA countries, by county of applicant (1993-2013)

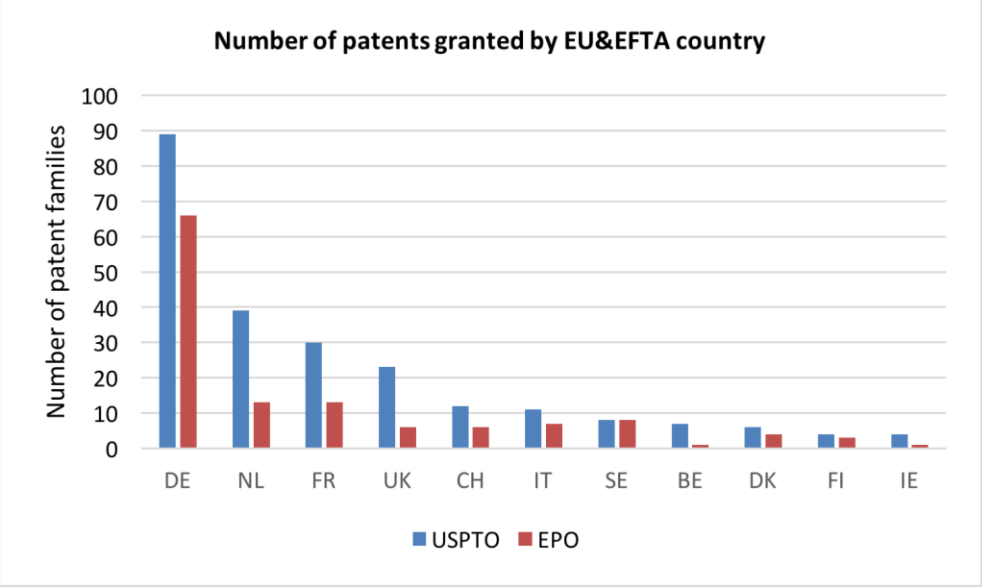

Figure A2.47. Granted patents by country of applicant for the top EU28&EFTA countries (1993-2013)

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 (the diagonal cells in the table below. However, it is not uncommon to have inventions that are patented outside of the country in which they originate.

INVT	BE	CA	FR	DE	IN	IT	JP	KR	NL	CN	ES	SE	CH	UK	US
APPL															
BE	11	0	1	2	0	0	0	0	2	0	0	0	0	1	3
CA	0	25	1	4	1	0	0	0	0	1	1	0	0	1	10
FR	1	0	60	5	1	0	0	0	1	2	0	0	4	4	6
DE	3	3	7	204	1	5	2	0	8	4	0	0	9	10	19
IN	0	1	0	1	17	0	0	0	0	0	0	0	0	0	7
IT	0	0	0	2	0	18	0	0	0	0	1	0	3	0	3
JP	0	0	0	3	0	0	328	0	0	2	0	0	0	2	9
KR	0	0	0	0	0	0	1	83	0	0	0	0	0	0	8
NL	2	0	7	10	0	0	0	0	52	2	0	7	0	5	5

INVT	BE	CA	FR	DE	IN	IT	JP	KR	NL	CN	ES	SE	CH	UK	US
APPL															
CN	0	0	2	2	0	0	3	0	2	41	0	0	1	1	11
ES	0	1	0	0	0	1	0	0	0	0	8	0	0	0	0
SE	0	0	0	0	0	0	0	0	1	0	0	18	1	0	2
CH	0	0	4	10	0	4	0	0	0	1	0	0	20	2	7
UK	1	2	2	7	1	1	0	1	3	0	0	1	1	47	8
US	2	15	12	26	7	4	10	5	1	15	2	2	5	8	651

Table A2.114. Country of applicant and country of inventor table for cross-comparison (1993-2013)

Patenting activity by organisation type

Universities and public research organisations

PATENT APPLICATIONS

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

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
8	US	University of California	22	68%	82%	18%
9	DE	Fraunhofer Gesellschaft	19	37%	21%	47%
12	US	Massachusetts Institute of Tech	17	82%	76%	24%
20	FR	CEA	12	50%	58%	42%
23	US	Harvard College	11	64%	91%	27%
24	CN	Tsinghua University	10	0%	100%	0%
26	FR	CNRS	9	67%	44%	78%
39	US	Dartmouth College	8	0%	100%	0%
40	SG	Agency For Science Tech & Research	7	71%	86%	43%
43	JP	National Institute of Advanced Ind. Science & Tech	7	0%	100%	43%

Table A2.115. Number of patent families for top ten universities and PROs (1993-2013)

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

World rank	Country	Organisation	No. of patent families	Share of applications		
				PCT	USPTO	EPO
9	DE	Fraunhofer Gesellschaft	19	37%	21%	47%
20	FR	CEA	12	50%	58%	42%
26	FR	CNRS	9	67%	44%	78%
53	DE	Leibniz Institut fuer Neue Materialien	7	43%	14%	14%
77	ES	Consejo Superior de Investigaciones Cientificas CSIC	4	25%	50%	100%

Table A2.116. Number of patent families for the top EU28&EFTA universities and PROs (1993-2013)

GRANTED PATENTS

The table below shows the PROs ranked by the highest number of EPO patents granted between 1993 and 2013. Only fourteen PROs have granted patents by the EPO, and eight are from the EU28&EFTA countries (from Germany, France and Spain).

World rank	Organisation	Country	EPO	USPTO
7	Fraunhofer Gesellschaft	DE	5	3
38	CNRS	FR	2	2
45	CEA	FR	2	5
80	Leibniz Institut Fur Polymerforschung Dresden Ev	DE	1	0
85	Karlsruher Institut Fur Technologie Kit	DE	1	0
88	Institut fur Neue Materialien Gemeinnutzige GmbH	DE	1	0
117	BAM Bundesanstalt Fur Materialforschung & Prufung	DE	1	0
154	Consejo Superior De Investigaciones Cientificas CSIC	ES	1	1
170	JP Science & Tech Agency	JP	1	2
172	Institute Of Gas Tech	US	1	2
181	UT Battelle Llc	US	1	3
191	Battelle Memorial Institute	US	1	3
201	National Institute Of Advanced Ind. Science & Tech	JP	1	5
204	Agency For Science Tech & Research	SG	1	6

Table A2.117. Universities/research organisations granted patents, ranked by EPO patents (1993-2013)

Ranking by the number of USPTO patents granted between 1993 and 2013, eight universities and research organisations have five or more patents granted by the USPTO. Only one of these organisations is from a EU28&EFTA country, CEA (FR).

World rank	Country	Organisation	USPTO	EPO
5	US	University of California	15	0
13	US	Harvard College	10	1
14	US	Massachusetts Institute of Technology	9	3
16	US	Dartmouth College	8	0
17	CN	Tsinghua University	8	0
23	SG	Agency for Science Tech & Research	6	1
28	FR	CEA	5	2
31	JP	National Institute of Advanced Ind. Science & Tech	5	1

Table A2.118. Universities/research organisations with five or more patents granted by USPTO, ranked by USPTO patents (1993-2013)

Activity of companies

PATENT APPLICATIONS

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

World rank	Country	Company	No. of patent families	Share of applications		
				PCT	USPTO	EPO
1	US	Molecular Imprints Inc	48	77%	98%	46%
2	JP	Canon KK	33	30%	94%	36%
3	NL	ASML Netherlands Bv	30	13%	93%	23%
4	TW	Hon Hai Precision Ind. Co Ltd	30	0%	100%	0%
5	JP	Asahi Glass Co Ltd	25	88%	76%	68%
6	US	Corning Inc	24	79%	29%	79%
7	KR	Samsung Elect Co Ltd	22	5%	73%	18%
10	US	3m Innovative Properties Co	18	83%	78%	78%
11	DE	Evonik Degussa GmbH	18	39%	67%	67%
13	DE	Merck Patent GmbH	17	82%	41%	76%

Table A2.119. Number of patent families for top ten companies (1993-2013)

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[165]. The first table shows the top ten when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In the first table, three companies from Germany and one from the Netherlands appear as the main companies in EPO patents.

Country	Company	EPO	USPTO
US	Molecular Imprints Inc.	8	40
DE	Evonik Degussa GmbH	8	11
JP	Canon KK	7	27
US	3M Innovative Properties Co	7	12

[165] 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.

Country	Company	EPO	USPTO
US	Corning Inc	6	7
DE	Wacker Chemie AG	6	2
NL	ASML Netherlands BV	4	23
JP	Asahi Glass Co Ltd	4	14
DE	BASF SE	4	5
JP	Nissan Chem Ind. Ltd	4	5

Table A2.120. Companies granted USPTO and EPO patents ordered by decreasing number of EPO patents (1993-2013)

Country	Company	EPO	USPTO
US	Molecular Imprints Inc.	8	40
JP	Canon KK	7	27
NL	ASML Netherlands BV	4	23
TW	Hon Hai Precision Ind. Co Ltd	0	21
JP	Asahi Glass Co Ltd	4	14
US	PPG Ind. Ohio Inc	3	13
JP	KK Toshiba	1	13
USA	3M Innovative Properties Co	7	12
DE	Evonik Degussa GmbH	8	11
KR	Samsung Elect Co Ltd	2	10

Table A2.121. Companies granted USPTO and EPO patents ordered by decreasing number of USPTO patents (1993-2013)

Several companies are found in both lists. From the companies in the top three of the USPTO list, two are in the top three of the EPO list (Molecular Imprints Inc. and Canon KK).

The next annex looks at products and markets that relate to nanotechnology.

ANNEX 3: PRODUCTS AND MARKETS BY SECTOR

This annex looks at each of the eight sectors in turn, their products and markets that relate to nanotechnology:

- ICT;
- Manufacturing;
- Health;
- Energy;
- Photonics;
- Environment;
- Transport; and
- Construction.

1 Products and Markets for ICT through Nanotechnology

Commercialised products for ICT through nanotechnology: Overview

To date, 226 ICT-related products using nanotechnology have been identified as being commercially available.

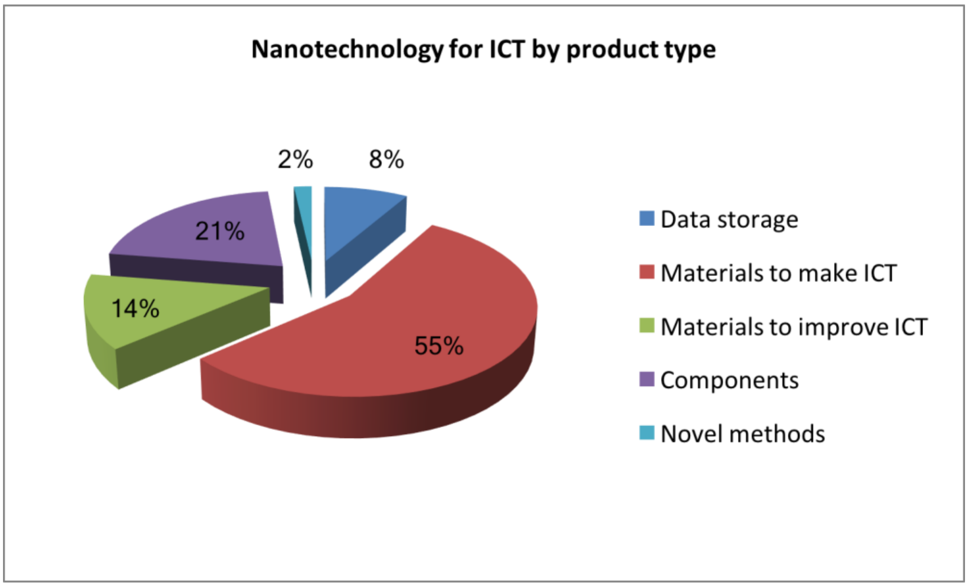

Figure A3.1. Nanotechnology products in ICT

Source: JIIP, 2017

Materials to make ICT (55%) account for the biggest share of these commercialised products and components the second largest share (21%). Materials to improve ICT (14%) and products for data storage (8%) form a smaller percentage of the products. Noteworthy is the presence of products in the area of novel methods (2%), i.e. quantum computers and spintronic-based sensors.

Products for ICT through nanotechnology, by application market

The products identified are divided as follows:

- Data storage;

- Printed electronics;
- Chemical-mechanical polishing compounds (CMP compounds);
- Electrostatic discharge protection and prevention (ESD);
- Low-k dielectric coatings;
- Electro-conductive coatings;
- Electronic shielding (POSS); and
- Components.

In each case, details are given of the technology and its purpose, as well as market estimates and forecasts. Existing and emerging applications are considered.

Data Storage

Products by application market

Hard disc media and heads

The total materials cost of sputtered magnetic coatings used on hard discs in 2015 was estimated at USD 361 million. This figure is expected to have decreased to USD 340.7 million in 2016 and to decrease further to USD 204.4 million by 2021, a CAGR (compound annual growth rate) of -9.7% from 2016 through 2021.

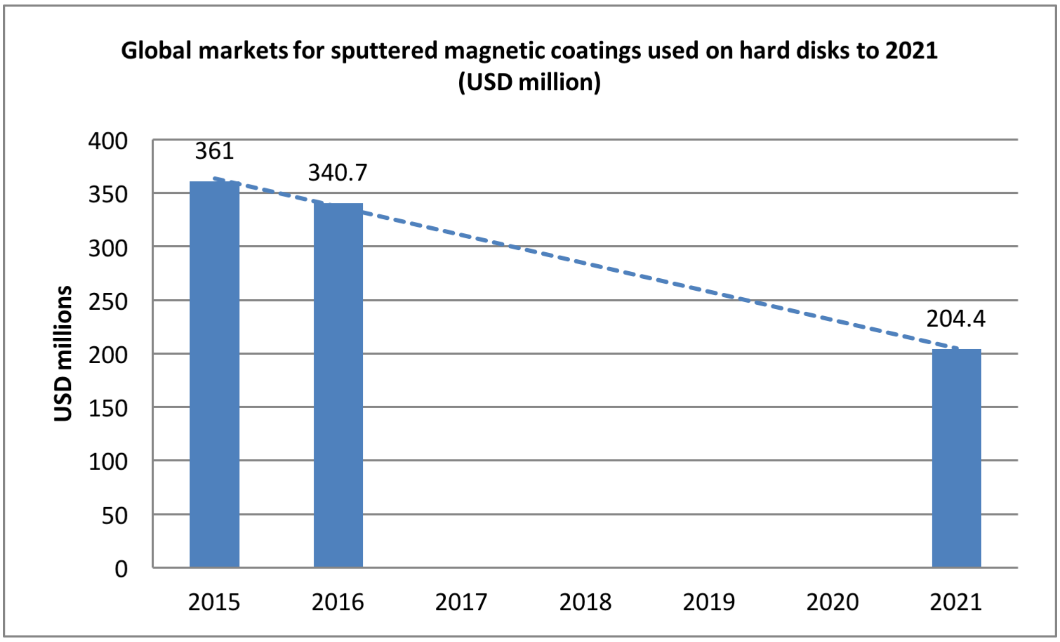

Figure A3.2. Global market for sputtered magnetic coatings used on hard discs to 2021 (USD millions)

Source: BCC Research 2016

Magnetic recording tapes

Magnetic recording media consume significant but declining amounts of alumina and iron oxide thin film materials, as shown below.

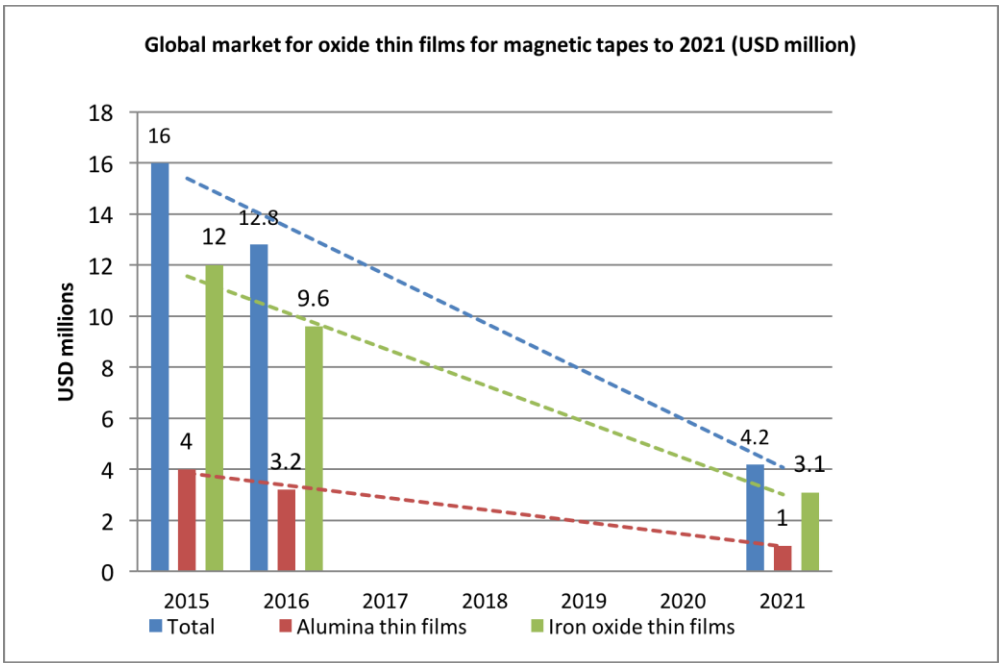

Figure A3.3. Global market for oxide thin films for magnetic tapes to 2021 (USD millions)

Source: BCC Research 2016

Optical recording media[166]

In 2015, global consumption of nanostructured aluminium film materials used in the production of optical recording media (e.g. CDs and DVDs) was about 48 metric tonnes, with a value of USD 1.6 million. In the near- to mid-term, consumption will be driven by trends in unit sales. Data on total global shipments of optical recording media are hard to obtain, but the amounts are likely to decrease as alternative storage and delivery technologies gain market share. The figures in the table below assume that shipments of optical storage media are decreasing at a CAGR of -2.8%, with a proportional reduction in consumption of nanostructured aluminium thin film materials.

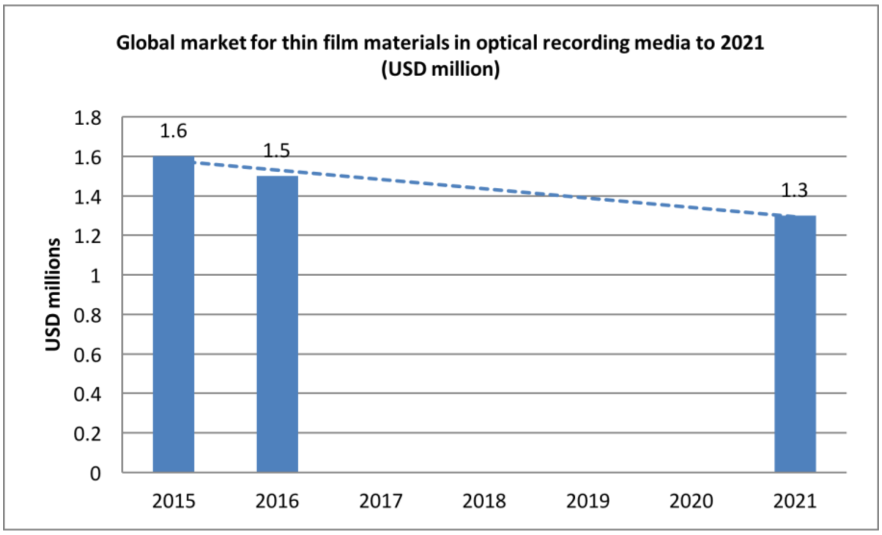

Figure A3.4. Global market for thin film materials in optical recording media to 2021 (USD millions)
Source: BCC Research 2016

Products by emerging market

[166] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.120

Holographic memory

In holographic data storage, a 'data beam' holding information is crossed with a 'reference beam' to produce an interference pattern that is recorded in a light-sensitive material. To retrieve data from a particular spot, a reference beam is shone onto it, and the combination of the reference beam and the patterned material reconstructs the original data beam, which is read and translated into a series of electrical signals. The recording material is typically either an inorganic crystal or a polymer. Polymers are more sensitive and require less powerful lasers, but they have disadvantages also, e.g. that they can deform, thereby corrupting the data[167]. Holographic memory offers the possibility of storing 1 terabyte (TB) of data in a sugar-cube-sized crystal. Data from more than 1,000 CDs could fit on a holographic memory system. Most computer hard drives only hold 10 to 40 GB of data, a small fraction of what a holographic memory system might hold[168].

Sales of nanodevices currently under development, primarily nanostructured holographic memory, are projected to reach USD 50 million by 2021[169].

Printed Electronics

Products by application market

The forecasts and market assessments concentrate on silver conductive nano-ink. The market for all types of conductive silver ink was worth USD 1.5 billion in 2015 and USD 1.6 billion in 2016, and is expected to grow to USD 2.2 billion by 2021.[170]

Conductive inks made with silver nanoparticles are a new technology, and they accounted for a relatively small share (approximately 15%) of the market for conductive silver inks in 2015 to 2016. However, by 2021, the nano-silver ink share of the conductive silver ink market is expected to increase to at least 50%. While there was no data available on the cost of the silver nanoparticles used to produce these inks, it is estimated that materials costs account for about 50% of the finished value, and that the silver nanoparticles represent about half of the total material cost on average, depending on the price of silver.[171]

[167] MIT Technology Review: Holographic Memory, September 1, 2005

[168] How Stuff Works Tech: How Holographic Memory Will Work,

[169] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.192

[170] BCC Research

[171] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.70

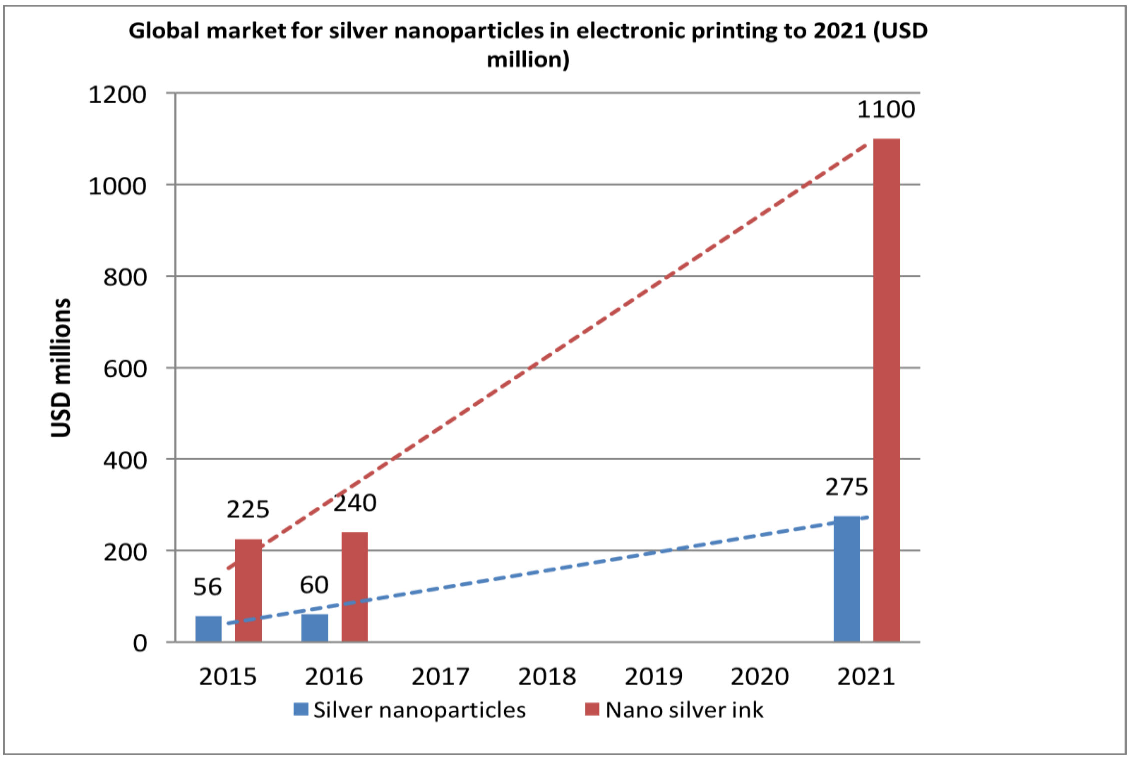

Figure A3.5. Global market for silver nanoparticles for electronic printing to 2021 (USD millions)

Source: BCC Research 2016

Products by emerging market

Graphene Printed Electronics

The conductivity of certain inks derives from the inclusion of materials such as silver, carbon or graphite. Common conductive inks have three categories (noble metals, conductive polymers, and carbon nanomaterials) and are used in electronics, sensors, antennae, touch screens, printed heaters and more. Due to its high charge carrier mobility, superlative thermal and chemical stability and intrinsic flexibility, graphene appears well-suited to a number of applications in printed electronics including chemical and thermal sensors and supercapacitors. Graphene inks often need to be specially formulated or adjusted for specific uses, needing unique substrates or processing/printing methods (rotogravure, flexo, or screen printing processes etc.)[172].

Vorbeck Materials, currently the sole commercial producer of graphene-based inks, does not publish sales data, but it has been estimated[173] that sales of graphene inks were significantly less than USD 1 million in 2015. To assess the future market potential of graphene-based electronic inks, projected sales of carbon nanotube-based inks were used as a proxy. It was estimated that sales of carbon nanotube inks could exceed USD 15 million by 2021 and that graphene inks could reach a similar level. Assuming that, as in the case of silver nanoparticle-based conductive ink (see above), materials costs account for about 50% of the finished value of the ink, and that the graphene nanoparticles represent about half of the total materials cost on average, these figures were used to develop the projections shown below[174].

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[172] http://www.graphene-info.com/graphene-inks

[173] BCC Research

[174] BCC (2016), The Maturing Nanotechnology Market: Products and Applications, p.76

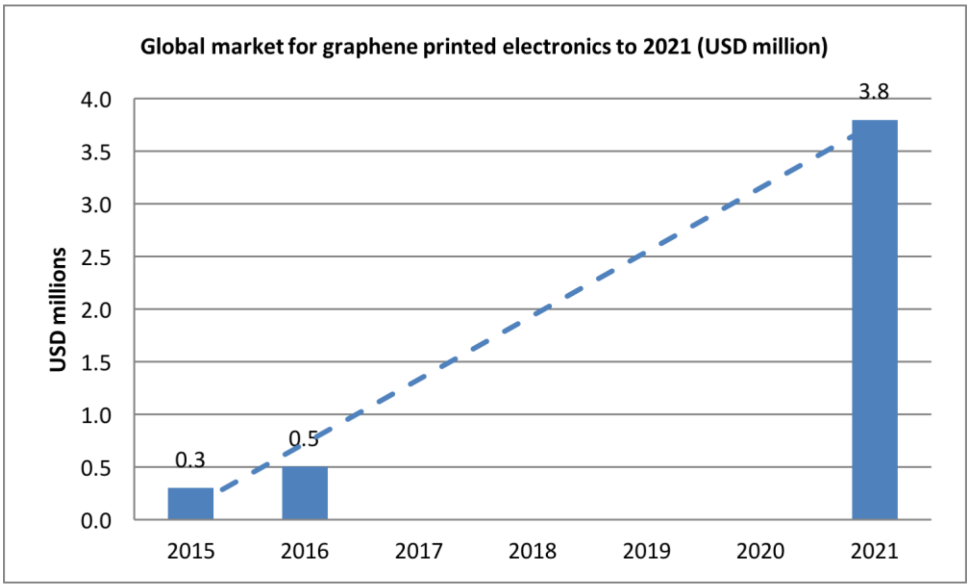

Figure A3.6. Global market for graphene printed electronics to 2021 (USD millions)

Source: BCC Research 2016

CNT Printed Electronics

Carbon nanotubes are being used in radio frequency identification (RFID) tags in nanotube RFID, an emerging technology. Currently RFID tags are made of silicon which is rather costly. Tags made of organic materials (i.e. plastics) would be significantly cheaper so researchers are developing semiconducting inks comprised of carbon nanotubes (CNTs) that can be used to print transistors. Nanotube RFID are passive tags and do not require a power source (battery), thereby giving them extended life-time. Carbon nanotube-based RFIDs are expected to replace barcodes and silicon-based RFIDs in the near future[175]. RFID tags printed using CNT ink are expected to be on the market by 2021.

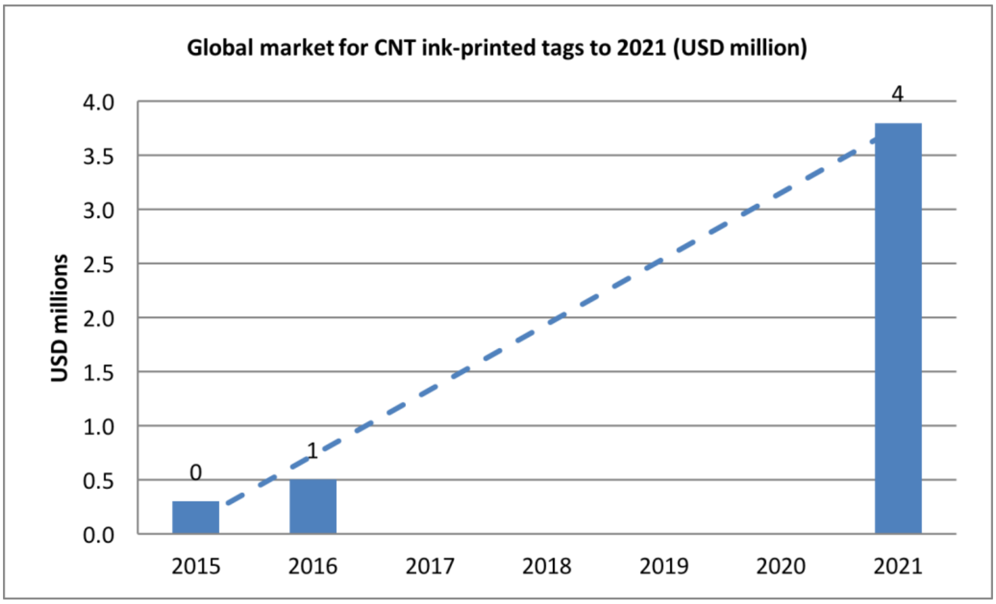

Figure A3.7. Global market for CNT ink-printed tags to 2021

Source: BCC Research 2016

According to industry sources, the global market for all types of printed RFID tags could

[175] https://www.mepits.com/tutorial/346/Latest-Technologies/Nanotube-RFID

exceed USD 3.6 billion by 2021, although it is predicted that carbon nanotube ink-printed tags will account for only 2% to 3% of this market.[176] In general, inks account for an estimated 40% of the cost of printed electronics. Applying this percentage to projected sales of carbon nanotube ink-printed tags (USD 90 million in 2021) yields the projection shown above.

Graphene Interconnects

Graphene is a viable alternative to copper interconnects in electronic circuits due to its large carrier mobility and high thermal conductivity, coupled with small material volume[177]. The market for high-performance interconnects could exceed USD 3.5 billion in 2021, with graphene interconnects capturing 0.5% of the market (the graphene materials used to fabricate the interconnects accounting for an estimated 25% of their value, or USD 4.4 million).[178]

Chemical-mechanical polishing compounds (CMP compounds)

Chemical mechanical polishing (CMP) technology was first put forward by Monsanto in 1965 as a step in semiconductor device fabrication, in wafer polishing for dynamic memory, microprocessor applications and glass mechanical polishing. As a new nanotechnology fabrication process, it is widely used in the semiconductor industry to produce mirror-like surfaces with no measurable sub-surface[179].

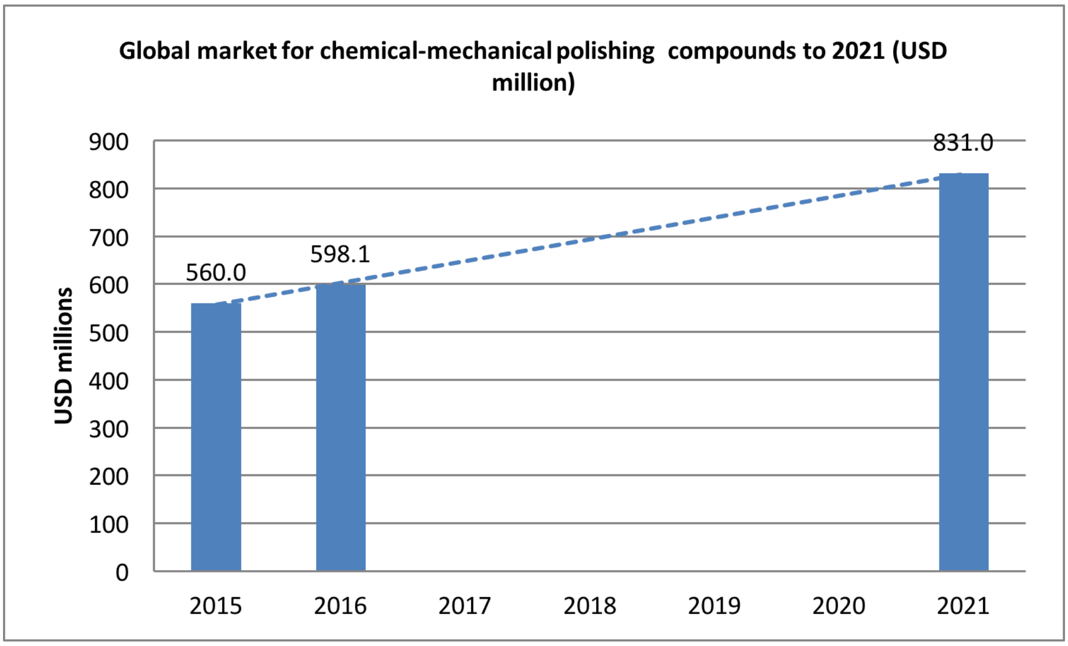

Figure A3.8. Global market for chemical-mechanical polishing (CMP) compounds to 2021 (USD millions)

Source: BCC Research 2016

Global consumption in 2015 of silica and alumina nanoparticles used in CMP compounds was about 36,650 metric tons, with a value of USD 556 million. (Silica accounted for about 87% of this figure.) CMP nanoparticle consumption should reach USD 598.1 million in 2016 and USD 831 million by 2021, for a CAGR of 2.1% from 2016 through 2021.[180]

Electrostatic discharge protection and prevention (ESD)

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[176] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.76

[177] http://www.graphenea.com/blogs/graphene-news/14869129-graphene-for-interconnects

[178] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.76

[179] Sivanandini M (2013), Chemical Mechanical Polishing by colloidal silicon slurry, International Journal of Engineering Research and Applications, Vol. 3, Issue 3, May-Jun 2013: 1337

[180] BCC Research, (2016), The Maturing Nanotechnology Market: Products and Applications, p.54

Carbon-based static dissipative plastics have been widely used in the electronics industry for electrostatic discharge protection and prevention. Carbon nanotube plastic, a new material, has many superior properties for the electronics industry[181]. Examples of equipment made with nanotube-filled plastics include ESD shipping trays, wafer cassette holders, removable media cartridges, clean room equipment, front opening unified pods (FOUPs) and, standard mechanical interface (SMIF) pods[182].

In 2015, global consumption of polycarbonate/carbon nanotube compounds, most of which are used to make ESD electronics products and clean room equipment, was USD 15.5 million. It is estimated that the market should reach USD 16.9 million in 2016 and USD 25 million in 2021, a CAGR of 8.1% between 2016 and 2021.[183] [184]

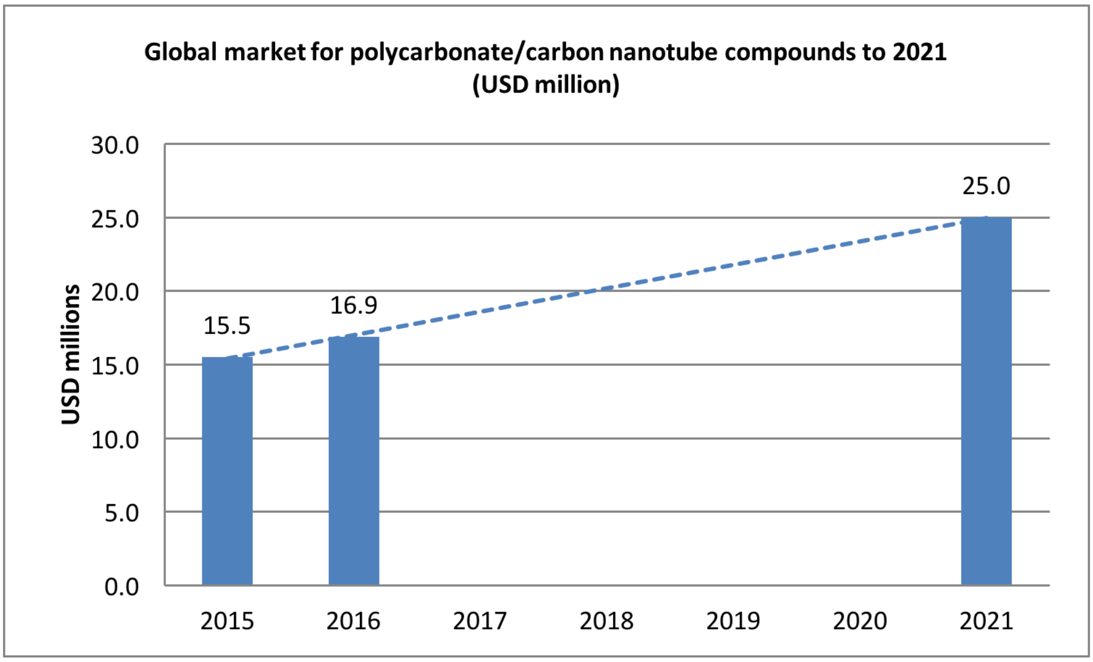

Figure A3.9. Global market for polycarbonate/carbon nanotube compounds to 2021 (USD million)

Source: BCC Research 2016

Low-k dielectric coatings

In 2015, global consumption of low-k nanofilm materials was about 15 metric tonnes with a value of USD 1.3 billion. Polymeric materials, notably Dow's SiLK resins, dominate the market but their market share is expected to decline with the emergence of other low-k materials, especially inorganics.

The market for low-k dielectric materials is projected to grow rapidly as the semiconductor industry increasingly moves into the nanometre range. Low-k dielectric applications are also expected to expand outside leading-edge semiconductors into other applications such as memory and logic devices. While the likely impact of these trends on future consumption of low-k dielectrics is hard to predict, it has been estimated that the total market for low-k dielectric films by 2021 is likely to be at least 300 tonnes, or about USD 7.5 billion[185].

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[181] Zhang Y, et al. (2008), Carbon nanotube plastic-packaging material for class 0 device ESD protection -Real life electrical performance comparison for carbon-filled plastics, Electrical Overstress/Electrostatic Discharge Symposium, 2008

[182] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.85

[183] BCC Research NAN021G Global Markets for Nanocomposites: Nanoparticles, Nanoclays, and Nanotubes

[184] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.167

[185] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.125

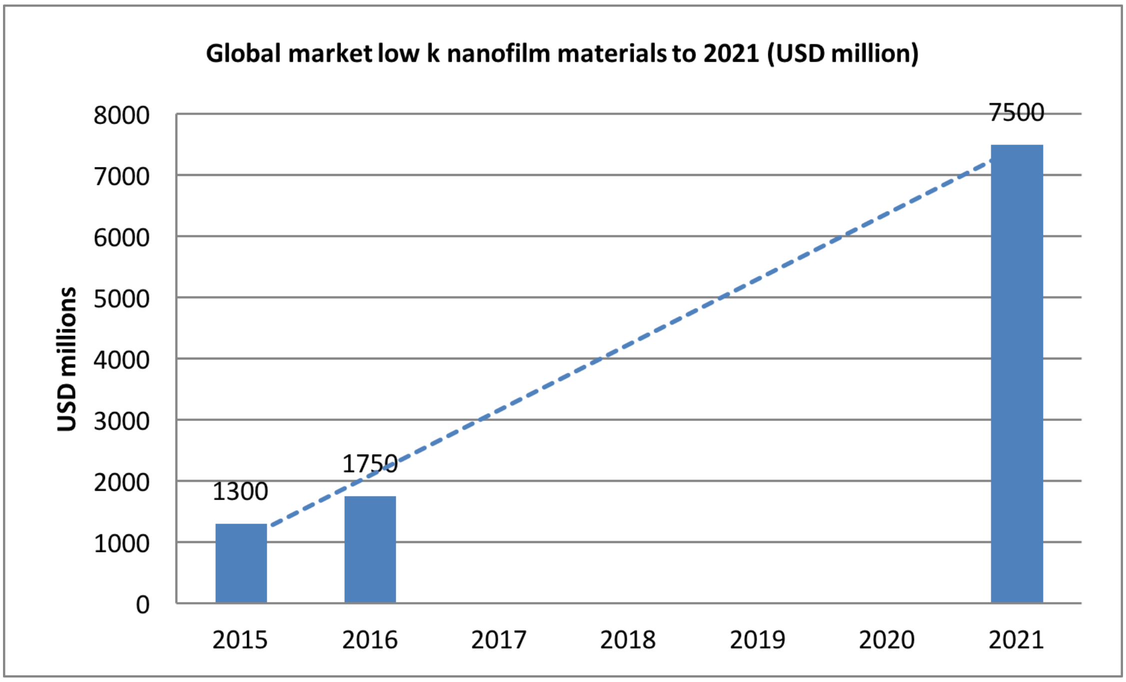

Figure A3.10. Global market for low-k nanofilm materials to 2021 (USD millions)

Source: BCC Research 2016

Electro-conductive coatings

Electroconductive coatings are used to protect a variety of products and devices from static charge build-up that can result in unwanted static discharge (sparking), the accumulation of dirt, and other problems. Metal and conductive oxide nanoparticles are in commercial use or under development for a number of electroconductive coating applications including CRT screens and photographic films, and electronic device packaging and parts[186].

The market for nanoscale electroconductive coatings has been estimated at USD 35 million in 2015, with a predicted compound annual growth rate (CAGR) of 8.4% between 2016 and 2021, reaching USD 56.8 million by 2021[187].

[186] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.66

[187] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.126

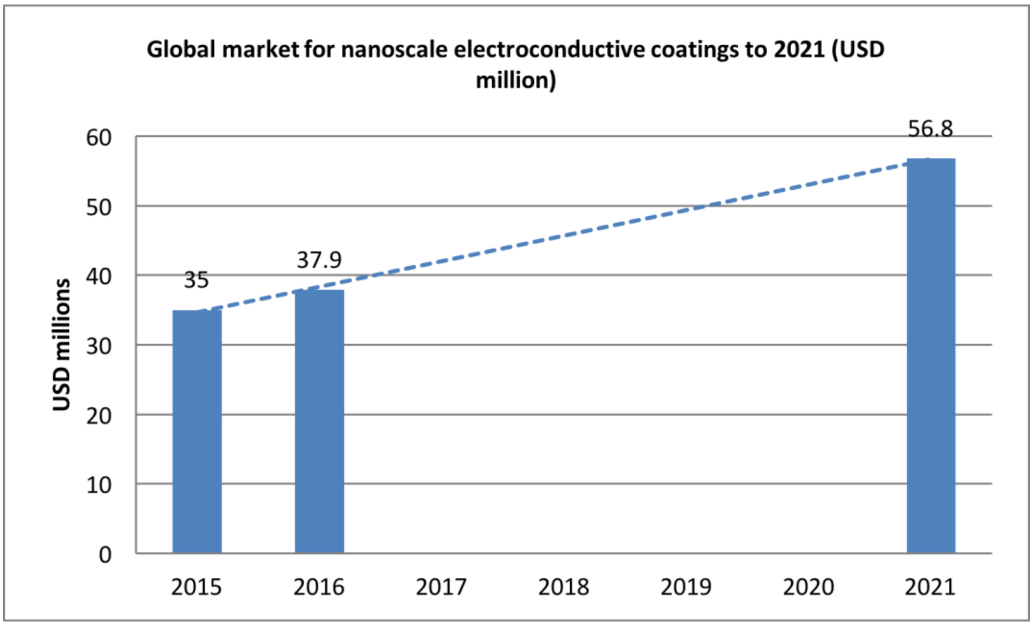

Figure A3.11. Global market for nanoscale electroconductive coatings to 2021 (USD millions)

Source: BCC Research 2016

Electronic shielding (POSS)

Polyhedral oligomeric silsesquioxane (POSS) nanocomposites have a very low dielectric constant (the electric polarisability of the material) making them good electrical insulators, i.e. electric shields.

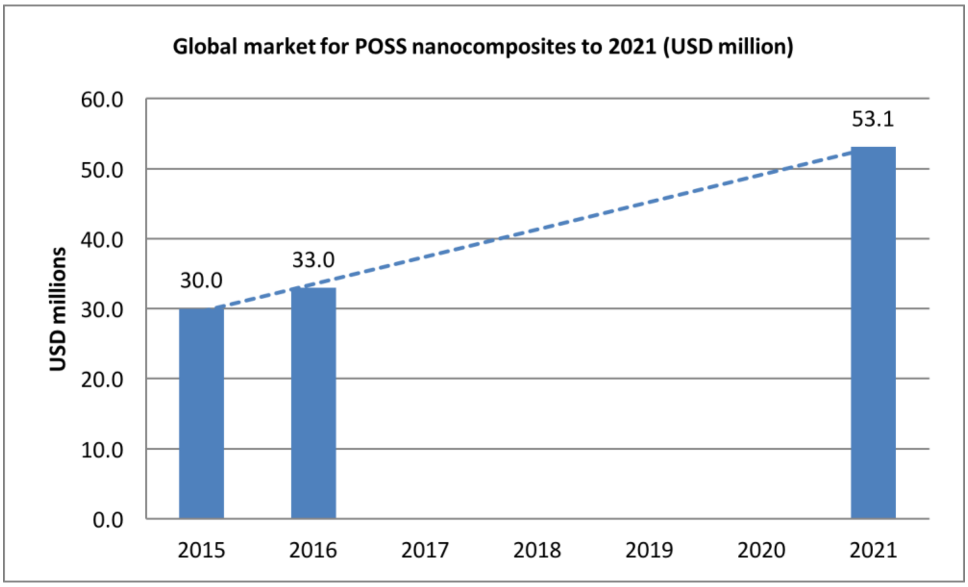

Figure A3.12. Global market for POSS nanocomposites to 2021 (USD million)

Source: BCC Research 2016

Hybrid Plastics (Hattiesburg, US) has found that its POSS-based NeuShield plastic chip caps are among their most marketable products. The caps fit over a computer chip to reduce the effects of neutron-induced memory damage, e.g. in X-ray equipment used for treating tumours. The cost of the caps is only a fraction of the cost of competitor products. Hybrid Plastics has introduced several other POSS-based electronics products to the market. These products include Short-Stop conformal coating with tin whisker suppressant and MA0735 cage mixture for ultra-low-k materials. [188]

Based on sales data for Hybrid Plastics Inc. (the main supplier of POSS nanocomposites for US aerospace, defence and medical applications) and the limited amount known about POSS sales by competing suppliers, the total global market for POSS nanocomposites has been estimated at USD 30 million in 2015, increasing at a CAGR from 2016 to 2021 of around 10%. [189]

Components

Products by application market

Multilayer Ceramic Capacitors

Multilayer ceramic capacitors, or MLCCs, are important for electronics being approximately 30% of the components in a typical hybrid circuit module. Multilayer capacitors consist of a monolithic ceramic block with comb-like sintered electrodes. These electrodes come to the surface at the ends of the ceramic block where an electrical contact is made by burnt-in metallic layers[190].

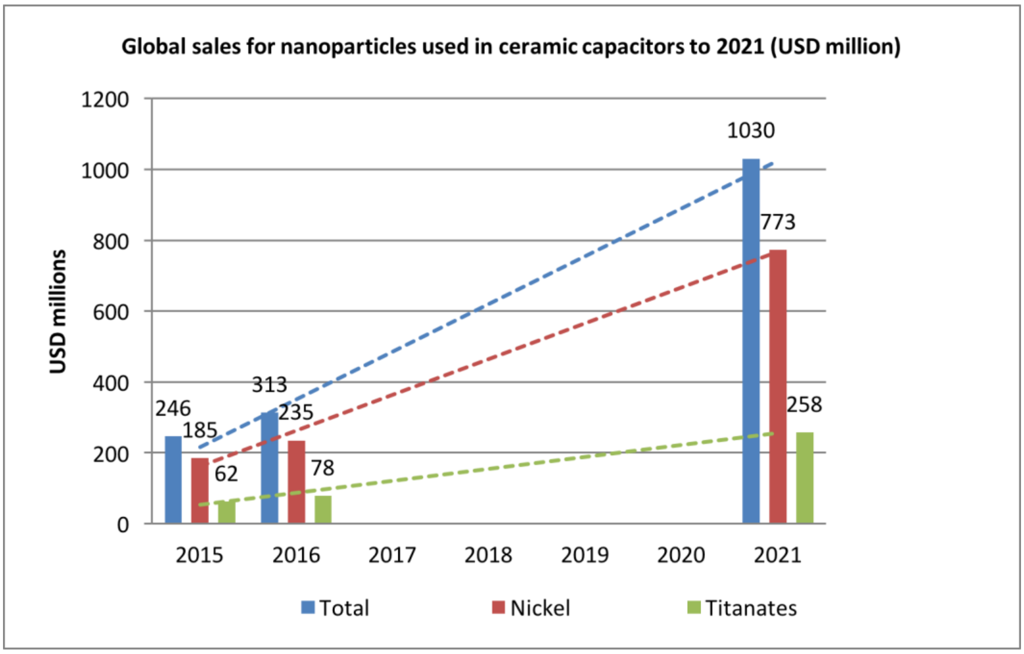

Figure A3. 13. Global market for nanocomposites used in ceramic capacitors to 2021 (USD million)

Source: BCC Research 2016

Nanoscale barium titanate or strontium titanate powders are typically used to form dielectric ceramic layers, with noble metals, such as platinum or silver-palladium, traditionally used in the internal electrode layers of MLCCs. More recently, nickel and other base metal powders are being substituted for these expensive and rare noble metal powders, the dielectric powder being mixed with a binder and solvent to obtain slurry that is cast into a rectangular ceramic green sheet. The conductive metal paste is then screen-printed onto the sheet. Sheets are interspersed with conductive paste layers and fired to make the multilayer ceramic capacitor[191].

Global MLCC output was about 2.2 trillion units in 2015 and it has been estimated that

[188] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.87

[189] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.168

[190] Future Electronics: What is a ceramic capacitor

[191] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.37

5% of those MLCCs (i.e., 110 billion units) were made using nanoscale powders, the material costs being estimated as 28% of the selling price (at USD 0.01 per unit, an average materials cost of USD 0.0028 per MLCC). The total materials cost of the MLCCs fabricated using nanoparticulate materials in 2015 was thus USD 308 million (i.e., 110 billion times USD 0.0028). Ceramic dielectric materials account for around 20% of the cost of a typical high-capacitance MLCC, and nickel electrode powder an additional 60%. Applying these percentages to the material costs of USD 308 million yields the estimate (total USD 246 million in 2015) shown in the figure.[192]

Global consumption of MLCCs has increased at a CAGR of 12.9% since 2004. The projections above assume that MLCC consumption continues to grow at a CAGR of 12.9%, reaching nearly 3.6 trillion units by 2021. The projections further assume that 10% (460 billion) of the MLCCs produced in 2021 incorporate titanate and nickel nanoparticles[193].

Electrical and Electronic Devices

Magnetic nanocomposites are bulk materials which consist of magnetic nanocrystals that are embedded in an amorphous, usually magnetically-soft phase (matrix). There is growing interest in this class of magnetic materials for existing and potential applications of such nanocomposites[194].

Nano-magnetic composites used in low-loss transformers and other electrical and electronic devices had an estimated value of USD 200 million in 2015 and the overall market for nanomagnetic materials is forecast to grow at a CAGR of 11.9% between 2016 and 2021. Applying this growth rate to 2015 consumption of nanomagnetic composites and assuming it continues through 2021 yields the projections shown in the following figure. [195] [196]

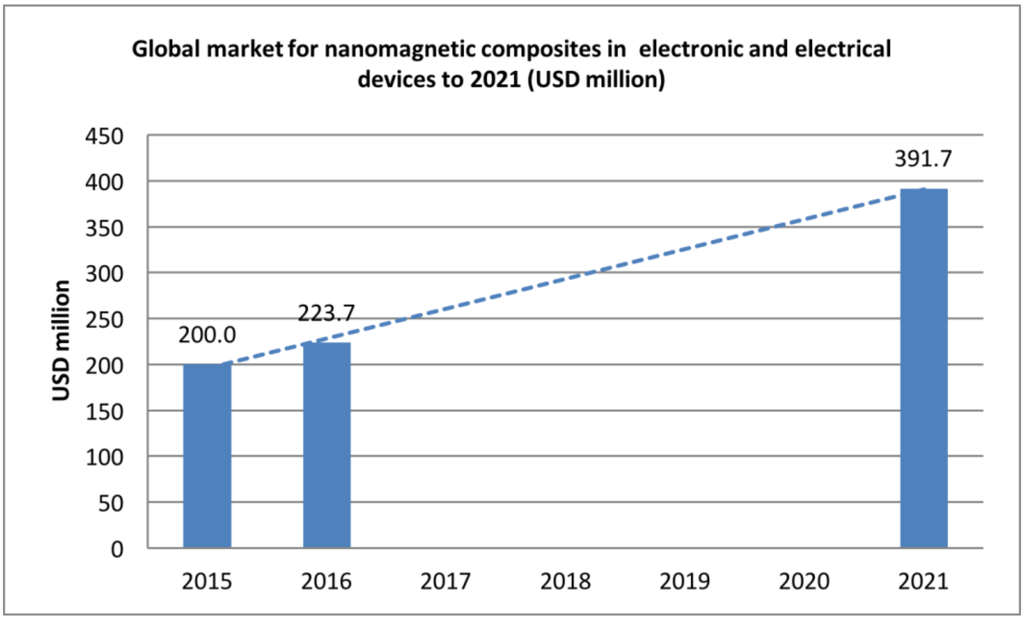

Figure A3.14. Global market for nanomagnetic composites in electronic and electrical devices to 2021 (USD million)

Source: BCC Research 2016

[192] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.70

[193] Ibid

[194] Erokhin S, et al. (2011), Magnetic nanocomposites: new methodology for micromagnetic modeling and SANS experiments, Cornell University, Working paper, p.1

[195] BCC Research, NAN033A Nanomagnetics: Materials, Devices and Markets

[196] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.167

Products by emerging market

Photonic Add/Drop Filters

Starting with a collection of signals propagating down a waveguide (called the bus waveguide), a channel-drop filter picks out one small wavelength range (channel) and reroutes (drops) it into another waveguide (called the drop waveguide)[197]. Channel-drop filters are important for optical communications and other applications.

The forecast is for sales of all types of optical add/drop filters to approach USD 1.6 billion by 2021[198]. If a commercial project can be brought to the market in the next few years, they could capture 10% of the total market by 2021, for total sales of USD 160 million, making a value of USD 53 million in 2021, material costs being about one-third of the total value in these types of electronics[199].

Optical Switches

Optical switches (all-optical fibre-optic switching devices) maintain the signal in the form of light from input to output, traditional switches for optical fibre lines being electro-optic (converting light (photons) from the input side to electrons internally in order to do the switching and converting the electrons back to photons on the output side). Optical switches support all transmission speeds and unlike electronic switches which have specific data rates and protocols, optical switches direct the incoming bitstream to the output port no matter what the line speed or protocol (IP, ATM, SONET) and do not have to be upgraded to deal with any changes. Optical switches can also separate signals at different wavelengths and direct them to different ports[200].

Quantum dots (nano-sized semiconductor particles) can help to improve the performance of all-optical switches by allowing for higher switching, although no quantum dot optical switches are yet on the market and it is uncertain when they will be. Given their advantages over competing technologies, through concerted efforts quantum dot switches could reach the market before 2021. Optical switches are forecast to achieve a market value of over USD 1.3 billion by 2021, of which quantum dot switches have been forecast to potentially capture 2% to 5% (USD 26 million to USD 65 million, or a mean of USD 45.5 million) by 2021. Again using the estimate that material costs represent nearly one-third of the total cost of such devices, the market for PBG nanocomposites in optical switches could reach USD 15 million by 2021. [201]

Optical Amplifiers (Op Amps)

To be able to transmit signals in optical communication systems over long distances (>100 km) attenuation losses within the fibre must be compensated, conventionally using an optoelectronic module consisting of an optical receiver, a regeneration and equalisation system, and an optical transmitter, a system limited by the optical-electrical and electrical-optical conversions. Optical amplifiers have been developed to overcome these drawbacks, the two types most commonly in use being semiconductor optical amplifiers (SOA) and rare earth-doped fibre amplifiers (erbium – EDFA 1500 nm, praseodymium – PDFA 1300 nm)[202].

Optical amplifiers using quantum dots offer an ultrawide operating wavelength range, suppressed waveform distortion in high power output, and capability of noise reduction (signal regeneration) by limiting amplification.[203]. While nanoparticle-based optical

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[197] http://ab-initio.mit.edu/photons/ch-drop.html

[198] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications

[199] Ibid

[200] http://www.pcmag.com/encyclopedia/term/48554/optical-switch

[201] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.172

[202] Kostuk R (2006), Optical Amplifiers, mimeo

[203] Akiyama T, et al. (2006), Quantum-Dot Semiconductor Optical Amplifiers, IEEE LEOS - Lasers & Electro-Optics Society Newsletter, February 2006 Volume 20, Number 1, p.11

amplifiers were not yet commercially available in 2016, it has been forecast that global sales of all types of optical amplifiers will reach USD 3 billion by 2021, and that quantum dot PBG nanocomposite devices could capture 10% of this market, or USD 300 million in total sales, by 2021. With the estimate that material costs represent nearly one-third of the total cost of such devices, the consumption of quantum dot PBG nanocomposites is projected to reach USD 100 million by 2021[204].

Digital Image Sensors

Digital image sensors are used to record electronic images and are, for example, used in digital cameras to record images (in conjunction with a colour separation device and signal processing circuitry). The two main technologies used to fabricate digital image sensors are CCD (charge coupled device) and CMOS (complementary metal-oxide semiconductor) technologies[205].

InVisage Technologies is targeting high-end mobile phone handsets with their QuantumFilm image sensors. Using Philips' Luxeon LED flashlight for mobile phones as a benchmark, it is estimated that 100 million QuantumFilm sensor-equipped handsets will be sold in 2021. Like QuantumFilm sensors, the Luxeon flash is targeted at smartphones and other high-end mobile phone handsets, to produce brighter, clearer images. QuantumFilm sensors are expected to cost the same as the CMOS sensors they replace (about USD 5 each) giving a total market of USD 500 million in 2021. The exact cost of the quantum dot film in a QuantumFilm sensor is not known, but according to InVisage, the incremental cost is minimal. For analytical purposes, if the quantum dot film adds 5% to the cost of the sensor, about USD 25 million worth of quantum dots will be required[206].

Transparent Electrodes/ Transparent conducting oxides

Transparent conducting oxides (TCOs) are electrical conductive materials with low light absorption that are used in opto-electrical devices such as solar cells, displays, opto-electrical interfaces and circuitries. They are usually prepared using thin film technologies.[207]

To date, the industry standard in TCO is ITO, or tin-doped indium-oxide. Currently used in touch screens, LCD displays, solar cells, OLEDs and other electronic devices, the annual consumption of ITO is approximately USD 1 billion for the material alone (i.e., excluding deposition costs). Two nanomaterial-based thin film technologies are candidates to replace indium tin oxide (ITO): transparent carbon nanotube-based electrodes (such as the product Unidym is planning to launch in the near future) and graphene-based electrodes. Combined sales of these two transparent electrode materials could approach USD 116.5 million by 2021.

CNT-based transparent electrodes could capture one-sixth of the market from indium tin oxide electrodes within four years of commercialisation. If CNT electrodes reach the commercial market in 2017, sales could thus reach USD 167 million by 2021. If carbon nanotubes represent about half of the cost of the electrodes (similar to the figure for FED TV displays), the related market for CNTs could be close to USD 84 million by 2021.

In 2021, the market for graphene transparent electrodes is predicted to be at least USD 66 million. This projection is based on data that assume that the graphene accounts for half of the cost of the electrodes, or USD 33 million in 2021.[208] [209]

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[204] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.173

[205] https://illumin.usc.edu/101/the-digital-image-sensor

[206] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.74

[207] Andreas Stadler (2012), Transparent Conducting Oxides — An Up-To-Date Overview. Materials 2012, 5: 661

[208] BCC Research, AVM075D Graphene: Technologies, Applications and Markets

[209] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.129-130

2 Products and Markets for Nanotechnology Manufacturing

Commercialised products for nanotechnology manufacturing: Overview

The products identified, over 370 in number, were approximately one-third nanotools and two-thirds nanomaterials.

The 98 nanotool products included:

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

Of the 277 nanomaterials identified, the largest numbers of products were solid particles, graphene and carbon nanotubes. The nanomaterials included:

- 90 solid nanoparticle products, including powders, wires, fibres, rods and dots;
- 71 graphene products;
- 47 products that are some form of carbon nanotube;
- 16 nanostructures monoliths, including aerogels and membranes;
- 26 nanocomposites; and
- 27 nanoscale thin films, including protective coatings and sputtering targets.

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

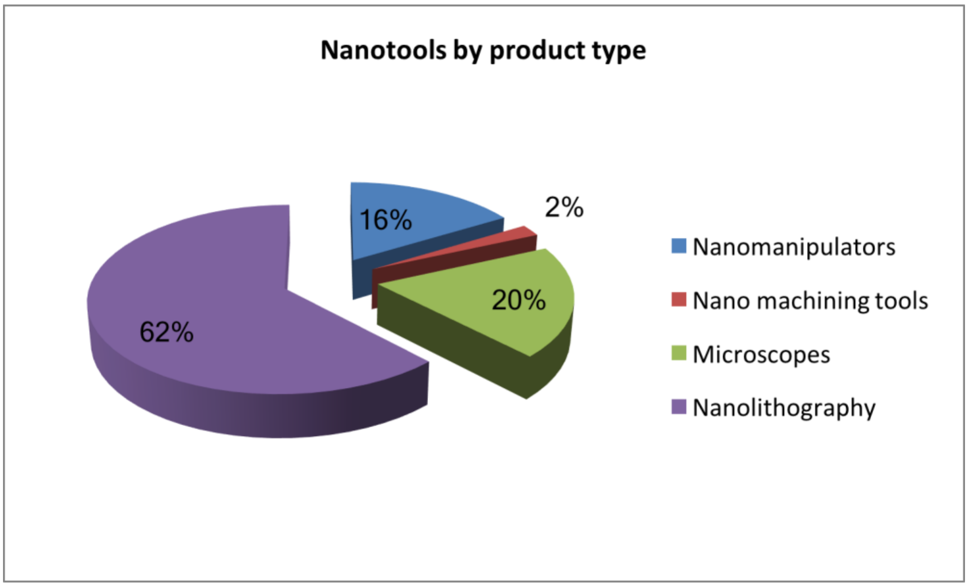

Figure A3.15. Nanotools by product type

Source: JIIP, 2017

Nanolithography accounts for the largest share (62%) of the commercially available products identified, as shown in the figure above. Further shares worth mentioning are microscopes (20%) and nano-manipulators (16%).

In terms of materials, solid nanoparticles (32%) account for the largest share of products as shown in the figure below, followed by graphene (26%), carbon nanotubes (17%), thin films (10%) and nanocomposites (9%).

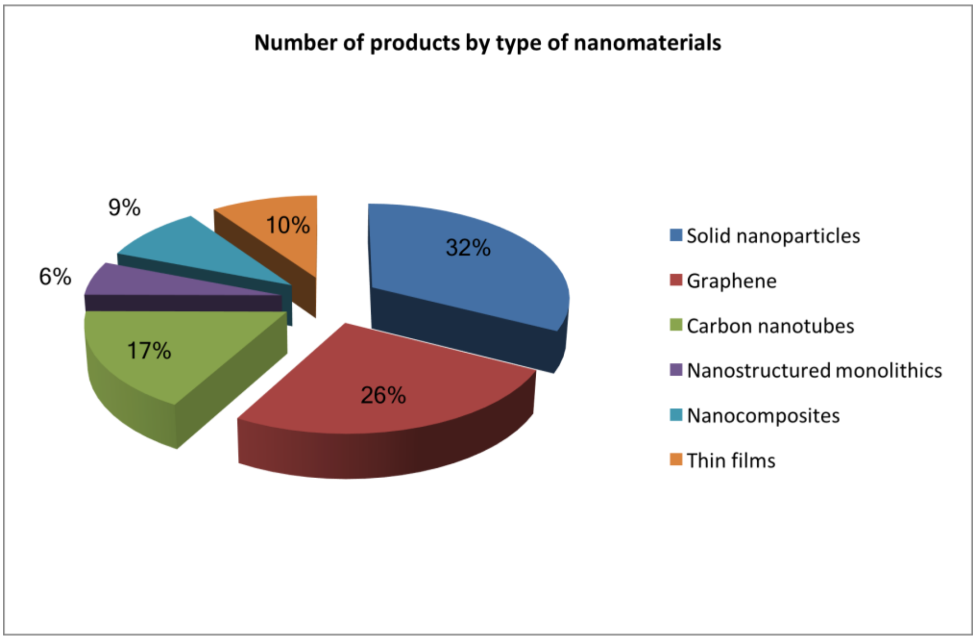

Figure A3.16. Number of products by type of nanomaterial

Source: JIIP, 2017

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

Products for nanotechnology manufacturing, by application market

Nanotools

Products by application market

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

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

Advanced optical lithography tools

Optical lithography is the patterning of masks and samples with photoresist prior to other processing steps (e.g. deposition, etching, doping)[210]. The technology has enabled the size-reduction of semiconductor devices and integrated circuits[211]. 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

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

[211] Rothschild M et al. (2003), Recent Trends in Optical Lithography, Lincoln Laboratory Journal Volume 14, Number 2, 2003: 221

creation of nanoscale patterns and structures on semiconductor chips, particularly optical immersion lithography and optical (laser) mask-less lithography[212].

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[213]. 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[214]. The only manufacturers that are currently selling immersion lithography systems are ASML, Canon, and Nikon[215].

Mask-less optical lithography is enabling the development of a competing technology. In mask-less lithography, the radiation used to expose a photosensitive material is in the form of a narrow beam[216] and no mask is needed. The beam is used to 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)[217]. 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[218].

The FP7 project MAGIC (MAsk-less lithoGraphy for integrated circuits (IC) manufacturing) 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 use of these tools in an industrial environment[219].

Mapper Lithography[220] (Delft, Netherlands) has developed a 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.

It is estimated that optical immersion tool manufacturers delivered about 100 immersion lithography tools in 2015. At a cost of about USD 45 million each, these tools represented a USD 4.5 billion market in 2015. It is expected that the delivery of new optical immersion tools will peak at 127 units (USD 5.1 billion) in 2016, and then increase slightly by 2021, as next-generation nano-lithographic technologies such as nano-imprint and extreme ultraviolet lithography begin to come online[221].

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212 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.98

213 http://www.nikon.com/about/technology/rd/core/optics/immersion_e/index.htm

214 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p. 98

215 EE Times: ASML, Canon, Nikon tip immersion tools, October 7, 2006

216 http://www.definitions.net/definition/MASKLESS%20LITHOGRAPHY

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

218 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.98

219 MAGIC Project info Sheet, FP7 ICT – Nanoelectronics

220 http://www.mapperlithography.com/

221 BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.190

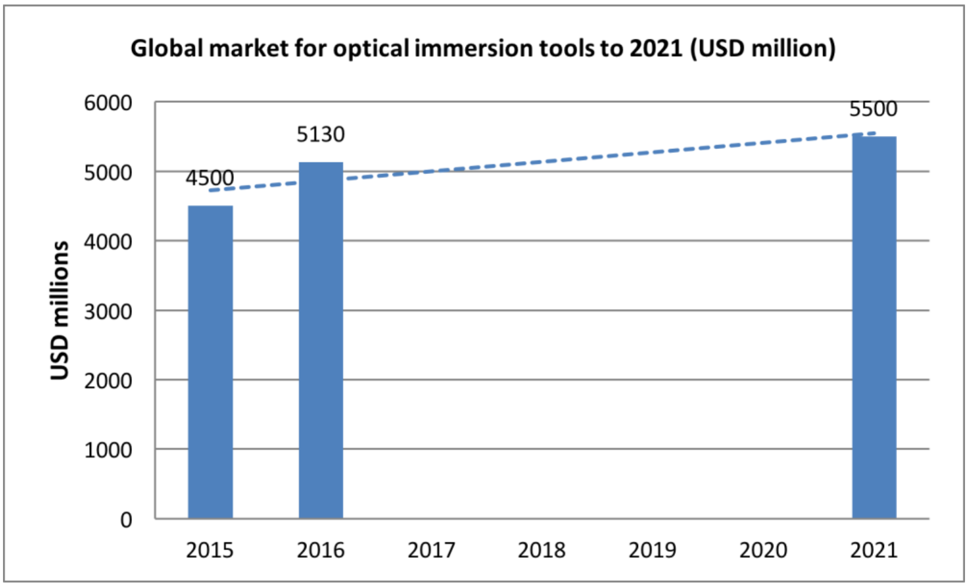

Figure A3.17. Global market for optical immersion tools

Source: BCC Research 2016

Nano-machining tools

Photomask repair technology has lagged well behind the capability requirements listed in the International Technology Roadmap for Semiconductors[222]. 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[223].

Nano-machining is an alternative option for the repair of photomasks. It is an extremely precise method of removing opaque mask defects, using an atomic force microscope (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[224].

- 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[225].

- 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[226].

Market data and forecasts227 indicate that sales of nanomachining systems by

[222] http://www.itrs.net/

[223] Brinkley D, et al. (200?), Investigation of Nanomachining as a Technique for Geometry Reconstruction, mimeo

[224] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.185

[225] Ibid

[226] http://www.eng.nus.edu.sg/EResnews/0302/hl/highlight.html

[227] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.184

companies such as Rave LLC and Tokyo instruments could not be quantified, but it has been estimated that the total market was worth USD 24 million in 2015. The global photomask market is projected to grow at a CAGR of around 2.2% through 2021. 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 4% between 2016 and 2021).

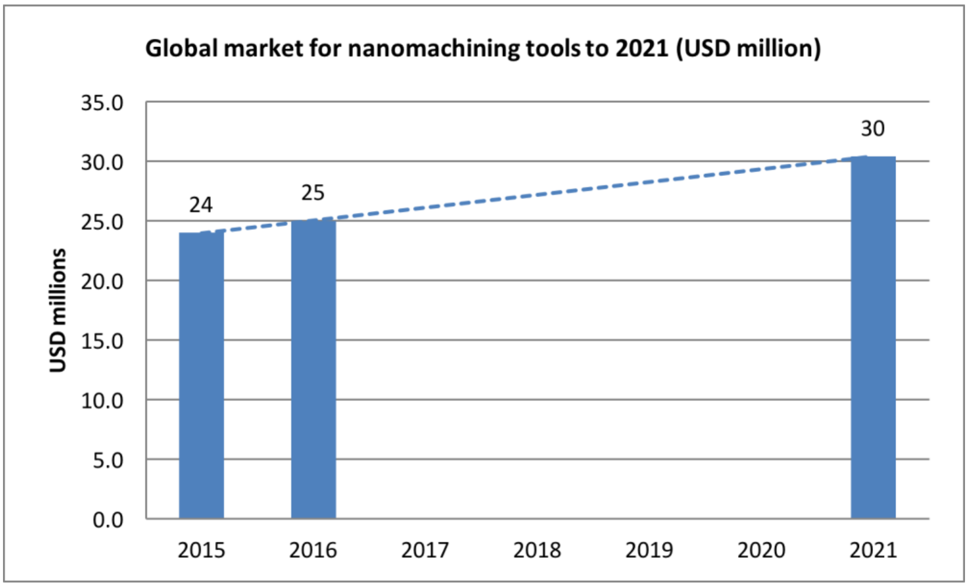

Figure A3.18. Global market for nanomachining tools to 2021 (USD million)

Source: BCC Research 2014

Nano-manipulators

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[228]. Nano-manipulators can be of either contact or non-contact type, with atomic force microscopes (AFMs) and scanning tunnel microscopes (STMs) being the most widely used[229].

Companies in this area include:

- Klocke Nanotechnik GmbH (Aachen, 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 wave produced by the same piezo tube for coarse movements[230].

- Piezosystems Jena GmbH (Jena, Germany)[231] 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

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[228] Sittin M (2001), Survey of Nanomanipulation Systems, University of California, Berkeley, mimeo. p.1

[229] Ibid

[230] http://nanomotor.de/

[231] http://www.piezosystem.de/nanopositionierung/

and SEM since 1995[232].

- 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[233].

Market data and forecasts[234] indicate that scanning probe microscopes were the main type of nano-manipulators in commercial use in 2015, with a market globally of USD 535 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 10 million in 2015.

Sales of scanning probe microscopes are projected[235] to grow at a CAGR of 11.4% from 2016 through 2021. Since most nano-manipulators are used in conjunction with STMs, they are expected to experience a similar growth rate.

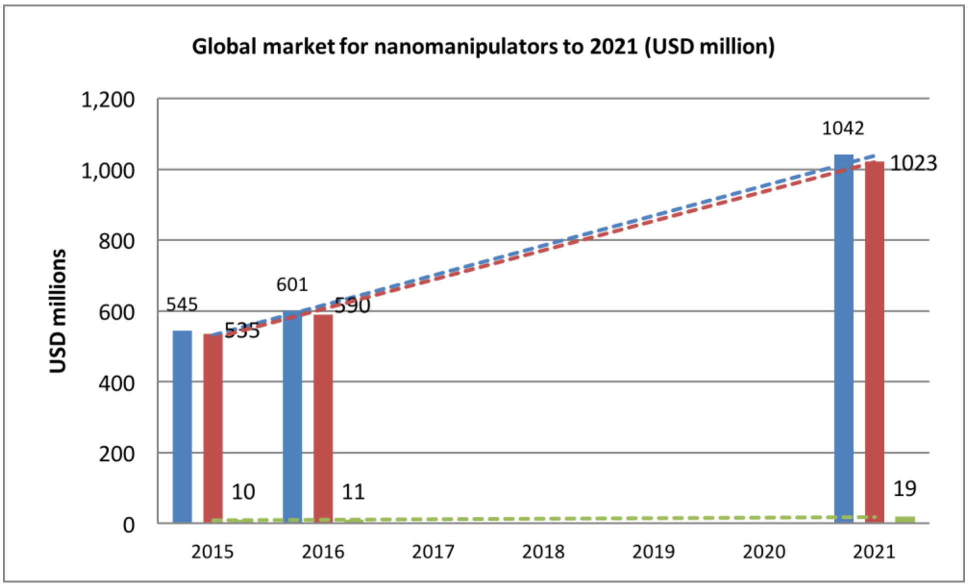

Figure A3.19. Global market for nanomanipulators to 2021 (USD million)

Source: BCC Research 2016

Near-field optical microscopes

Scanning near-field optical microscopy (SNOM), also known as near-field scanning optical microscopy (NSOM), is a scanning probe technique developed to overcome the spatial resolution constraints that traditionally limit conventional optical microscopy[236]. 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)[237] while NSOM results from the focus of the Cornell group on near-field optics.

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[232] http://www.oxford-instruments.com/products/nanomanipulation/nanomanipulator

[233] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.95

[234] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.183

[235] Microscopy: The Global Market

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

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

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 lithography, and light-activated release of caged biochemical compounds[238] [239].

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 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[240].

The market for near-field optical microscopes was worth USD 68 million in 2015. Sales of SNOMs are expected to grow at a CAGR of 5.2% 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. [241]

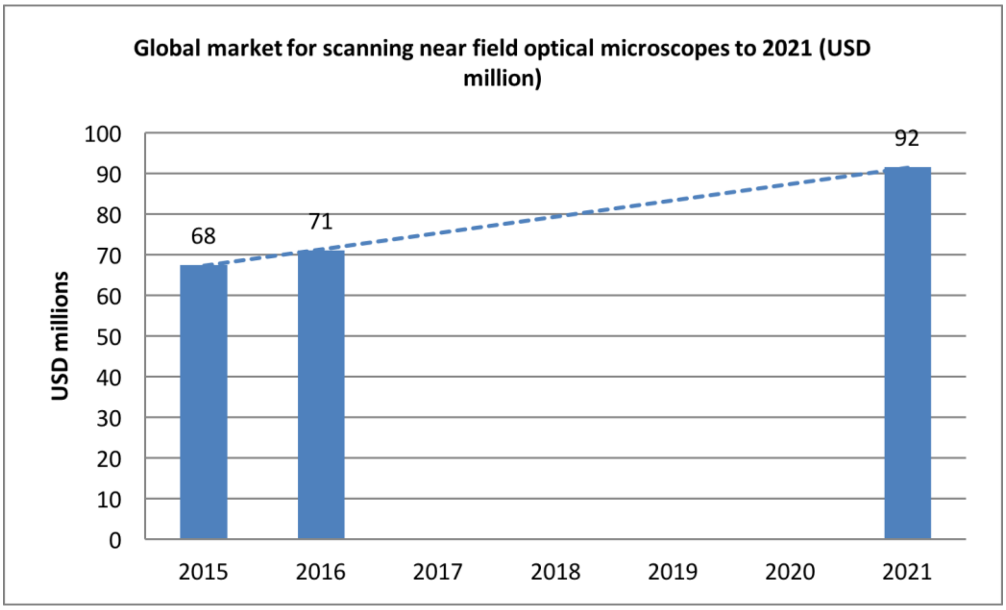

Figure A3.20. Global market for scanning near field optical microscopes to 2021 (USD million)

Source: BCC Research 2016

Products by emerging market

Next-generation nanolithographic tools

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

[239] "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

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

[241] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.184

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[242].

Extreme UV lithography (EUVL) is generally accepted as the leading candidate[243], extending optical lithography by using wavelengths in the range of 11 to 14 nm to shrink the size of features printed[244]. Repeated delays in the commercialisation of EUVL have made companies reluctant to pursue it in the short term.[245] 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 material is in the form of a narrow beam[246] and no mask is needed. The beam is used to 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)[247]. 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[248]. 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 lithography patterns from one run to the next, without incurring the cost of generating a new photomask. This may prove useful for double patterning[249].

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 principle 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[250]. Canon recently acquired the semiconductor unit of Molecular Imprints (MII), a supplier of nanoimprint tools. That group is called Canon Nanotechnologies (CNT)[251].

Applications	Global market (USD millions)	CAGR% 2016-2021

[242] Semiconductor Engineering: Waiting for Next-Generation Lithography, January 23rd, 2014

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

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

[245] 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

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

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

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

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

[250] Lan, H, Ding, Y (2010), Nanoimprint Lithography, in: Wang, M. (ed.), Lithography, pp. 656-657

[251] Semiconductor Engineering: What Happened to Next-Gen Lithography? September 3rd, 2014

	2015	2016	2021	
Extreme ultraviolet lithography	500	750	6,250	58.2
Mask-less optical lithography*	0.0	0.0	125	–
Nanoimprint lithography	50	50	50	0.0

Table A3.1. Global market for developmental nanotool applications, through 2021 (USD millions)

Source: BCC Research

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 2021. The market for these systems, including those sold for R&D purposes, was USD 550 million in 2015 and should reach USD 800 million in 2016, and more than USD 6.4 billion by 2021[252].

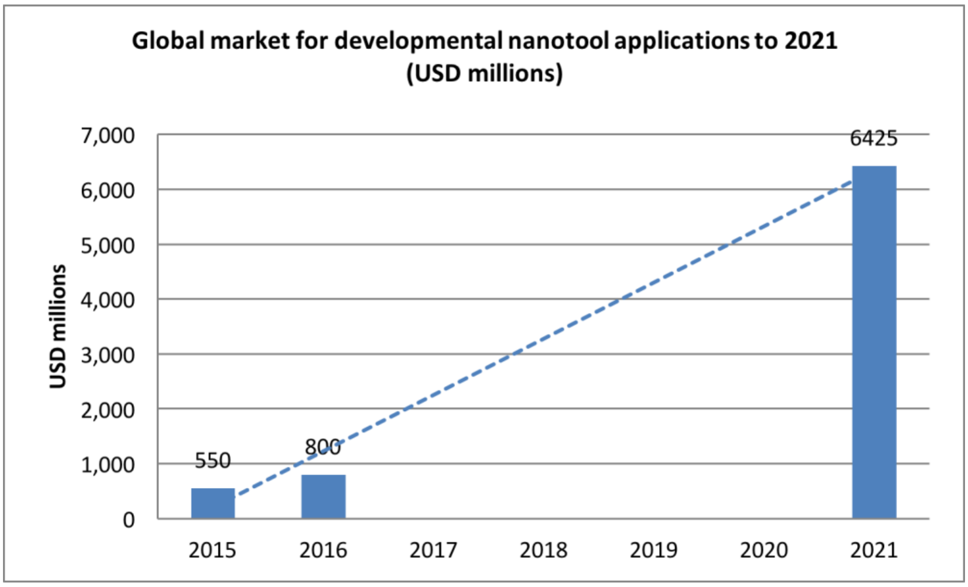

Figure A3.21. Global market for developmental nanotool applications to 2021 (USD millions)

Source: BCC Research

Nanomaterials

Products by application market

Solid nanoparticles

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[253].

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.

[252] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications p.185

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

Market data and forecasts[254] give an estimated global market for solid nanoparticles at over USD 3.2 billion in 2015, rising to over USD 3.6 billion in 2016, and forecast to approach USD 8.8 billion in 2021, a CAGR of 91.1% over five years.

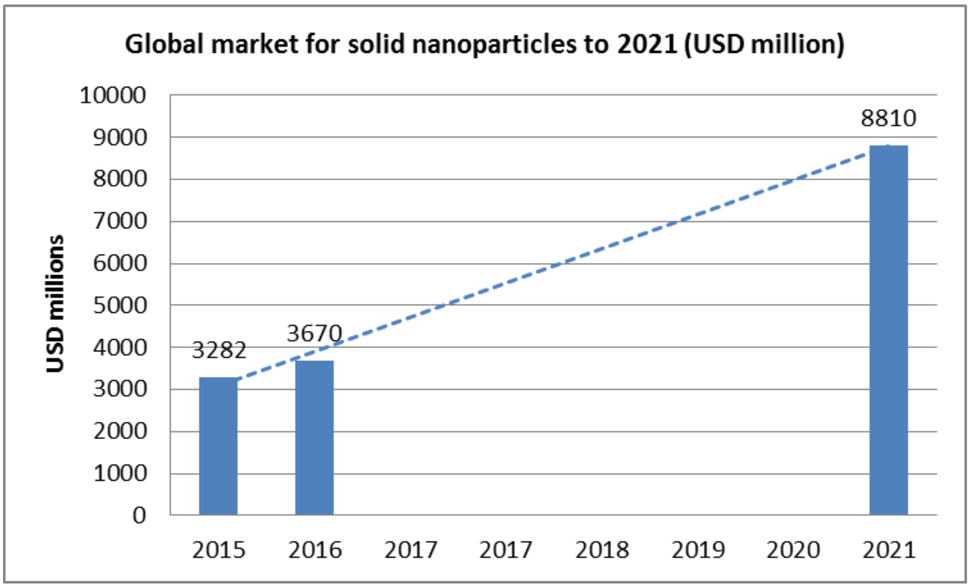

Figure A3.22. Global market for solid nanoparticles to 2021 (USD millions)

Source: BCC Research 2016

Cellulose nanoparticles

Nanocellulose is a material with a high aspect ratio made of cellulose fibres at the nanoscale. Nanocellulose comes in different forms, for instance, as crystals or fibrils, and can be manufactured via different processes and from different raw materials like wood pulp. Nanocellulose possesses some remarkable mechanical and chemical properties, for which it has gained much popularity in the past few years. For example, crystalline nanocellulose has high tensile strength and very high stiffness, comparable to that of Kevlar, the synthetic fibre commonly used in body armour. Some forms are also gas and moisture impermeable[255].

Nanocellulose crystals are a recent promising development in the area of solid nanoparticles[256]. 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 to be used in 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[257].

[254] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.51-52

[255] BCC Research (2015), Cellulose Nanoparticles: Processing, Applications and Global Markets, p.6.

[256] IPW online: Nanocellulose – On the Cusp to Commercialisation? Oct/Nov 2012

[257] Converting Quarterly: Stora Enso to build nano-tech cellulose plant in Finland, May 2011

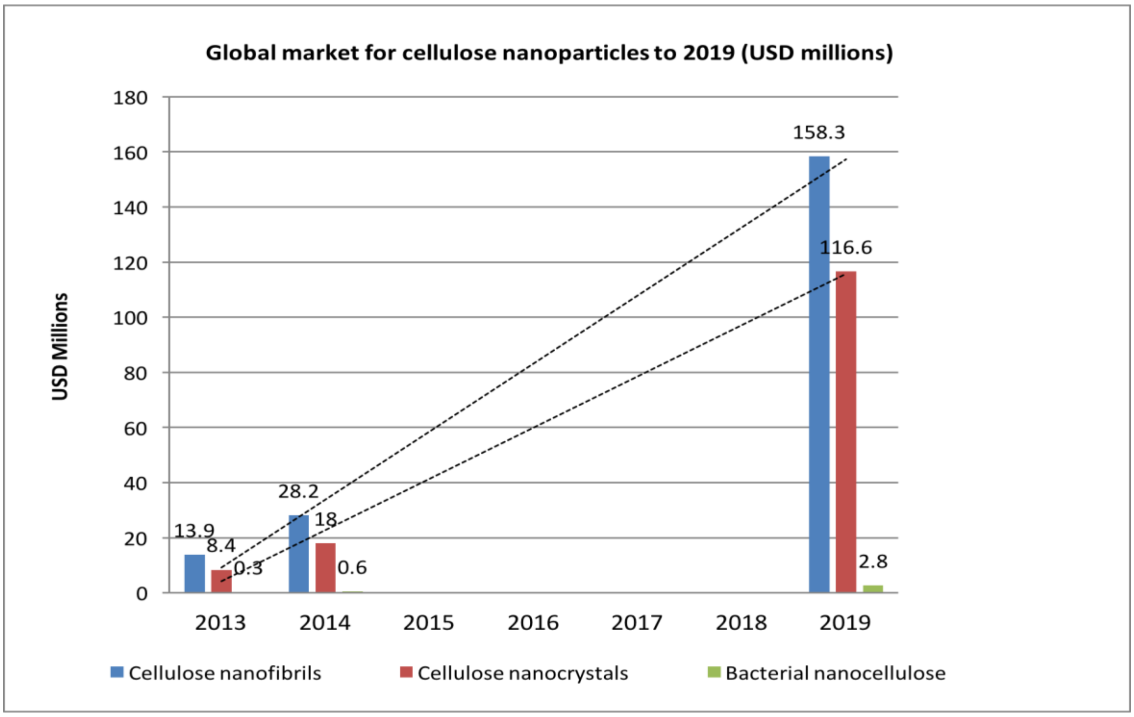

Figure A3.23. Global market for cellulose nanoparticles to 2019 (USD millions)

Source: BCC Research 2015

Nanostructured monoliths

Nanostructured monolithics are bulk solids that have macroscale external dimensions but a nanoscale internal structure e.g. nanoporous solids (e.g. fuel cell membranes), some bulk metals and alloys, and aerogels[258].

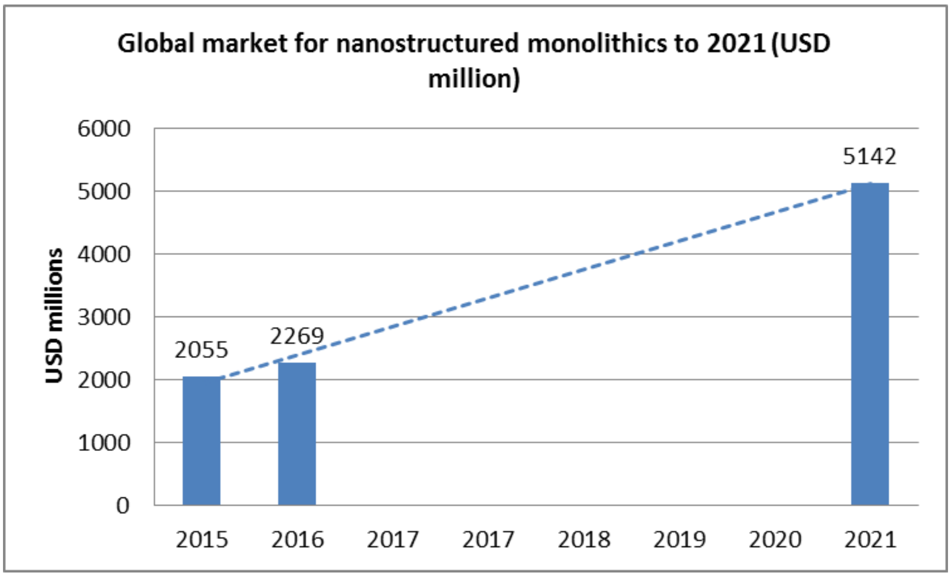

Figure A3.24. Global market for nanostructured monoliths to 2021 (USD million)

Source: BCC Research 2016

The global market for nanostructured monolithic materials was estimated to be over USD 2.05 billion in 2015 and almost USD 2.3 billion in 2016, and is forecast to grow to more

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

than USD 5 billion by 2021.[259]

Carbon nanotubes

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[260].

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.

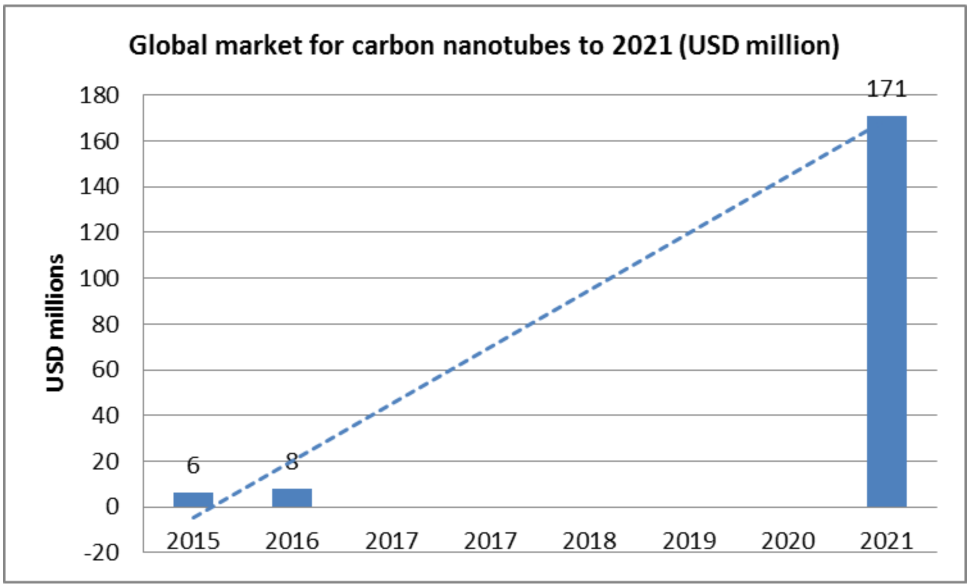

Figure A3.25. Global market for carbon nanotubes to 2021 (USD million)

Source: BCC Research 2016

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[261]. (See the NanoData Landscape compilations on ICT, photonics, energy and health.)

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[259] BCC Research (2016), Nanotechnology: A Realistic Market Assessment, p.138-139

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

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

The global market for CNT and other hollow nano particles was estimated to be USD 6.2 million in 2015 and expected to grow to over USD 171.1 million in 2021, a growth rate of over 84% (CAGR).[262]

Nanocomposites

A nanocomposite material is a solid multiphase material where at least one or more phases have dimensions of less than 100 nanometres (nm), giving it unique properties relative to conventional composite materials, e.g. including improved mechanical properties, chemical resistance, gas permeability, electrical conductivity and processing capabilities. In most nanocomposites, a nanoscale filler material (e.g. clay, carbon black, carbon nanotubes, silicon carbide or graphene) is embedded in a matrix material (e.g. polymers such as polyester, epoxy or polyamide).[263] Biodegradable and lightweight nanocomposites have specific potential in the aerospace, automotive, electronics and biotechnology industries.[264]

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[265].

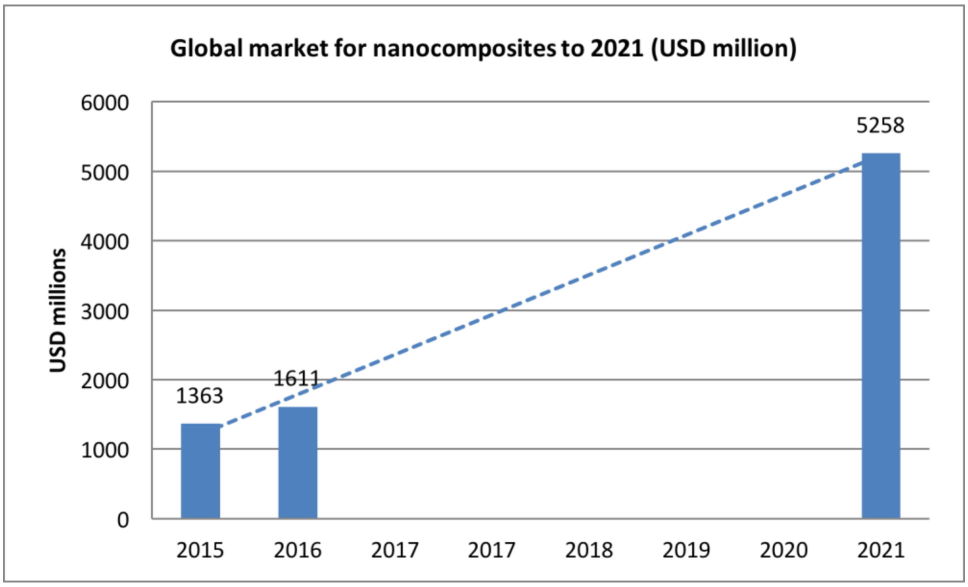

Figure A3.26. Global market for nanocomposites to 2021 (USD millions)

Source: BCC Research 2017

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,

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[262] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.89

[263] Observatory Nano (2013), Nanocomposite Materials, BRIEFING No.30

[264] 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

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

non-linear optics, battery cathodes and ionics, nanowires, sensors and other systems[266].

The global market for nanocomposites was estimated[267] to be over USD 1.3 billion in 2015 and more than USD 1.6 billion in 2016, and forecast to grow to almost USD 5.3 billion by 2021 (a CAGR of 18.9% in unit terms and 26.7% in value terms between 2016 and 2021).

Clay nanocomposites accounted for 56.2% of total nanocomposite consumption by value in 2015, followed by carbon nanotube composites (14.5%) and metal/metal oxide nanocomposites (14.7%). The market share of clay nanocomposites is expected to increase to 57.4% in 2021, while that of carbon nanotube composites is forecast to fall to 9.2% 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.

	2015	2016	2021	CAGR%
	USD millions			2016-2021
Nanobiocomposites	0	0	69.9	
Ceramic nanocomposites	83.0	90.2	463.2	38.7
Metal/metal oxide nanocomposites	200.0	224.8	815.8	12.4
Other nanocomposites	116.3	140.5	462	48.4
Carbon nanotube composites	197.6	206.1	485.7	18.7
Clay nanocomposites	766.2	949.6	3,016.6	26.0

Table A3.2. Global market and CAGR for individual types of nanocomposites to 2019

Source: BCC Research 2017

Nanobiocomposites for commercial applications were still under development in 2016. It is difficult at this point to project a date for their commercialisation, but some industry sources believe that commercialisation is possible before 2021, with "green" (i.e., biodegradable) auto parts leading the way. Flame-retardant protective clothing is another promising potential application[268]. Forecasts for markets in the US, Europe and Asia-Pacific project sales of PVOH-cellulose nanocomposites (USD 5 m) and cotton/clay nanocomposites with USD 8 m in 2021.

Nanoscale thin films

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[269].

The market for nanoscale thin films was estimated to be USD 21.8 billion in 2015 and USD 25 billion in 2016, with a forecast rise to USD 57.8 billion in 2019, a CAGR of over

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

[267] BCC Research (2017), Global Markets for Nanocomposites, Nanoparticles, Nanoclays, and Nanotubes, p.77

[268] BCC Research (2017), Global Markets for Nanocomposites, Nanoparticles, Nanoclays, and Nanotubes, p.105

[269] BCC Research (2013), Nanotechnology in Energy Applications, p.11

18.3% from 2016 through 2021. [270]

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

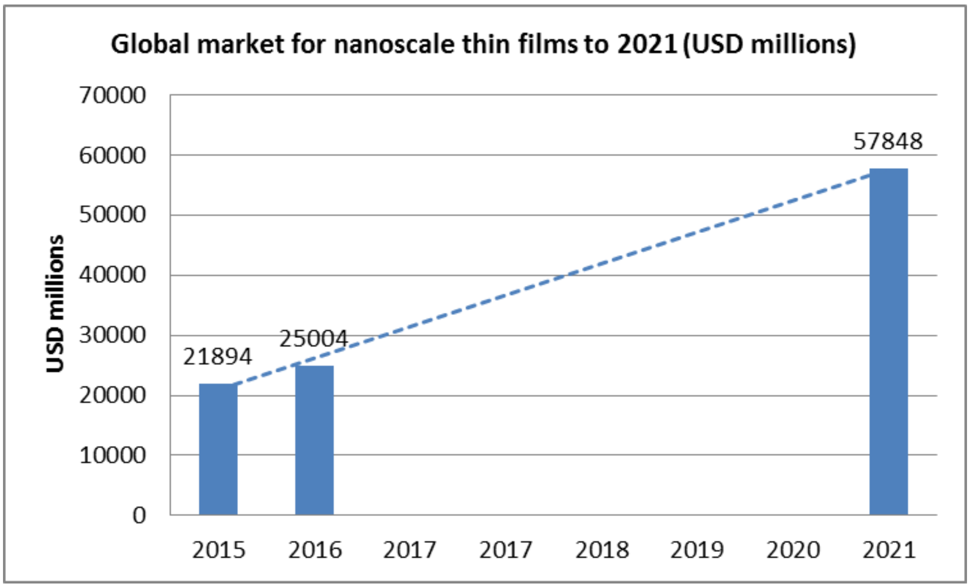

Figure A3.27. Global market for nanoscale thin films to 2021 (USD millions)

Source: BCC Research 2016

Graphene

Graphene is a single, tightly-packed layer of carbon atoms bonded together in a hexagonal honeycomb lattice. Applications of graphene are emerging, for example in composites. Dispersing a small amount of graphene in polymers, many properties of the resulting composites (such as tensile strength and elastic modulus, electrical and thermal conductivity, thermal stability, gas barrier, and flame-retardance) can be significantly improved. These properties make graphene-based polymers composites good candidates for structural materials for the automotive sector and aerospace sectors[271].

Graphene-based composites are already reaching prototype or product applications in aerospace and other aspects of transport, e.g. for protective clothing. Being strong but also light (very important in transport applications), graphene-based composites are being developed for thermal management, drag-reduction and electrical conductivity, e.g. protecting aircraft from lightning strikes. Products using graphene-based composites that are currently on the market include helmets[272] that use a graphene composite coating for better heat distribution and to protect from damage to the helmet by enabling better distribution of impact forces. They are also being developed for their mechanical and thermal properties, e.g. for propeller blades of drones. Other applications are also reaching prototype stage, e.g. the world's first graphene-skinned aircraft, a model aircraft called 'Prospero', was flown at the Farnborough International Air Show in the UK in 2016[273]. Graphene additive for resins are being used in corrosion-resistant tanks and pipes for storage and transport of potentially explosive chemicals where the electrical conductivity and mechanical strength of the graphene complements the corrosion resistance of the resin replacing the traditional metallic systems, an application that may

[270] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.114

[271] Elmarakbi, A. et al (2015), Novel Composite Materials for Automotive Applications: Concepts and Challenges for Energy-efficient and Safe Vehicles, paper presented at the 10th International Conference on Composite Science and Technology

[272] https://phys.org/news/2016-11-graphene-coated-motorcycle-helmet.html

[273] https://phys.org/news/2016-11-world-graphene-enhanced-aircraft.html

be applicable in transport applications in the future. [274]

Various graphene-filled polymer composites have been developed, including graphene-polystyrene composites. These are alternatives to carbon nanotube- and fullerene-polymer composites that have also been developed or investigated. The properties of graphene-polymer composites compare favourably with those of nanotube-polymer composites, with potential performance-related advantages over nanotubes as a filler material. Graphene-polymer composites have many of the same potential applications as carbon nanotube composites, including automotive components (e.g., fuel lines, exterior painted parts)[275].

It has been estimated that graphene-polymer nanocomposites could reach a market value of USD 94 million by 2021.[276] [277]

The next section of this annex looks at health products and markets.

[274] Several examples such as this are given on the website of the Graphene Flagship http://graphene-flagship.eu/graphene-shows-promise-for-composite-applications

[275] BCC Research (2014), Nanotechnology, a realistic market assessment, p.93-94

[276] BCC Research, AVM075D Graphene: Technologies, Applications, and Markets, the global market for these materials

[277] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.174

3 Products and Markets for Health through Nanotechnology

Commercialised products for health through nanotechnology: Overview

Etheridge et al. (2013) identified 147 confirmed and likely nanomedicine applications and products, 100 of those having reached the stage of approval for commercialisation[278]. To date in this project, 302 products have been identified that are already commercially available on the market. The biggest share of products (27%) can be found within nanopharmaceuticals (i.e. drug delivery). Biomedical markers (23%) account for the second largest share among commercially available products, as shown in the figure below.

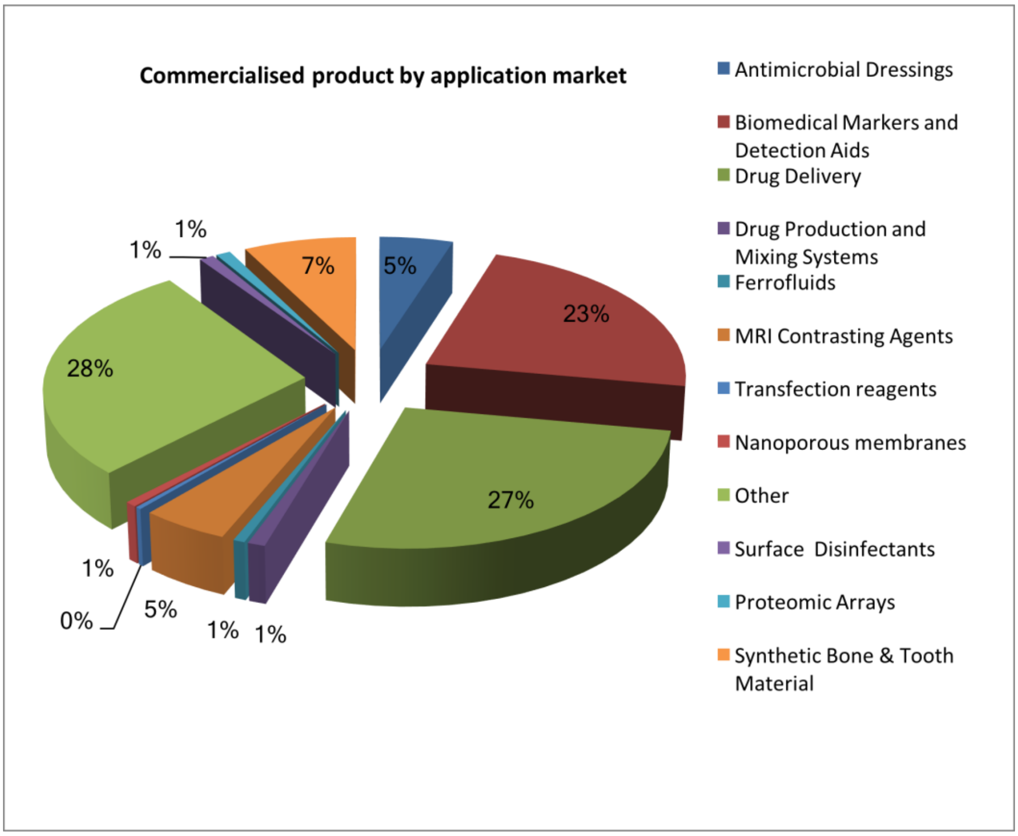

Figure A3.28. Nanotechnology products in health, by application market

Source: JIIP, 2017

Identified products distribute unevenly among the subsectors, as shown in the figure below. The largest share of products (43%) can be found in the category "Other" (OTH).

[278] Etheridge ML, et al (2014), The big picture on nanomedicine: the state of investigational and approved nanomedicine products. Nanomedicine: Nanotechnology, Biology, and Medicine 9 (2013): 5

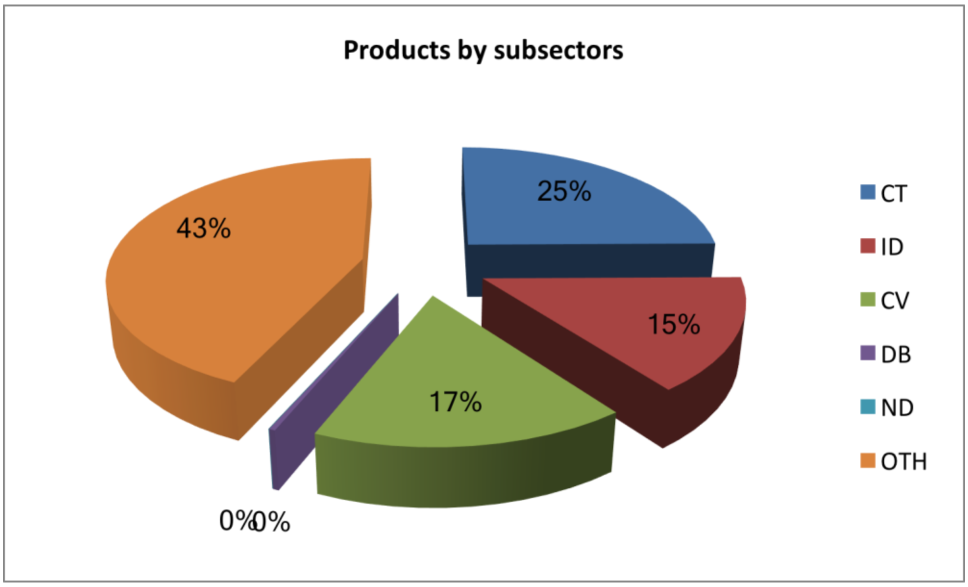

Figure A3.29. Nanotechnology products in health, by subsector

Source: JIIP, 2017

Cancer treatment (CT) is the second largest subsector (25%), in terms of products, and infectious diseases (ID) account for 15% of the identified products. No commercially available product could be identified in the subsector diabetes.

Products for health through nanotechnology, by application market

The products identified are divided as follows:

- Drug delivery vehicles;
- Biomedical markers & detection aids;
- Proteomic applications;
- MRI contrast agents;
- Antimicrobial dressings;
- Nanoporous membranes;
- Surface disinfectants;
- Synthetic bone and tooth materials;
- Transfection reagents; and
- Drug production and mixing systems.

In each case, details are given of the technology and its purpose as well as market estimates and forecasts. Existing applications and emerging applications are considered.

Drug delivery vehicles

Nanomaterials fall into a size range similar to proteins and other macromolecular structures found inside living cells. As such, nanomaterials are poised to take advantage of existing cellular machinery to facilitate the delivery of drugs. Nanoparticles (NPs) containing encapsulated, dispersed, absorbed or conjugated drugs have unique characteristics that can lead to enhanced performance in a variety of dosage forms. When formulated correctly, drug particles are resistant to settling and can have higher saturation solubility, rapid dissolution and enhanced adhesion to biological surfaces, thereby providing rapid onset of therapeutic action and improved bioavailability[279].

Many of the current nano drug delivery systems are remnants of conventional drug delivery systems that happen to be in the nanometre range, such as liposomes, polymeric micelles, nanoparticles, dendrimers, and nanocrystals. Liposomes and polymer micelles were first prepared in 1960's, and nanoparticles and dendrimers in 1970's. Colloidal gold particles in nanometre sizes were first prepared by Michael Faraday more than 150 years ago, but were not referred to as, or associated with, nanoparticles or nanotechnology until recently[280].

The total market for nanoparticle drug delivery vehicles was estimated at about USD 116 million in 2015 and more than USD 123.6 million in 2016, increasing to nearly USD 173 million by 2021 (a five-year CAGR of 7.1%)[281].

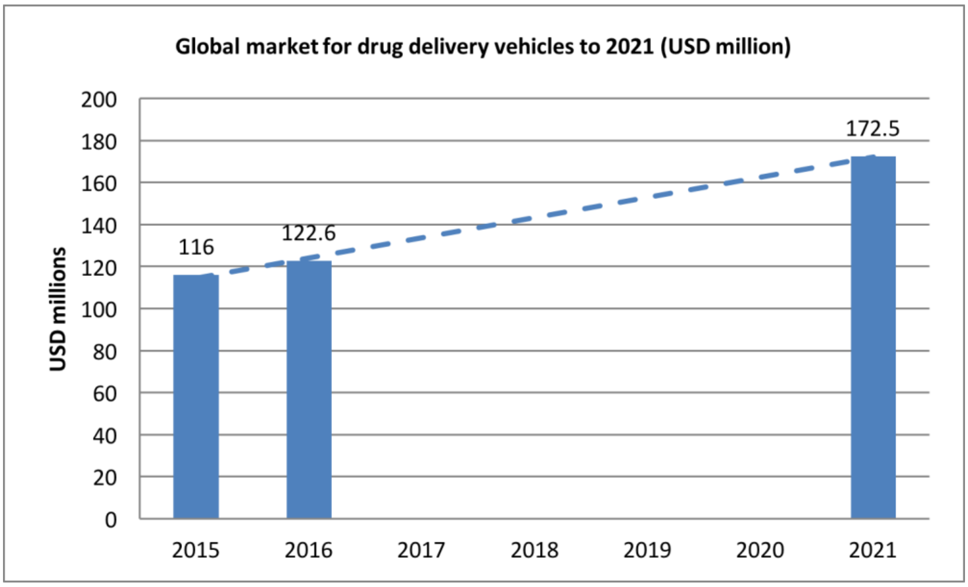

Figure A3.30. Global market for drug delivery vehicles to 2021 (USD millions)

Source: BCC Research 2016

Biomedical markers and detection aids

Nanotechnology-enabled biomedical markers and detection aids make use of modified or engineered nanoparticles to assist in the identification or visualisation of target analytes or anatomical/biological structures. Nanoparticles that are typically used for such applications comprise gold, dendrimers, quantum dots and iron oxides.

Types	Market to 2021 (USD million)			CAGR%
	2015	2016	2021	2016-2021
Colloidal gold	60.0	62.7	78.2	4.5
Quantum dots	18.0	31.9	555.0	77.0
Iron oxide	12.24	14.6	36.4	20.0

279 Bamrungsap S, et al. (2012), Nanotechnology in Therapeutics. Nanomedicine 2012;7(8): 1253

280 Park, K (2007), Nanotechnology: What it can do for drug delivery. J Control Release, 2007 July 16; 120(1-2): 1

281 BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p. 58

Dendrimers	1.7	2.2	8.2	30.1
Total	91.9	111.4	677.8	43.5

Table A3.3. Global market for nanoparticles used as biomedical markers and detection to 2021 (USD millions)

Source: BCC Research 2016

Global consumption of nanoparticles used in biomedical marker and detection applications has been estimated at about USD 91.9 million in 2015. This total includes colloidal gold, dendrimers, iron oxide and quantum dots. Each type of nanoparticle is used in different types of tests, so the market drivers and projected growth rates vary (see table above). [282]

Colloidal gold consumption for bio-labelling applications will grow at a CAGR of 4.5% over the near to mid-term. If this growth rate continues through 2021, consumption of colloidal gold will reach USD 62.7 million in 2016 and USD 78.2 million in 2021.

Estimation of sales of dendrimers in 2015 was USD 1.7 million with an expected market growth rate of 30.1% (CAGR). Additional diagnostic applications for dendrimers are expected to be commercialised between 2016 and 2021, resulting in a doubling of the market share of dendrimer reagents. The dollar value of the market for dendrimer-based diagnostic reagents is thus expected to grow at a CAGR of about 30%, reaching USD 82 million by 2019, or USD 8.2 million for the dendrimers themselves.

For the clinical diagnostics market as a whole, sales of diagnostic reagents are equal to an estimated 37.5% of instrument sales. Applying this percentage to superparamagnetic clinical diagnostic instrument sales implies reagent sales of USD 12.2 million in 2015. The market for iron oxide nanoparticles for biomagnetic separation applications is projected to grow at a CAGR of 20% from 2016 through 2021.

In 2015, semiconductor nanoparticles (quantum dots) accounted for about 0.2% of the estimated USD 9 billion global market for fluorescence-based biological reagents, worth USD 18 million. The market for fluorescence-based biological reagents is projected to reach USD 18.5 billion by 2021 and the share of that market that will be taken by quantum dots is forecast to reach 3% or USD 555 million by 2019[283].

Proteomic applications

Aptamers are oligonucleotide or peptide molecules that bind to a specific target molecule. Aptamers are usually created by selecting them from a large random sequence pool, but natural aptamers also exist in riboswitches[284]. Aptamers have also been selected to targets which have a suspected or verified role in diseases in the brain, eyes and kidneys as well as in arthritis, inflammatory, cardiovascular and autoimmune diseases. Whereas antibodies have the ability to specifically recognise, for example tumour cell markers, large size and immunogenicity often limit their pharmacological value. Aptamers are new promising alternatives to antibodies in diagnostics[285].

The market for protein arrays (which is also the target market for aptamer arrays) has been estimated at USD 2.2 billion in 2015 and growing at a CAGR of 15%. At this rate, the market should reach USD 2.5 billion in 2016 and USD 5.1 billion by 2021.[286]

It is difficult to predict with any certainty what share of this market might be captured by

[282] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p. 62

[283] Ibid

[284] Darvas F et al. (eds.) (2013), Chemical Genomics and Proteomics, Second Edition, p. 205

[285] Hjalmarsson K et al. (2004), Aptamers - Future tools for diagnostics and therapy, Swedish defence Agency, FOI-R—1216—SE, p. 19

[286] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications

the new aptamer arrays. However, another nanotechnology used in proteomics, nano-high-performance liquid chromatography or nano-HPLC, offers a potential benchmark for assessing the potential market for aptamer arrays. Nano-HPLC systems are a subsegment of the capillary HPLC market, consisting of capillary HPLC instruments that have tubes with an inside diameter of less than 100 nm. It was estimated that nanoscale HPLC instruments had captured between 15% and 25% of the capillary HPLC market within five years of their commercialisation. Applying similar percentages to the protein array market implies that aptamer arrays, if commercialised, might capture a market valued between USD 765 million and USD 1.3 billion from conventional protein arrays by 2021.[287]

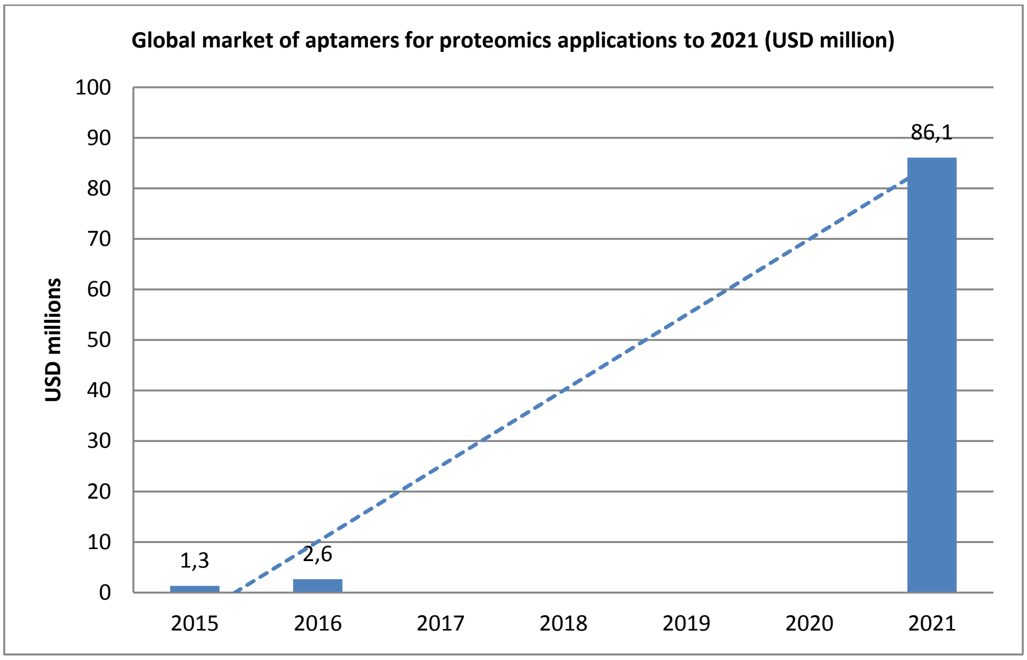

Figure A3.31. Global market for aptamers for proteomics applications to 2021 (USD million)

Source: BCC Research 2016

MRI contrast agents

MRI contrast agents have become an indispensable part of modern magnetic resonance imaging. Although MRI was initially hoped to provide a means of making definitive diagnoses non-invasively, it has been found that the addition of contrast agents in many cases improves sensitivity and/or specificity. Nanoparticles are also being used to enhance imaging techniques[288].

Two types of iron oxide contrast agents exist: superparamagnetic iron oxide (SPIO) and ultrasmall superparamagnetic iron oxide (USPIO). These contrast agents consist of suspended colloids of iron oxide nanoparticles and when injected during imaging reduce the T2 signals of absorbing tissues[289]. The iron oxide nanoparticles are coated with an inert material, such as dextran or starch, which reduces absorption (and thus toxicity from the iron), and also helps to suspend the particles in solution. SPIO and USPIO contrast agents have been used successfully in some instances for liver tumour enhancement.

Estimates of the global consumption of iron oxide nanoparticles as MRI contrast agents were USD 13 million in 2015. Historically, the market for iron oxide MRI contrast agents

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[287] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.71-72

[288] http://radiopaedia.org/articles/mri-contrast-agents

[289] Nakamura, H et al. (2000), Tumor-detecting capacity and clinical usefulness of SPIO-MRI in patients with hepatocellular carcinoma. Journal of Gastroenterology 35 (11): 849–55.

has grown more slowly than the MRI contrast agent market as a whole (i.e., at a CAGR of about 9% versus 13%, respectively). The relatively slow growth of iron oxide contrast agents has been due to regulatory hurdles in getting new products approved, as well as competition from gadolinium-based contrast agents in applications such as liver imaging. Iron oxide nanocrystal contrast agents, on the other hand, are used only for specific indications (e.g., suspected metastases in the liver), while non-specific gadolinium-based contrast agents are used for much more general screening.

Based on data from industry sources, it is expected that the overall market for contrast agents will grow at a CAGR of between 4% and 5% from 2016 through 2021. The projections in the table below assume that the market for iron oxide nanoparticle contrast agents will continue to grow at a slower rate than the contrast agent market as a whole (e.g., at a CAGR of 3.6%). [290]

Figure A3.32. Global market for MRI contrast agents to 2021 (USD millions)

Source: BCC Research 2016

Antimicrobial dressings

Silver has long been used to fight infection. It interrupts the bacteria cell's ability to form the chemical bonds essential to its survival. These bonds produce the cell's physical structure so when bacteria meet silver it literally falls apart. Wound dressings containing silver have been an important aspect of healthcare for more than a century, e.g. soldiers in World War I relied heavily upon such dressings. Today, consumer healthcare companies like Johnson & Johnson and others sell bandages and ointments that use silver as an active ingredient[291].

Global consumption of silver thin film materials has been estimated at USD 95 million in 2015. With an estimated CAGR of 6.8%, global sales volumes should reach USD 101.5 million in 2016 and USD 141 million in 2021.

It has been forecast that sales of graphene-containing antimicrobial dressings could exceed USD 17 million by 2021, assuming that, like silver nanomaterial dressings, the graphene nanomaterial accounts for 25% of the cost of the dressings, or USD 4.3 million in 2021. [292] [293]

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[290] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.64-65

[291] https://www.silverinstitute.org/site/silver-in-technology/silver-in-medicine/bandages/

[292] BCC Research, AVM075D Graphene: Technologies, Applications and Markets

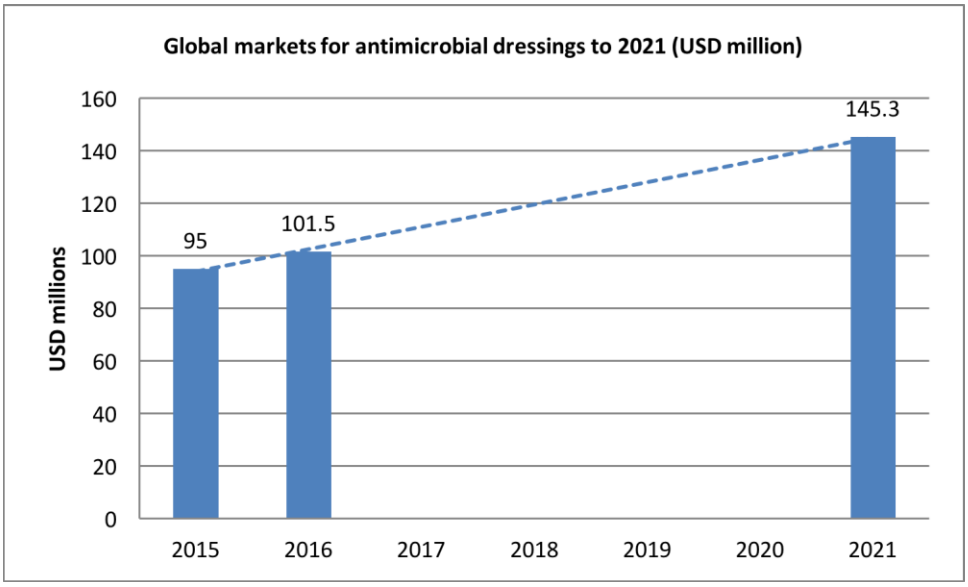

Figure A3.33. Global market for antimicrobial dressings to 2021 (USD millions)

Source: BCC Research 2016

Nanoporous membranes

Molecular transport controlled at the nanometre-scale using membranes offers great potential for high selectivity and high fluxes. Many applications, including protein separation and purification, biomolecule detection and drug delivery, are now being realised with nanoscale pore structures that can provide high selectivity based on specific molecular characteristics[294]. In the last 35 years or so, nanoporous membranes with a reasonably uniform pore-size distribution have become commercially available. Membranes with nanometre-scale features have many applications, such as in optics, electronics, catalysis, selective molecule separation, filtration and purification, biosensing and single-molecule detection[295].

Organic polymeric nanoporous membranes have been used for dialysis filters since the late 1990ies. Notable examples are Polysulfone® or Helixone® by Fresenius SE & Co KGaA[296] (Bad Homburg, Germany) and the Polyflux® 210H by Gambro AB (Lund, Sweden)[297].

Further health application areas for nanoporous membranes can be found in blood gas analysers. Epigem Ltd.[298] (Redcar, UK) and Radiometer Medical aps[299] (Brønshøj, Denmark) have recently developed sensor platforms for blood analysis on the basis of nanoporous membranes.

While there is no market data on the specific use of nanoporous membranes in medical applications, the table below displays global market estimates for water filtration membranes, refinery separation membranes and aggregate values.

Nanoporous thin film membranes include membranes used in water filtration applications (e.g. Dow Chemical's Filmtec) and refinery separation membranes. Water filtration

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[293] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.119-120

[294] Stroeve P, Nazar N (2011), Biotechnical and other applications of nanoporous membranes, Trends in Biotechnology 879: 1

[295] Ibid

[296] www.fresenius.de/

[297] Gambro AB is since 2012 part of Baxter

[298] epigem.co.uk

[299] www.radiometer.com

membranes are expected to grow with CAGR of 15.0% and will reach global sales of USD 1156.5 million in 2021. Although it is difficult to quantify the potential global market for nanoporous membranes in the refinery industry, there are estimates for global consumption in 2021 of USD 100 million[300].

Types	Market to 2021 (USD million)			CAGR%
	2015	2016	2021	2016-2021
Water filtration membranes	500.0	575.0	1156.5	15.0
Refinery separation membranes	Neg.*	Neg.*	100.0	–
Total	500.0	575.0	1,256.5	16.9

Table A3.4. Global market for nanoporous thin film membranes to 2021 (USD millions)

Source: BCC Research 2016

Surface disinfectants

EnviroSystems'[301] (Mooresville, NC, USA) introduced in 2002 its EnviroTru - a nanoemulsion formulation of the biocide parachlorometaxylenol (PCMX). Nanospheres of oil droplets are suspended in water to create a nanoemulsion requiring only miniscule amounts of EnviroTru's active ingredient, PCMX. The nanospheres carry surface charges that efficiently penetrate the surface charges on microorganisms' membranes EnviroTru, with its U.S. EPA Tox. Category IV classification, has been proven to be completely safe for people, animals and the environment. EnviroTru shows no toxicity toward the cells of higher animals and is therefore safe for humans, animals, wildlife and the environment.

Data on current sales of EnviroTru nanoparticle-based surface disinfectant are unavailable, but sales are believed to be small. Estimates for the oily nanospheres that EnviroTru uses to deliver biocide are set at around USD 1 million in 2021.[302]

Synthetic bone and tooth materials

Bone is a biocomposite material of which the major constituents are a complex mineral mixture (60-70% by weight) of calcium and phosphate in the form of hydroxyapatite, proteins (20-30%) with predominately type I collagen fibrils, and water (10%). The dimensions of the mineral and organic constituents are on the nanometre scale)[303]. Hydroxyapatite nanoparticles used as bone replacement material, i.e. bone cement with improved mechanical properties, are commercially available. Bone replacement materials are used for accidental fractures, periprosthetic fractures during hip prosthesis revision surgery, acetabulum reconstruction, osteotomies, filling cages in spinal column surgery, and filling in defects in children[304].

Hydroxyapatite (HA) is the main component of enamel, which gives an appearance of bright white and eliminates the diffuse reflectivity of light by closing the small pores of

[300] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.118

[301] envirosi.com

[302] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.65

[303] Rho JY et al. (1998), Mechanical properties and the hierarchical structure of bone. Med. Eng. Phys. (20): 92-102

[304] Szpalski M, Gunzburg R (2002). Applications of calcium phosphate-based cancellous bone void fillers in trauma surgery. Orthopedics 25: pp601-609

the enamel surface[305]. Nano-hydroxyapatite has a wide use in dentistry. With regard to restorative and preventive fields, nano-hydroxyapatite has remarkable remineralising effects on initial lesions of enamel, certainly higher than traditional fluorides used until now for this purpose. Nano-hydroxyapatite is, in fact, a better source of free Ca, and this is a key element as regards the remineralisation, the protection against caries and dental erosion[306].

In 2015, total global consumption of nanoparticulate calcium phosphate and hydroxyapatite used as bone substitutes or toothpaste ingredients was around 50 metric tons, with a value of USD 440 million, this figure should reach USD 550 million in 2016 and about USD 1.6 billion by 2019[307].

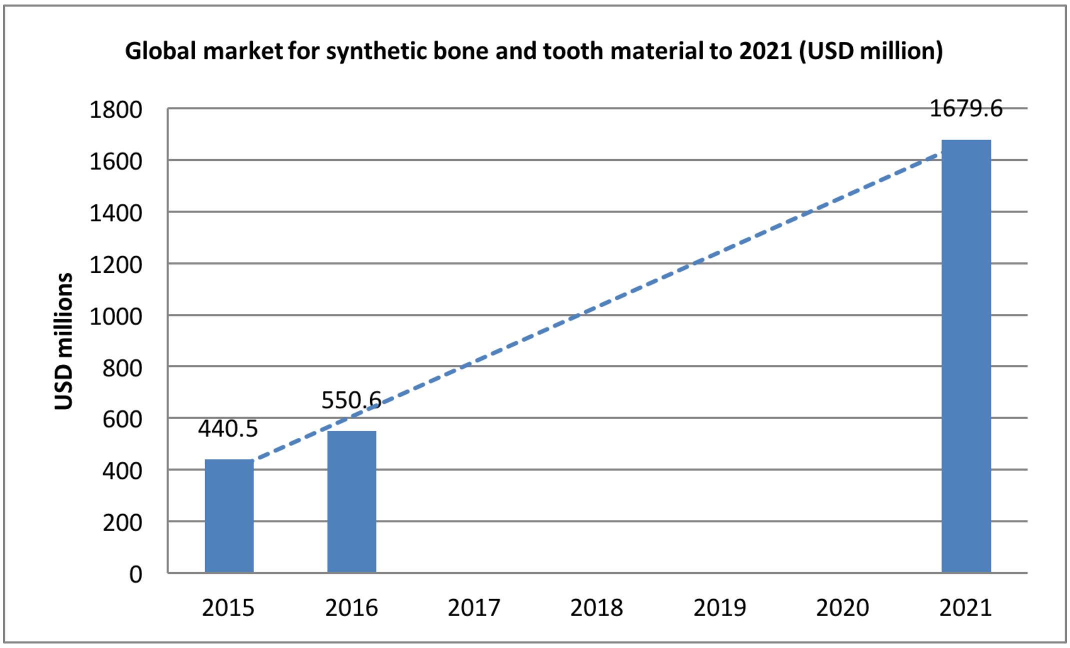

Figure A3.34. Global market for synthetic bone and tooth material to 2021 (USD millions)

Source: BCC Research 2016

Transfection reagents

Transfection generally refers to the introduction of foreign DNA into bacterial and/or mammalian cells. Transfection is an important tool used in studies investigating gene function and the modulation of gene expression, thus contributing to the advancement of basic cellular research, drug discovery, and target validation. Protocols and techniques vary widely and include DEAE-dextran, calcium phosphate, electroporation, liposomes, viral vectors, non-liposomal lipids and activated dendrimers, with the choice of technology being somewhat application-specific[308].

Potential market drivers for dendrimer-based transfection reagents include growth in the overall market for transfection reagents as well as an increase in the share of the market of dendrimer-based reagents. The global market for transfection reagents was worth at least USD 260 million in 2015, increasing at a CAGR of about 8.5%. At this rate, the total market for transfection reagents should be worth USD 282.1 million in 2016 and USD 424.2 million by 2021. Dendrimer-based transfection reagents could achieve a 10% share of the transfection reagent market by 2021, representing sales of USD 42.4

[305] Pepla E et al. (2014), Nano-hydroxyapatite and its applications in preventive, restorative and regenerative dentistry: a review of literature. Annali di Stomatologia 2014 Jul-Sep; 5 (3): 108–114

[306] Ibid

[307] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.56

[308] http://www.bio-rad.com/de-at/applications-technologies/transfection

million. At an estimated 10% of total transfection reagent cost, related consumption of dendrimers should be worth about USD 4.2 million in 2021. [309]

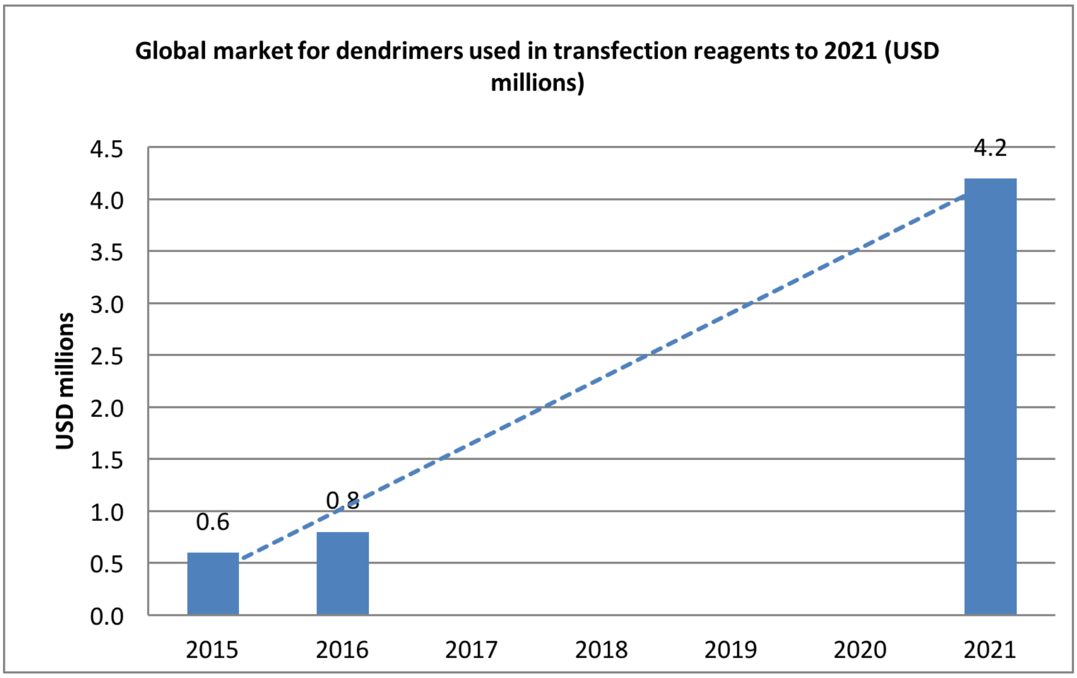

Figure A3.35. Global market for dendrimers used in transfection reagents to 2021 (USD millions)

Source: BCC Research 2016

Drug production and mixing systems

The number of poorly soluble drugs is steadily increasing, especially the drugs simultaneously poorly soluble in water and in non-aqueous media. Therefore there will be a high demand for formulations overcoming the problems related to these drugs[310].

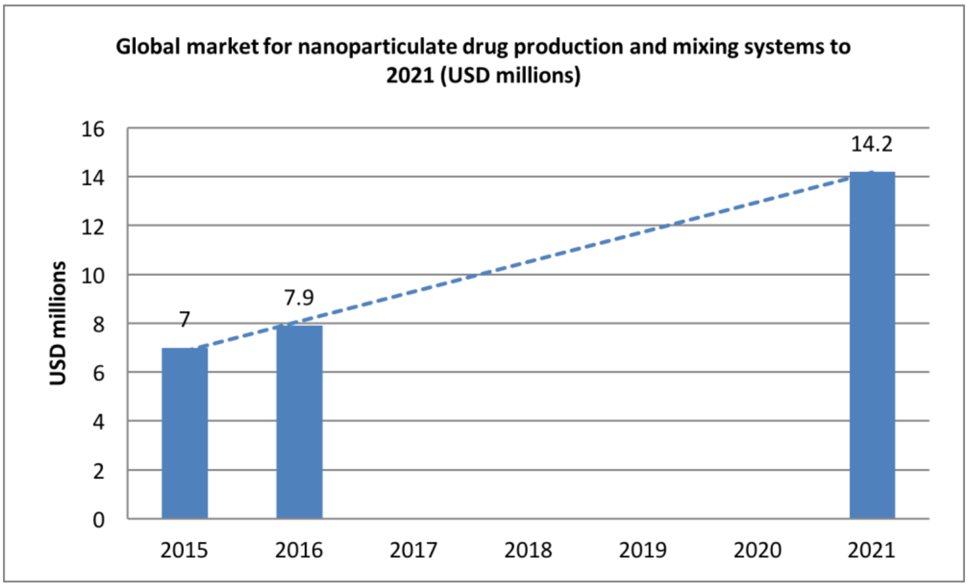

Figure A3.36. Global market for nanoparticulate drug production and mixing systems to 2021 (USD millions)

Source: BCC Research 2016

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[309] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.62

[310] Radtke M (2001), Pure drug nanoparticles for the formulation of poorly soluble drugs. New Drugs 2001 (3): 62–68.

Microfluidic devices that are capable of producing and mixing nanoparticulate drugs, such as Microfluidics Corp.'s Microfluidizer system, are available on the market. In 2015, Microfluidics Corp. had sales of about USD 7 million. Although not all of the Microfluidizers sold by Microfluidics Corp. are used to produce nanoscale particles, they are capable of nanoscale operations and this report classifies them as nanodevices. Growth in sales of Microfluidizer are forecast to be at least as fast as the overall market for pharmaceutical equipment, at a CAGR of 12.4% from 2016 through 2021.[311]

Products for health through nanotechnology, by emerging market

Emerging markets considered here are:

- Aptamer-based molecular imaging agents
- Nanostructured magnetic coatings for medical devices
- Medical implants
- Nanocomposite-based bone replacements and cements

Aptamer-based molecular imaging agents

Molecular imaging is the science of visually representing, characterising, and quantifying (sub)cellular biological processes in intact organisms. These processes include gene expression, protein-protein interaction, signal transduction, cellular metabolism, and both intracellular and intercellular trafficking. Molecular imaging has the potential to quantify these events in three spatial dimensions, and to monitor these events serially in time, i.e. in a temporal dimension. Thus, biological processes can be observed in space and time. The emergence of molecular imaging has coincided with and has been made possible by the enormous advances in molecular biology, cell biology, transgenic animals, as well as the development of imaging probes that are specific, reproducible, and quantifiable[312].

Non-modified aptamers are cleared rapidly from the bloodstream, with a half-life of minutes to hours, mainly due to nuclease degradation and clearance from the body by the kidneys, a result of the aptamers inherently low molecular weight. This rapid clearance can be an advantage in applications such as *in vivo* diagnostic imaging. An example is a tenascin-binding aptamer under development by Schering AG for cancer imaging[313]. Aptamer based MI has also potential clinical applications in neuropsychiatry, angiogenesis and the monitoring of gene therapy[314].

No aptamer-based molecular imaging agents were available commercially as of 2016. However, that such agents will likely enter the market before 2021. The size of the molecular imaging market has been forecast at approximately USD 6 billion by 2021, when aptamer molecular imaging reagents should be available. In general, the market for medical imaging contrast agents is estimated at about 40% the size of the imaging equipment market, so total sales of imaging agents for molecular imaging studies are estimated at USD 2.4 billion in 2021.A conservative estimate is that aptamer-based imaging agents could capture 10% of this market in 2021, worth USD 240 million, reflecting a number of factors, including competition from other established types of imaging contrast agents and uncertainty about the prospective commercialisation date for aptamer-based agents.[315]

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[311] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.193

[312] Roszek B et al. (2005), Nanotechnology in medical applications: state-of-the-art in materials and devices, RIVM report 265001001/2005, p. 88

[313] http://www.protein.pl/?name=aptamers

[314] INTECH OPEN: Nucleic Acid Aptamers for In Vivo Molecular Imaging

[315] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.73

Nanostructured magnetic coatings for medical devices

Certain types of implantable medical devices are contraindicated for use with MRI, such as pacemakers, defibrillators and neurostimulators, guidewires, and catheters. Such devices can experience unsafe heating in an MRI field and can experience induced voltages, which also present a safety concern[316].

The market for all types of implantable drug delivery devices is projected to grow from USD 15.7 billion in 2015 to USD 25.3 billion in 2021. Nanomagnetic-coated devices are unlikely to capture a large share of this market, especially in view of the need for extensive clinical testing before they are released commercially.

Medical implants

Titanium (Ti) and its alloys have been widely used as implant materials for orthopaedic applications owing to their excellent wear, corrosion resistance, light weight but strong mechanical and acceptable biocompatibility properties. However, such implants still widely experience lifetimes of less than 20 years owing to a variety of reasons eventually leading to implant separation from bone[317]. An alternative approach to overcome the problem of harmful ion release is to abandon the alloying concept altogether and to enhance the mechanical properties of pure titanium by nanoscale grain refinement using severe plastic deformation (SPD) processing[318].

Worldwide consumption of titanium for use in orthopaedic implants was approximately USD 240 million in 2015, a figure projected to rise to USD 252 million in 2016 and USD 321.6 million in 2021 (a CAGR of 5% from 2016 through 2021).[319]

Nanocomposite-based bone replacements and cements

Natural bone tissue possesses a nanocomposite structure that provides appropriate physical and biological properties. For bone tissue regeneration, it is crucial for the biomaterial to mimic living bone tissue. Since no single type of material is able to mimic the composition, structure and properties of native bone, nanocomposites are the best choice for bone tissue regeneration as they can provide the appropriate matrix environment, integrate desirable biological properties, and provide controlled, sequential delivery of multiple growth factors for the different stages of bone tissue regeneration[320].

The nanocomposite material that appears closest to commercialisation in orthopaedic implants is a porous resorbable silica-calcium phosphate nanocomposite material for spinal and maxillofacial applications. A Kentucky start-up firm called Ostech tried for several years to commercialise such a nanocomposite, but apparently has since gone out of business. However, there is still significant research interest in silica-calcium phosphate nanocomposite[321].

Calcium phosphate/silica nanocomposite bone replacement materials were not available commercially as of mid-2016. While the global bone graft market is projected to exceed USD 3.6 billion by 2021, nanocomposite bone graft materials will compete with natural bone, macroscale artificial bone and nanoparticulate hydroxyapatite implants for a share of this market. It is estimated that all forms of synthetic bone (nanoparticulate as well as nanocomposite) may capture one-third, or at least USD 1.2 billion, of the total market in

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[316] BCC Research (2014), Nanotechnology, a realistic market assessment. p. 70

[317] Durmus NG, Webster TJ (2012), Nanostructured titanium: the ideal material for improving orthopedic implant efficacy? Nanomedicine (2012) 7 (6): 791

[318] Mishnaevsky L Jr. et al. (2015), Nanostructured titanium-based materials for medical implants: Modelling and development. Materials Science and Engineering R 81 (2014) 1– Volume 81, July 2014: 2

[319] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.143

[320] Sahoo NG et al. (2013), Nanocomposites for Bone Tissue Regeneration, Nanomedicine. 2013; 8 (4): 639-653.

[321] BCC Research (2014), Nanotechnology, a realistic market assessment. p. 185

2021. Out of this share, nanotechnology-based bone substitutes should capture at least half, or a minimum of USD 600 million in sales, by 2021. Nanoparticulate bone substitutes such as Stryker's (formerly Orthovita) VITOSS nanoparticulate bone filler, which has been on the market since 2000, have a substantial head start over nanocomposite-based products, which still must complete clinical testing before they are approved for use.[322]

The next section of this annex looks at products and markets for energy and nanotechnology.

[322] BCC assumes that nanocomposite bone replacement materials may be able to capture 10% of the total market for nanotechnology-based bone replacement materials, worth about USD 60.6 million, by 2021.

4 Products and Markets for Energy through Nanotechnology

Commercialised products for energy through nanotechnology: Overview

To date, 269 products have been identified as commercially available on the market. The largest share of products (41%) can be found within photovoltaics. A large share of products that fall under this category belong coatings and conductive inks that are being used in the production of photovoltaic cells. Lithium ion batteries (25%) account for the second largest share among commercially available products, as shown in the figure below.

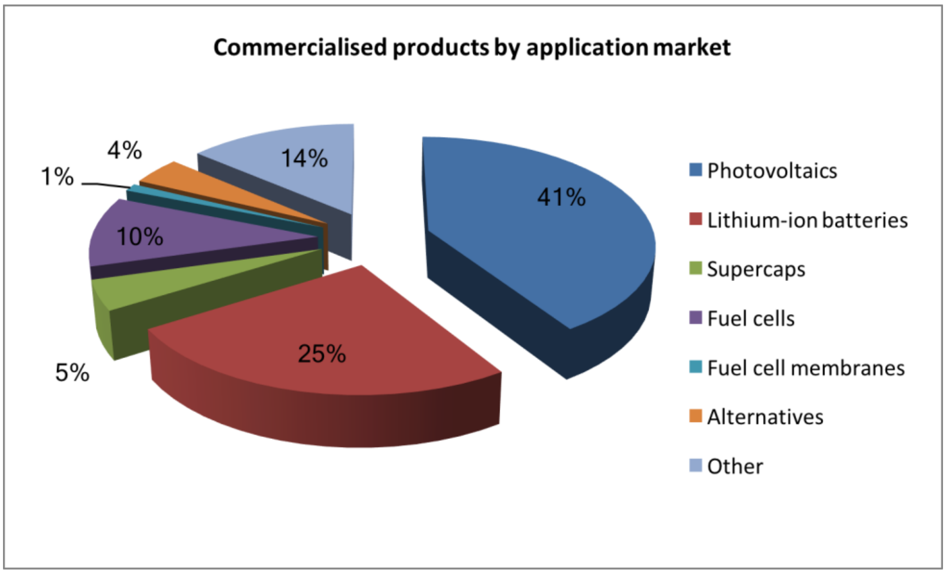

Figure A3.37. Nanotechnology products in energy, by application market

Source: JIIP, 2017

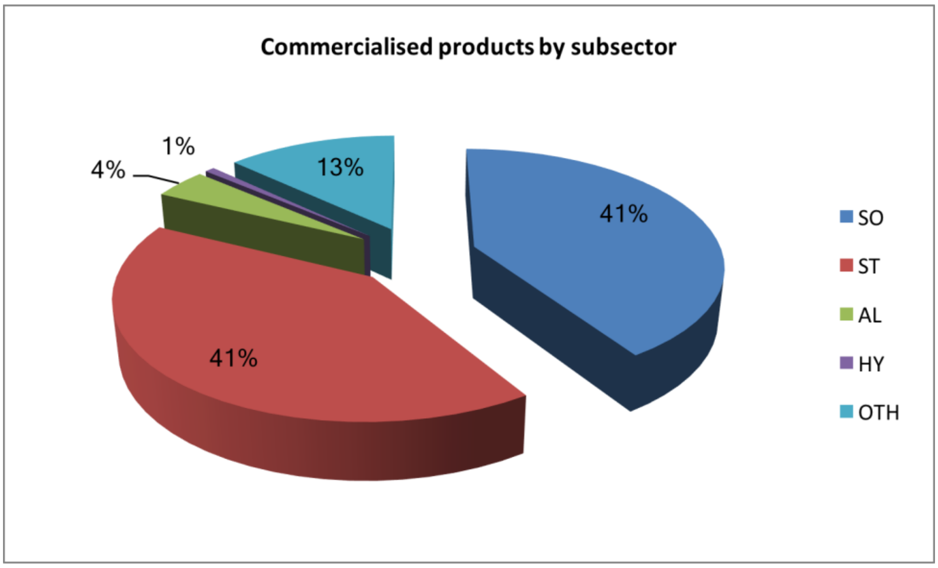

Figure A3.38. Nanotechnology products in energy, by subsector

Source: JIIP, 2017

Products that have been put into the category 'Other' (mainly aerogels and fuel additives) account for 14%. The products distribute unevenly among the defined subsectors, as shown in the figure below. The largest shares of products can be found in the categories 'solar' (SO) and 'energy storage' (ST) (46% each). 13% of the products cannot be categorised within the existing set of subsectors[323].

Products for energy through nanotechnology, by application

Products identified are discussed below under the headings:

- Energy storage;
- Fuel cells;
- Fuel cell membranes;
- Hydrogen storage;
- Solar; and
- Other, e.g. fuel additives and building insulation.

In each case, details are given of the technology and its purpose as well as market estimates and forecasts. Existing applications and emerging applications are considered.

Energy storage

Products by application market

Rechargeable lithium ion batteries

Lithium ion batteries are generally based on the reversible transfer of lithium ions between two materials through an electrolyte. [324] The cathode (positive electrode) materials are lithium transition metal oxides represented by the general formula Li y MO 2 (y ≈ 1), whereas graphite is the most frequently used negative electrode (anode) material. With graphite, the battery operates at about 3.5 V during discharge, which makes the system very attractive for its high energy density[325].

With the arrival of the lithium ion technology in the 1990's, cell energy density was boosted by a factor of three compared to lead acid batteries (35–40 Wh/kg) and two compared with Ni–Cd batteries (50–60 Wh/kg) and, more significantly, the energy density has doubled, from 100 Wh/kg to about 200 Wh/kg, over the past 25 years. However, even this falls short of meeting future application demands linked to the field of renewable energies and automotive transportation in terms of energy density, power and life span[326]. They eventually wear out, and they cannot discharge energy quickly enough for applications requiring power surges, such as camera flashes and power tools[327].

Lithium-titanate batteries (lithium titanium oxide or LTO) are one approach to overcome shortcomings of traditional lithium ion batteries. The LTO technology is based on modified lithium-ion batteries – the addition of lithium-titanate nanocrystals on the surface of the anode increases the surface area from 3 m^2/g to around 100 m^2/g and allowing electrons to enter and leave the anode far more quickly, resulting in faster charging times, increasing stability and making the battery safer[328]. A disadvantage of LTO batteries is that they have a lower inherent voltage (2.4 V), which leads to a lower energy density of about 30-110Wh/kg than conventional lithium-ion battery technologies

[323] Selected by the client for the NanoData project

[324] Patrice Simon and Jean-Marie Tarascon (2013), Electrochemical Energy Storage: The Benefits of Nanomaterials, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.157

[325] Elzbieta Frackowiak and François Béguin (2013), Carbon-Based Nanomaterials for Electrochemical Energy Storage, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p. 194

[326] Ibid

[327] Graham-Rowe, Duncan (7 March 2005). "Charge a battery in just six minutes". New Scientist.

[328] Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015

(3.7 V)[329].

LTO batteries have applications in electric vehicles and charging stations, coaches, yachts, wind and solar energy storage power, traffic signals, solar hybrid street lighting, uninterruptible power supply, home power storage, weather radar, electricity, hospitals and telecommunications, as well as mobile and backup power systems[330].

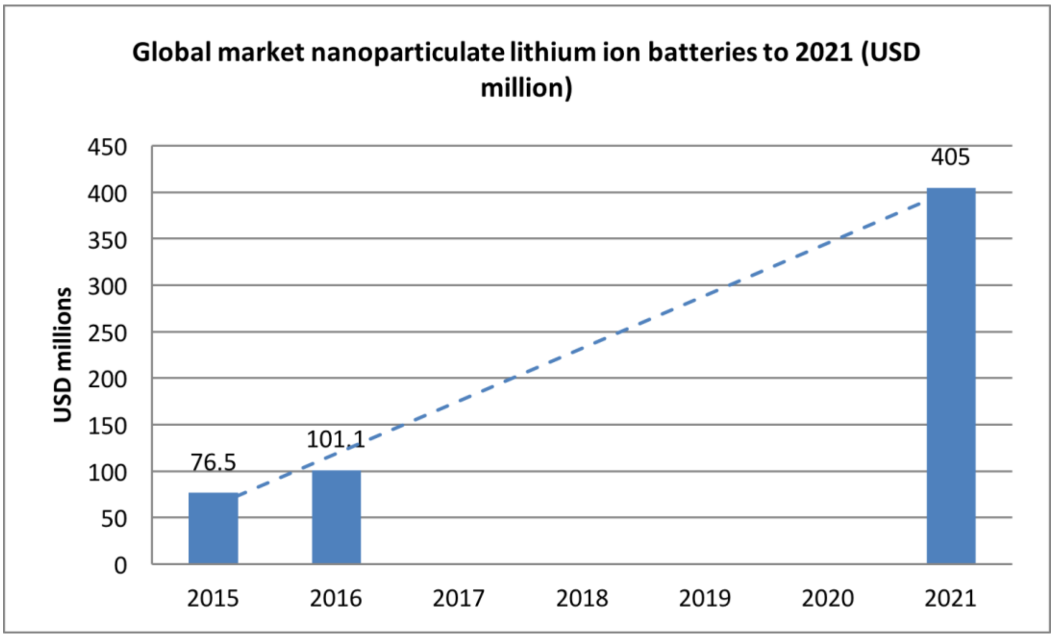

Figure A3.39. Global market for nanoparticulate lithium ion batteries to 2021 (USD millions)

Source: BCC Research 2016

The market in 2015 for advanced lithium ion batteries incorporating nanoparticulate electrode materials was estimated as USD 340 million, based partly on sales of major manufacturers such as A123 Systems and Valence Technology. Material costs represent about 45% of the value of all types of storage battery shipments, a percentage assumed to be characteristic of nanoparticulate lithium ion batteries as well. Materials used in fabricating the electrodes of these batteries in turn account for about half of the total material cost of lithium ion batteries, or USD 76.5 million in 2015 based on the projected value of nanoparticulate lithium ion battery sales.

In the longer term, the greatest potential market for nanoparticle-based lithium ion batteries is in electric vehicles. According to some estimates, the total market for automotive lithium ion batteries could approach USD 18 billion per year by 2021, with nanoparticle-based lithium ion batteries could capture 10% of the automotive market over the mid- to long term[331]. Based on a total market of USD 18 billion and following the cost-estimating logic described above, such a market implies a potential demand for nanoparticulate electrode materials of USD 405 million in 2021.[332]

Products by emerging market

Carbon nanotube batteries

By 2021, it has been forecast that CNT batteries will hold a market share of 2% to 3%, or USD 50 million, analogous to the share of the market of carbon nanotube ink-printed

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[329] Green Car Congress: Toshiba Developing 3.0 Ah High Power SCiB Li-Ion Cell for HEV Applications. 21 May 2008.

[330] Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015

[331] BCC Research

[332] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.71

RFID tags. The electrode accounts for an estimated 45% of the cost of the battery, while the carbon nanotubes account for about half of the cost of the electrodes, or 22.5% of the total cost of the battery. This percentage, applied to projected sales of USD 50 million, yields a potential market for carbon nanotube battery electrode materials of USD 11.3 million in 2021.[333]

Carbon nanotube supercapacitors

It is equally difficult to project the market for carbon nanotube supercapacitor materials in 2019, when FastCAP's supercapacitors or their equivalents are expected to be on the market. Assuming that the supercapacitor market will roughly equal the battery market for nanotube electrodes, it value is forecast as USD 11 million in 2021[334].

Graphene supercapacitors[335]

The global market in 2015 for electronic and capacitive energy storage devices (including supercapacitors, supercapacitors and air capacitors) has been estimated at about USD 2 billion in 2015, rising to USD 2.4 billion in 2016 and almost USD 6 billion in 2021. There are several competing technologies that are further advanced in their development, as well as technical and cost versus manufacturability issues that need to be resolved for graphene ultracapacitors to significantly enter the market so they are seen to be unlikely to capture more than 1% (USD 60 million) of the supercapacitor market by 2021. The graphene electrode accounts for an estimated 45% of the cost of the battery, while the graphene materials account for about half of the electrodes' cost, or 22.5% of the total cost of the battery, making for an estimated value in 2021 for graphene materials in supercapacitors at USD 13.5 million.

Aerogel supercapacitors

Potential electrochemical device applications of nanotechnology include aerogel capacitors. The global market for electronic and capacitive energy storage devices (including supercapacitors, ultra capacitors and aerocapacitors) was estimated at USD 2 billion in 2015. This figure is expected to rise to USD 2.4 billion in 2016 and almost USD 6 billion in 2021, a CAGR of 20% from 2016 through 2021.As with graphene ultracapacitors, the future market value is hard to forecast but aerogels are seen as unlikely to capture more than 5% of the electronic and capacitive energy storage market (about USD 300 million) by 2021.[336]

Fuel cells

Products by application market

Fuel cells

A fuel cell is an electrochemical energy converter in which a fuel (e.g. hydrogen, methanol) reacts with an oxidant (e.g. oxygen, air) at electrodes separated by an electrolyte (e.g. a liquid or a polymer membrane). The electrodes act as catalysts, promoting oxidation at the anode and reduction at the cathode. Electrons released at the anode pass through an outer circuit to do useful work.[337]

Nanostructured fuel cell electrodes increase the surface area (per unit weight) for catalysis to take place, increasing contact between the fuel and the catalysts, thereby enhancing cell efficiency. The preparation of nanoscale electrocatalysts for fuel cells typically starts from either supported or unsupported colloidal nanomaterial precursors,

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[333] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.93

[334] Ibid

[335] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.131

[336] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.144

[337] Elena Serrano, Kunhao Li, Guillermo Rus, and Javier García – Martínez (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.22

for example, colloidal platinum (Pt) sols[338]. Nanoscale thin film platinum catalyst material is currently used in proton exchange membrane fuel cells (PEMFCs), phosphoric acid fuel cells (PAFC), and direct methane fuel cells (DMFCs).

The 2013 market for platinum nanocatalyst thin film materials used in PAFC, PEMFC and DMFC fuel cells was worth over USD 20 million. It is expected that the combined sales of PAFC, PEMFC and DMFC fuel cells will rise from about USD 1.9 billion in 2015 to almost USD 2.6 billion in 2016 and nearly USD 16.8 billion by 2021, a CAGR of 45.3% from 2016 through 2021. Taking the estimate that platinum thin film catalysts represent between 1.3% and 1.9% of the total cost of fuel depending on the type of fuel cells, an estimate the related consumption of platinum nano thin film catalyst materials is shown in the table below.[339]

Types	**Market to 2021 (USD million)**			**CAGR%**
	2015	2016	2021	2016-2021
PEMFCs				
Total sales	1,635.0	2,107.5	7,449.6	28.9
Pt consumption at 1.9%	31.1	40.0	142.5	28.9
PAFC				
Total sales	70.0	83.6	202.8	19.4
Pt consumption at 1.8%	1.3	1.5	3.7	19.8
DMFC				
Total sales	215.0	401.2	9,076.3	86.6
Pt consumption at 1.3%	2.8	5.2	118.0	86.7
Total Pt catalyst consumption	35.1	46.8	264.1	41.3

Table A3.5. Global market for fuel cells and platinum thin film catalysts to 2021 (USD millions)

Source: BCC Research 2016

Fuel cell membranes

A key performance limitation in polymer electrolyte fuel cells (PEMFCs) is the so-called “mass transport loss”. Typically, perfluorosulfonic polymer electrolyte membranes (for

[338] Elena Serrano, Kunhao Li, Guillermo Rus, and Javier García – Martínez (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.24

[339] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.115-116

example, Nafion™) are used in PEMFCs because of their electrochemical stability and conductivity. Unfortunately, methanol cross–over and membrane dehydration processes hinder the efficiency of the cells. Nanostructured membranes can help to address some of these issues[340].

DuPont™ Nafion® perfluorosulphonic acid (PFSA) membranes are non-reinforced films based on chemically-stabilized perfluorosulfonic acid/PTFE copolymer in the acid (H+) form. Nafion® PFSA membranes are chemically-resistant and durable and are widely used for Proton Exchange Membrane (PEM) fuel cells and water electrolysers. The membrane acts as a separator and solid electrolyte in a variety of electrochemical cells that require the membrane to selectively transport cations across the cell junction.[341]

However, Nafion suffers from chemical crossover and fuel cell operation is limited to 80^{O} Celsius because of its inability to retain water at higher temperatures. Therefore there is a need for new proton-conducting materials in order to improve the commercialization of PEMFCs.[342]

Sales of Nafion fuel cell membrane materials were estimated at about USD 92.5 million in 2015, and sales of PEMFC and DMFC USD 1.8 billion, with Nafion being used in the majority. DuPont estimates that the Nafion membrane represents about 5% of the total cost of a fuel cell. Future sales of Nafion will be driven in part by sales of PEMFC and DMFCs, in addition to competition from alternative (non-nano and well as nano-) materials. As shown in the following table, total sales of PEMFC and DMFC fuel cells are expected to approach USD 16.6 billion annually by 2021.[343]

Types	Market to 2021 (USD million)			CAGR%
	2015	2016	2021	2016-2021
PEFMC	1,635.0	2,107.5	7,499.6	28.9
DMFC	215.0	401.2	9,076.3	86.1
Total	1,850.0	2,508.7	16,575.9	45.9

Table A3.6. Fuel cell sales by type of technology to 2021 (USD millions)

Source: BCC Research

The prospect of increasing competition from alternative (nanoscale and non-nanoscale) fuel cell membrane materials makes it difficult to project the future market for nanoporous polymer membranes like Nafion. It has been forecast that fuel cells equipped with Nafion and similar nanoporous polymer membrane materials will drop from being most of the market in 2016 to about half of the global market by 2021[344].

[340] Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.22.

[341] DuPont Fuel Cells: DuPont™ Nafion® PFSA Membranes, product information

[342] Jurado J, et al. (2002), Protonic Conductors for Proton Exchange Fuel cells: an overview, Chem. Ind. 56 (6): 265

[343] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.141

[344] BCC Research (2014), Nanotechnology, a realistic market assessment p.169

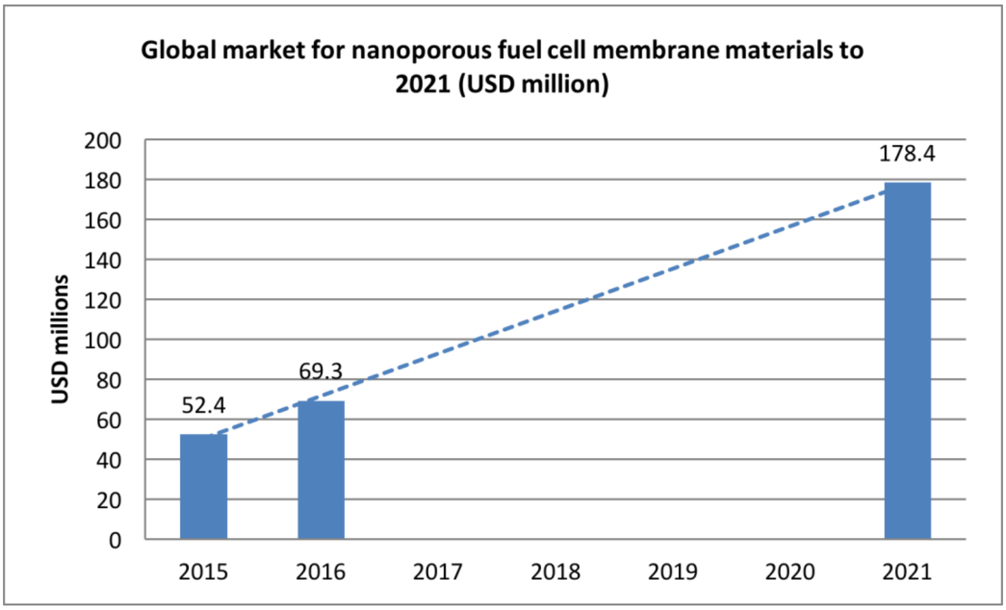

Figure A3.40. Global market for nanoporous fuel cell membrane materials to 2021 (USD millions)

Source: BCC Research 2016

Products by emerging market

Nanocomposite fuel cell membranes

Nanocomposite membranes are being developed for use in PEMFCs and DMFCs as a potential replacement for existing polymer membranes (such as DuPont's Nafion mentioned above). To overcome the limitations of existing technology, a variety of nanocomposite membranes incorporating inorganic nanoparticles such as clay, ZrO_2, SiO_2, TiO_2 and zeolites have been developed. As a group, these nanocomposite membranes show higher conductivity and water uptake than unmodified Nafion as well as better thermomechanical properties[345].

By 2021, it is forecast that sales of PEMFCs and DMFCs will reach USD 16.6 billion and will use more than 82 million m^2 of membrane material. It is difficult to predict the potential share of the market that will be taken by nanocomposite membranes as they are still under development and face competition from other non-nano membrane technologies that may be under development, such as the now-defunct PolyFuel's hydrocarbon membranes. It is conservatively forecast that nanocomposite membranes may capture 10% of the market by 2021, that is, 8.2 million m^2. At an average cost of USD 35/m^2, this implies a market worth around USD 287 million[346].

Hydrogen storage

Products by emerging market

Carbon nanotube-based hydrogen storage

In the field of hydrogen storage, application possibilities of nanotechnologies are mainly found in the optimisation of solid-state storage tanks, which reversibly bind hydrogen chemically, or by adsorption in the storage material and release it again[347]. Storing hydrogen as solid may offer the best option to store hydrogen through two basic mechanisms: physisorption (or physical adsorption) and chemisorption (or chemical adsorption). In physisorption, molecular hydrogen is adsorbed by intermolecular (van der

[345] BCC Research (2014), Nanotechnology, a realistic market assessment, p.124

[346] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.170

[347] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.51

Waals) forces. Examples of physisorption include the storing of hydrogen in carbon structures and organic or inorganic frameworks[348].

Carbon materials with a high surface area, good chemical stability and low density have received considerable attraction for solid hydrogen storage. Nanostructured carbon materials, such as graphitic nanofibres (GNF), multiwalled carbon nanotubes (MWNT), single – walled carbon nanotubes (SWNT), carbon nanorods and carbon aerogels, demonstrate novel but distinct properties that relate to the many possible configurations of the electronic states of carbon atoms[349].

Early reports on hydrogen storage in carbon nanotubes and graphitic nanofibres proposed high storage capacities (to 67 wt%) and started an extensive worldwide surge of research. Since then many experiments have been carried out with different methods, but such high values have not yet been reproduced by other groups. Nevertheless, hydrogen adsorption on carbon materials is still an attractive concept[350].

Solid-state storage of hydrogen has potential but there is still no material or method to achieve a suitable storage system[351]. Therefore expectations for successful commercial market applications of hollow carbon nanostructures to store hydrogen is expected to remain low for the coming years.

A commercial market for mobile hydrogen storage tanks is forecast to develop by 2019, when sales of the tanks are projected to reach at least USD 10 million.[352] However, carbon nanotubes are only one of several technologies competing to supply this market, along with metal hydrides, zeolites, polymeric foams and other technologies. In view of the technical obstacles to commercialisation of carbon nanotube storage of hydrogen, nanotubes are unlikely to share in the small market that is expected to develop in the next few years[353].

Solar energy

Products by application market

Photovoltaics (PVs)

Photovoltaic cells, more commonly known as solar cells, are devices that absorb energy radiated from the sun that reaches the earth in the form of light and convert it directly into electricity[354]. There have been three generations of photovoltaic technologies. First-generation solar cells are built on high quality single crystalline silicon wafers and consist of large area, single p-n junction diodes which can achieve very high efficiency (close to the theoretical efficiency of 33%) but their production costs are prohibitively high. Second generation solar cells, represented by thin-film devices based on cadmium telluride (CdTe), copper indium gallium selenide (CIGS), amorphous silicon and micromorphous silicon, have lower energy and production costs. Unfortunately, they suffer from much reduced energy conversion efficiencies compared to the first generation because of the defects inherent in their processing methods. Third-generation solar cell technologies aim to increase the efficiency of second generation solar cells while

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[348] Saghar Sepehri and Guozhong Cao (2009), Nanostructured Materials for Hydrogen Storage, in Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge: p.139

[349] Saghar Sepehri and Guozhong Cao (2009), Nanostructured Materials for Hydrogen Storage, in Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge: p.141

[350] Saghar Sepehri and Guozhong Cao (2009), Nanostructured Materials for Hydrogen Storage, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.141

[351] Saghar Sepehri and Guozhong Cao (2009), Nanostructured Materials for Hydrogen Storage, in: p.151

[352] BCC Research: EGY055B Building the Global Hydrogen Economy: Technologies and Opportunities

[353] BCC (2014), Nanotechnology, a realistic market assessment, p.144

[354] Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.6

maintaining low production costs[355]. In photovoltaics there are several new technologies available that make use of nanoscale thin film materials: These comprise in particular dye-sensitized solar cells (DSSCs), quantum dot PVs, nanocomposite PVs and graphene-based PVs.

Dye-sensitised solar cells (DSSCs) use titanium dioxide nanoparticles doped with dye molecules (e.g. different ruthenium complexes) for charge separation. The absorption of light results in the emission of electrons in the dye molecules, which are absorbed by the titanium dioxide particles and transferred to the electrode via a redox electrolyte. The dye molecules are again regenerated in the electrolyte by an iodide/tri-iodide redox couple. Advantages of dye solar cells are cheap manufacturing processes through screen printing, application possibilities even at diffuse incidence of light (e.g. for internal application) as well as the transparency and colour design possibilities of the cells, which open up interesting architectural application perspectives[356].

The use of quantum dots (QDs) in the fabrication of solar cells promises not only high power-conversion efficiencies, but also offers spectral tunability. Because the absorption properties of semiconductor quantum dots are size-dependent, they can be tuned from the red to the blue region (from 650 to 400nm) by decreasing the particle diameter. By assembling the particles in an orderly fashion, the photo-response of the photovoltaic cell can be tuned, optimising the spectral response as a function of wave length[357]. Photovoltaics (PVs) based on quantum dots have several potential advantages over other approaches to making solar cells: they can be manufactured at room-temperature, saving energy and avoiding complications associated with high-temperature processing of silicon and other PV materials; they can be made from abundant, inexpensive materials that do not require extensive purification, as silicon does; and they can be applied to a variety of inexpensive and even flexible substrate materials, such as lightweight plastics[358].

The first quantum dot-based PVs (Cyrium Technologies'[359] InAs/GaAs quantum dot PVs) have already begun appearing in the market, and several types of quantum dot PVs are under development. These include intermediate-band gap solar cells, which contain one or more layers of quantum dots sandwiched between the PV cell's ordinary p- and n-type semiconductor layers, and infrared PVs. The latter incorporate a quantum dot/polymer nanocomposite[360].

Nanocomposite PV cells made from cadmium selenide nanorod/p3HT polymer and lead sulphide nanocrystal/MEH-PPV polymer thin films could reach the commercial market in the 2017 to 2021 timeframe, along with carbon fullerene-doped polymer solar cells. Konarka's recent bankruptcy delayed the commercialisation of its fullerene-doped Power Plastic polymer solar cells. However, a German company, Belectric OPV acquired the Power Plastic Technology, and is collaborating with DAW SE (also of Germany) to integrate Power Plastic into industrial building materials. Meanwhile, other companies, such as NanoFlex, Nanosys, Matsushita Electric and STMicroelectronics, are developing various polymer and polymer hybrid solar cell technologies of their own.[361]

So far, significant effort has been devoted to using graphene for improving the overall performance of photovoltaic devices such as organic photovoltaic cells (OPVs) and dye sensitised solar cells (DSSCs). It has been reported that graphene can play diverse, but

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[355] Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.7

[356] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.37

[357] Laser Focus World: Photovoltaics: Quantum Dots promise - next-generation solar cells, Volume: 42, Issue: 4, April 2006

[358] MIT Energy Initiative: New solar-cell design based on dots and wires, March 25, 2013

[359] http://www.cyriumtechnologies.com/

[360] BCC Research (2014), Nanotechnology, a realistic market assessment, p.102

[361] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.109

positive roles such as an electrode, an active layer, an interfacial layer and an electron acceptor in photovoltaic cells[362].

Nanoscale thin film materials consumed in the fabrication of photovoltaics had a total value of USD 800,000 in 2015, expected to increase to USD 900,000 in 2016. By 2021, the market is expected to be USD 50 million[363].

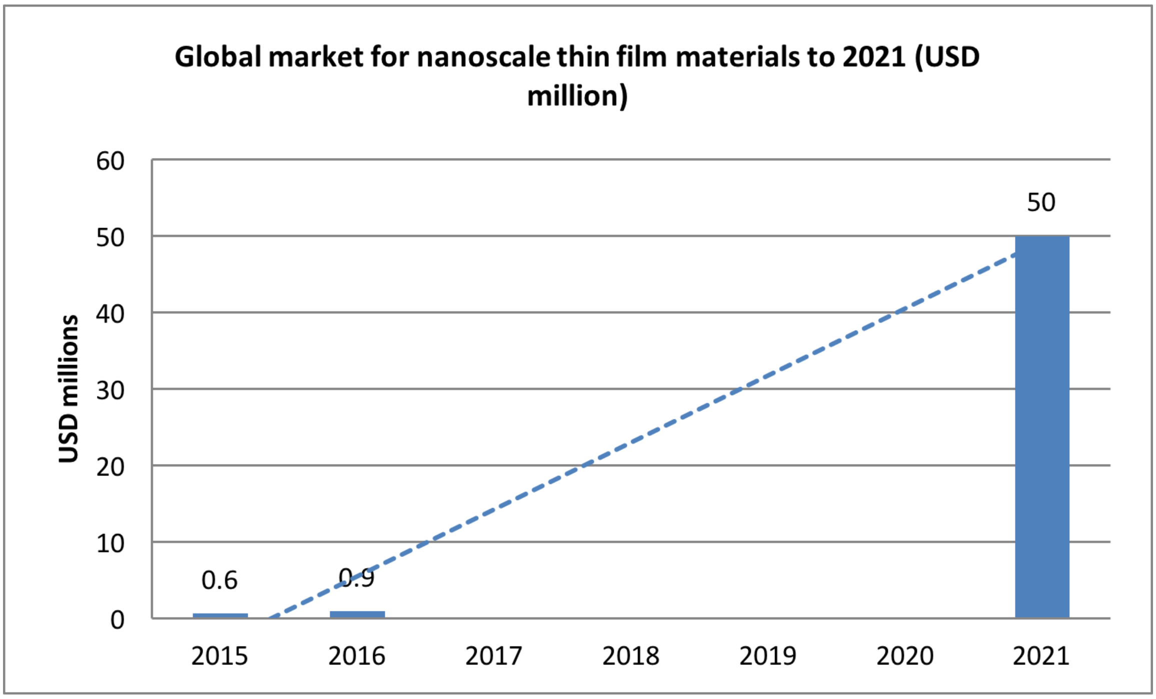

Figure A3.41. Global market for nanoscale thin film materials to 2021 (USD millions)

Source: BCC Research 2016

Products by emerging market

Transparent electrodes/Transparent conducting oxides

Transparent conducting oxides (TCOs) are electrical conductive materials with low light absorption that are used in opto-electrical devices such as solar cells, displays, opto-electrical interfaces and circuitries. They are usually prepared using thin film technologies.[364]

To date, the industry standard in TCO is ITO, or tin-doped indium-oxide. Currently used in touch screens, LCD displays, solar cells, OLEDs and other electronic devices, the annual consumption of ITO is approximately USD 1 billion for the material alone (i.e., excluding deposition costs). Two nanomaterial-based thin film technologies are candidates to replace indium tin oxide (ITO): transparent carbon nanotube-based electrodes (such as the product Unidym is planning to launch in the near future) and graphene-based electrodes.

CNT-based transparent electrodes could capture one-sixth of the market from indium tin oxide electrodes within four years of commercialisation. If CNT electrodes reach the commercial market in 2017, sales could thus reach USD 167 million by 2021. If carbon nanotubes represent about half of the cost of the electrodes (similar to the figure for FED TV displays), the related market for CNTs could be close to USD 84 million by 2021.

[362] Chang DW (2014), Graphene in photovoltaic applications: organic photovoltaic cells (OPVs) and dye-sensitized solar cells (DSSCs), Journal of Materials Chemistry A Issue 31, 2014: 12136

[363] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.126

[364] Andreas Stadler (2012), Transparent Conducting Oxides — An Up-To-Date Overview. Materials 2012, 5: 661

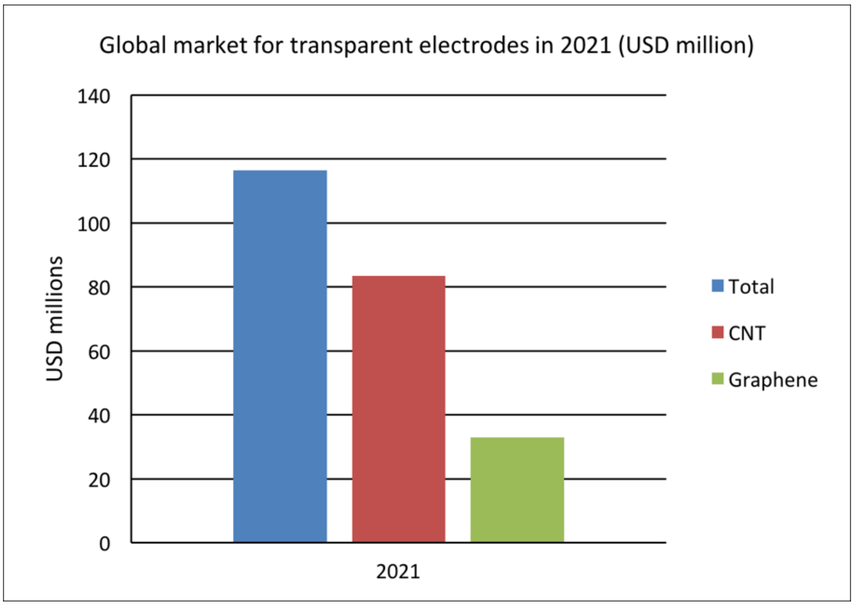

Figure A3.42. Global market for transparent electrodes in 2021 (USD millions)

Source: BCC Research 2016

Graphene is another promising material to replace ITO and has been investigated under the EU project GLADIATOR. The aim of the project is the cost-effective production of high quality graphene over a large area for electrode applications (e.g. integration in OLEDs)[365]. In terms of companies, the Chinese firm Chongqing Morsh Technology Co. Ltd is particularly active in the area, aiming to supply the Guangdong Zhengyang Technology Incorporated Company[366].

In 2021, the market for graphene transparent electrodes is predicted to be at least USD 66 million. This projection is based on data that assume that the graphene accounts for half of the cost of the electrodes, or USD 33 million in 2021. Combined sales of CNT and graphene transparent electrode materials could approach USD 116.5 million by 2021. [367] [368]

Other

Products by application market

Energy recovery systems for buildings

Energy recovery ventilation (ERV) is an energy recovery process in which the incoming air is treated (preconditioned) using the outgoing air of a building. Thus, for example, the incoming air can be pre-cooled and dehumidified in the summer or humidified and pre-heated in the winter[369]. The process leads to greater energy efficiency and reduced costs. A leader in the field is Dais Analytic Corporation, which uses nanotechnology in heating, cooling and refrigeration (NanoAir), energy storage (NanoCap supercapacitor) and water purification (NanoClear nanotechnology polymer), products that are at various stages of development and deployment (see https://daisanalytic.com) as well as in its ConsERV energy recovery ventilators using Aqualyte membranes.

While Dais Analytic Corp. does not publish separate data for its products, it has been

[365] http://cordis.europa.eu/news/rcn/128114_en.html

[366] Investorintel: Chinese Firms to launch First Mass Produced 15” Single-layer Graphene Film, March 27, 2013

[367] BCC Research, AVM075D Graphene: Technologies, Applications and Markets

[368] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.129-130

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

estimated[370] that its energy recovery ventilator applications (ConsERV and Aqualyte membranes) were worth USD 50,000 in 2015 and projected that sales could approach USD 4 million by 2021. If the membranes account for 5% of the total cost of a ConSERV system (similar to the share of nanostructured polymer membrane in a typical PEMFC or DMFC fuel cell), the revenue for the Aqualyte membrane could be as much as USD 200,000 by 2021.

Diesel fuel additives

Efforts to reduce diesel particulate emissions include the use of oxidation catalysts; diesel particulate filters (DPFs); low-sulphur diesel fuels; and fuel additives; some additives also improve fuel economy. One class of diesel fuel additives gaining acceptance comprises engineered nanomaterials composed of cerium compounds (nCe). These fuel additives also reduce fine particulate matter (PM2.5) emissions and alter the emissions of carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbon (HC) species, including several HAPs[371].

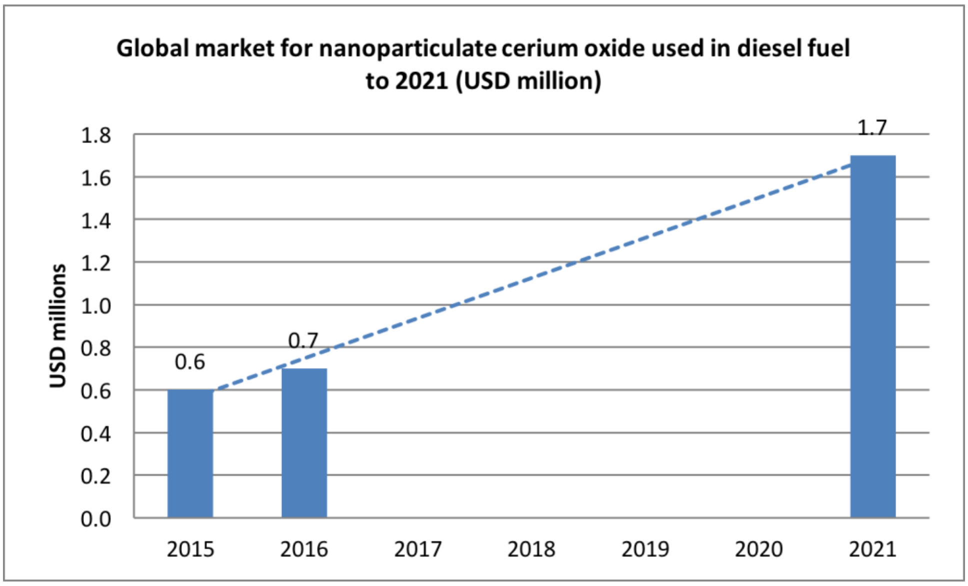

Figure A3.43. Global market for nanoparticulate cerium oxide used in diesel fuel to 2021 (USD millions)

Source: BCC Research

Energenics Ltd. does not publish sales data for its Envirox diesel fuel catalyst, which it acquired from Oxonica Ltd. in 2009. However, Envirox sales in 2015 were certainly much lower than they had been prior to 2007, when Oxonica had a contract to supply Petrol Ofisi (the Turkish national oil and gas company) with USD 12 million worth of Envirox per year. BCC Research estimates 2015 sales of Envirox at around USD 4 million, requiring the input of about USD 600,000 worth of cerium oxide nanocatalysts. For analytical purposes, BCC Research assumes that Energenics by 2021 will be able to restore sales of Envirox to at least the level it enjoyed before the loss of the Petrol Ofisi contract. Total Envirox sales in 2021 should thus be around USD 12 million, which would represent a 300% increase since 2015, or a CAGR of 19.4%. Such a level of Envirox sales could generate nearly USD 1.7 million in consumption of ceria nanopowders on a proportional basis in 2021[372].

Petroleum refining

Nanoparticulate catalysts used in petroleum refining include nanoparticulate iron and

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[370] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.142

[371] Green Car Congress: EPA researchers find widespread use of nano cerium diesel fuel additives could have measurable impact on air quality, 21 October 2014

[372] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.66

nickel for fluid catalytic cracking applications and molybdenum-disulphide (MoS_2) nanoclusters with cobalt and nickel nanoparticles for hydro-desulphurisation of petroleum. Many of these catalysts are proprietary, making it difficult to obtain much information about their properties, even to the extent of being able to confirm if they are in fact nanoscale (particularly in the case of the FCC [fluid catalytic cracking] catalysts). However, for market analysis purposes it is stipulated that they are in fact nanoparticulate[373].

It is difficult to estimate or segment global consumption of nanoparticulate refinery catalysts, in large part because many of them are proprietary. However, based on the available data, estimates of the overall market for nanocatalysts in the refining industry at USD 180 million in 2015. The projections in the figure below assume that the demand for refinery catalysts is proportional to the demand for refined petroleum products, and that the latter in turn is driven by trends in global GDP. After expanding by a projected 3.1% in 2016, global output is expected to increase at a CAGR of 3.4% over the next five years. [374]

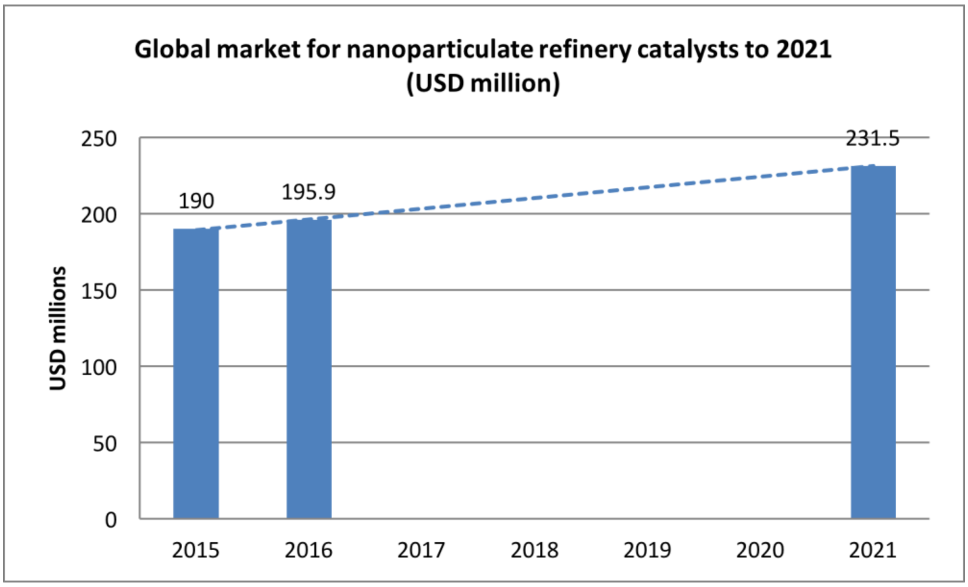

Figure A3.44. Global market for nanoparticulate refinery catalysts to 2021 (USD millions)

Source: BCC Research 2016

Synthetic fuel production

Liquid fuels from coal may be produced using two different approaches, i.e. direct and indirect coal liquefaction (DCL and ICL), which are at a different stage of development. In both DCL and ICL, the challenge is to increase the hydrogen to carbon (H/C) ratio of the final product, and to produce molecules with an appropriate boiling point at a reasonable overall cost[375]. The DCL process consists of the dissolution of coal in a mixture of solvents. This is followed by thermal cracking, whereby hydrogen is added as a donor solvent[376]. In the ICL process, the first step is the gasification of coal to produce a synthetic gas (syngas), which basically consists of carbon monoxide and hydrogen[377]. The second step consists of the conversion of the carbon monoxide and hydrogen in the syngas (using catalysts) to a range of hydrocarbon fuels/products such as gasoline,

[373] BCC Research (2014), Nanotechnology, a realistic market assessment, p.103

[374] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.67-68

[375] IEA ETSAP Technology Brief S02 – May 2010, p.1

[376] Ibid

[377] IEA ETSAP Technology Brief S02 – May 2010, p.3

diesel, methanol and chemicals)[378].

Nanoparticles used in HTI's coal liquefaction process include several proprietary nanoengineered catalysts, including catalysts synthesised from aqueous solutions of iron salts and using small percentages of cobalt, molybdenum, palladium, platinum, nickel, tungsten or combinations thereof. instead of the more common practice of allowing catalyst atoms to naturally form random geometric patterns on a support material, the HTI method guides these individual atoms into orderly and predictable arrangements[379]. HTI has also formed a strategic alliance with Axens (Rueil Malmaison, France) called "Alliance DCL" to provide a single-source solution for producing ultra-clean fuels by direct coal liquefaction alone or in combination with refinery residues or biomass. The two companies have combined their technologies and licensing activities for CTL projects worldwide[380].

HTI has entered into a process license agreement with Shenhua, China's largest coal company, for the world's first commercial-scale, direct coal-to-liquid-fuels plant. The Shenhua plant's first reactor began commercial production in 2010. The first reactor has a nominal annual capacity of 1.1 million tons per year (TPY) of low-sulphur diesel fuel, and gasoline from coal. Looking ahead to 2021, Shenhua's plant should have three reactors on line, with a total capacity of 6 million TPY of petroleum products. As of 2016, HTI is involved in project discussions, feasibility studies and engineering studies of other direct coal liquefaction plants in various countries. However, given the long lead times associated with such projects, it is not expected that any of these plants will be operating commercially by 2021.

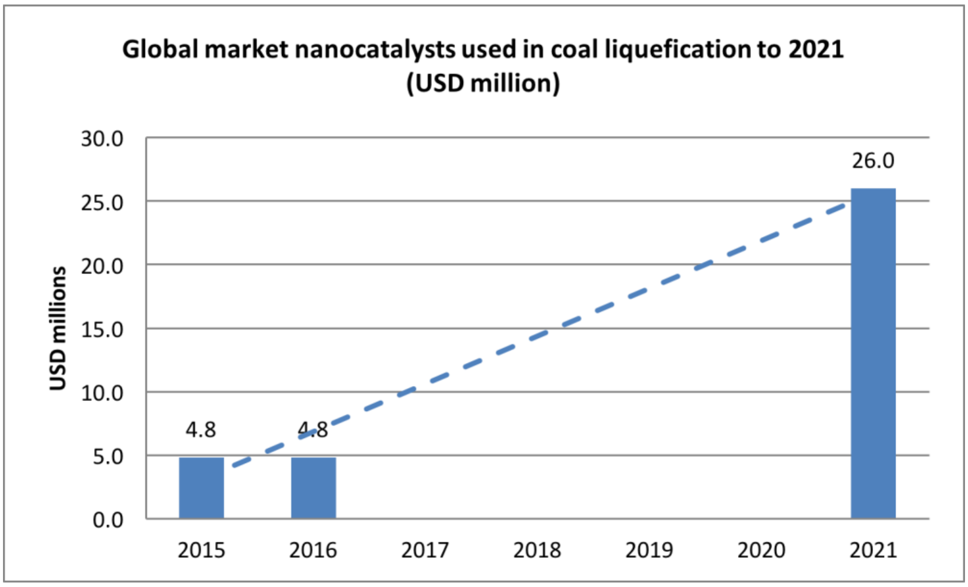

Figure A3.45. Global market for nanocatalysts used in coal liquefaction to 2021 (USD millions)

Source: BCC Research 2016

The cost of the nanocatalysts associated with the HTI coal liquefaction process are unknown, but a study of which several HTI employees are among the co-authors provides a general indication of the nanocatalyst costs. The study results, which date from about 1997, indicate an average catalyst cost of USD 0.34 per barrel of gasoline or similar product produced from coal, or about USD 0.62 in 2015. At this price, the Shenhua plant's annual consumption of nanocatalysts is on the order of USD 4.8 million in 2015 and 2016, based on its rated capacity of 1.1 million TPY. (The number of barrels in a ton of oil varies according to the type of oil, but it is generally around seven.) By

[378] http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/indirect-liquefaction

[379] BCC Research (2014), Nanotechnology, a realistic market assessment p.36

[380] Business Wire: Headwaters Incorporated and Axens Form Direct Coal Liquefaction Alliance, January 19, 2010

2021, the plant's nanocatalyst consumption is projected to reach USD 26 million, assuming it reaches its targeted output of 6 million tons[381].

Insulation for buildings

Aerogels are a porous, solid materials known for their extreme low densities (which range from 0.0011 to ~0.5 g cm-^{3}). In fact, the lowest density solid materials that have ever been produced are all aerogels, including a silica aerogel only three times heavier than air that could be made even lighter than air by evacuating the air out of its pores. In general, aerogels have densities of 0.020 g cm^{-3} or more (about 15 times heavier than air). Typically, aerogels are 95-99% air (or other gas) in volume, with the lowest-density aerogel ever produced being 99.98% air in volume[382]. Essentially an aerogel is the dry, low-density, porous, solid framework of a gel (the part of a gel that gives the gel its solid-like cohesiveness) with the liquid component removed. Aerogels are open-pored (that is, the gas in the aerogel is not trapped inside solid pockets) and have pores in the range of <1 to 100 nanometres (billionths of a metre) in diameter and usually <20 nm[383].

Aerogels have been prepared from many materials, including alumina, tungsten oxide, ferric oxide, tin oxide, nickel tartrate, cellulose, cellulose nitrate, gelatine, agar, egg albumen and rubber. However, most aerogels are formed from silica, hence their usual categorisation under that material. Aerogels reportedly have the highest thermal insulation value of any solid material[384].

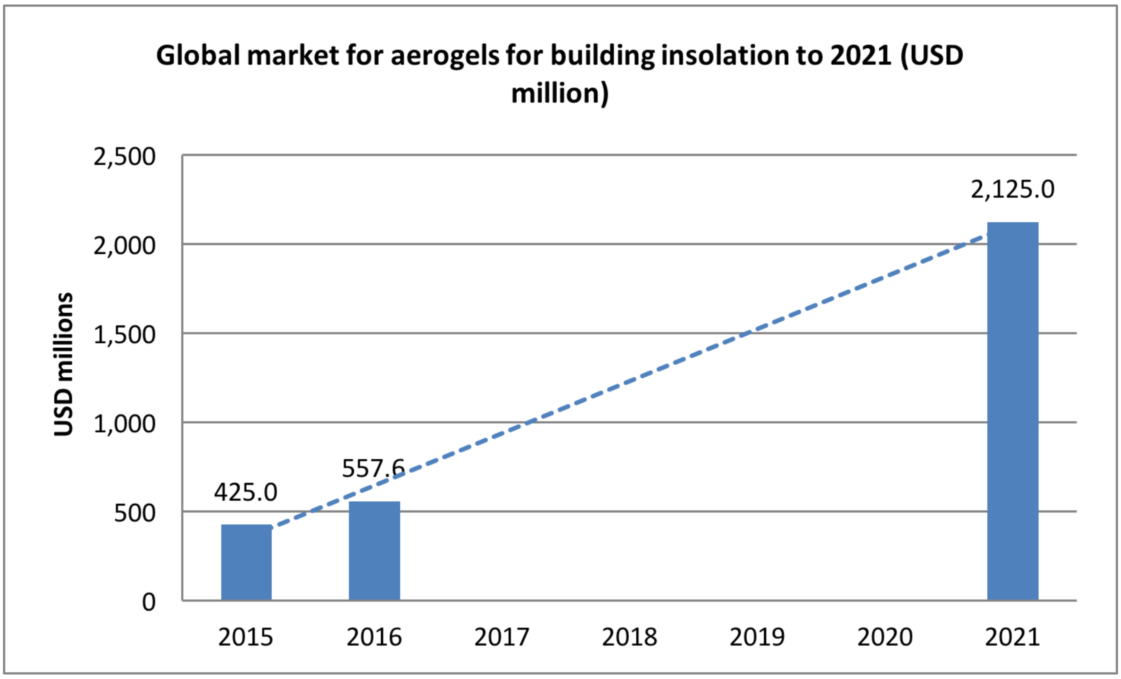

Figure A3.46. Global market for aerogels for building insolation to 2021 (USD millions)

Source: BCC Research 2016

The global consumption of aerogel insulation materials in 2015 was estimated[385] as USD 425 million. Silica aerogels are used commercially in a variety of applications, including oil and gas, aerospace, and cold-weather clothing. Over the next five years, the largest source of growth in the aerogel market is forecast for building insulation, which currently

[381] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.68

[382] http://www.aerogel.org/

[383] Ibid

[384] BCC Research (2014), Nanotechnology, a realistic market assessment, p.76

[385] BCC Research

has a total market estimate of USD 23 billion, growing to close to USD 29 billion in 2021. At present, aerogel insulation has about a 1.85% share of this market. As a benchmark for the potential market penetration of aerogels by 2021 cellulose insulation took about 10 years after its introduction in the early 1990s to capture a 15% share of the U.S. market. It seems unlikely that aerogel sales could go from USD 425 million in 2015 to USD 4.4 billion (i.e., 15% of the projected world market for building insulation), a nearly ten-fold increase, in just six years. However, a fivefold increase, to some USD 2.1 billion, might be achievable[386].

The next section of this annex looks at products in nanotechnology and photonics.

[386] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.139

5 Products and Markets for Photonics through Nanotechnology

The commercial applications of nanotechnology in the field of photonics include: lasers, and parts thereof; nano-engineered photonics materials; communications and all-optical signal processing; and nanoscale functional imaging and spectroscopy.

Commercialised products for photonics through nanotechnology: Overview

To date, 218 photonics-related products using nanotechnology have been identified as being commercially available.

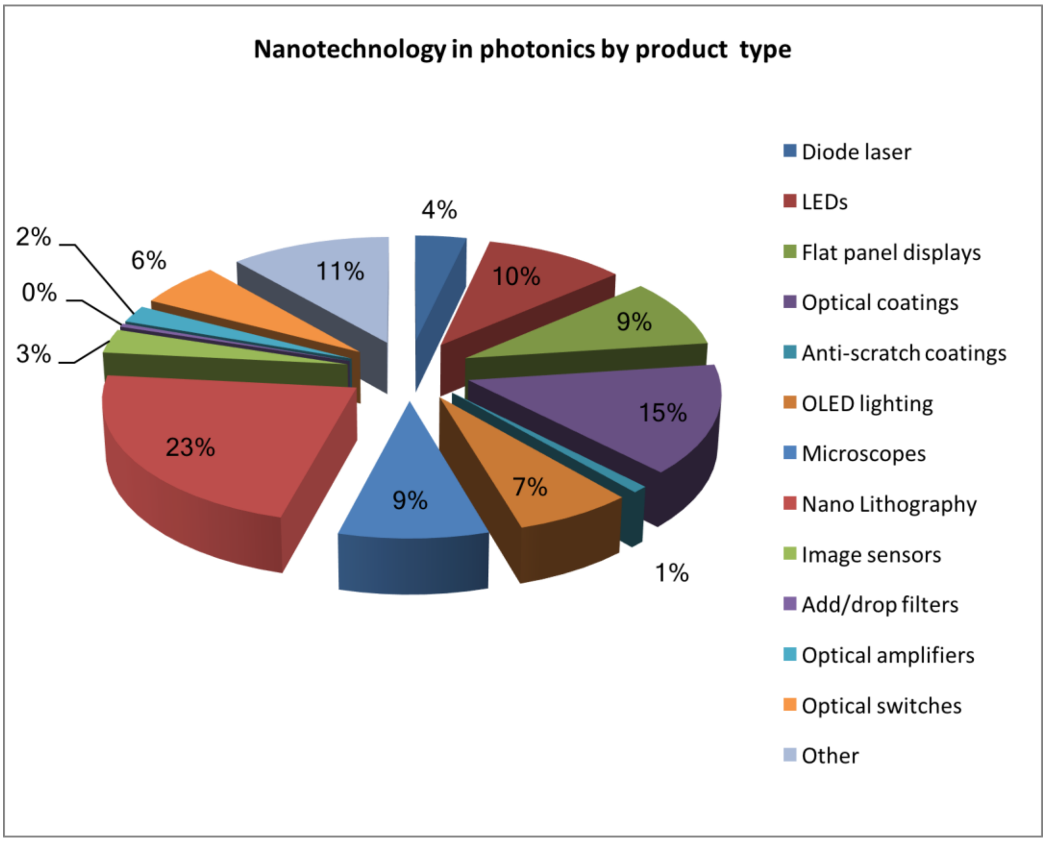

Figure A3.47. Nanotechnology products in photonics by product type

Source: JIIP, 2017

Around one-fifth (23%) of those are in the area of nano lithography. Optical coatings (15%) account for the second largest share among commercially available products as shown in the figure above. LEDs (10%), flat panel displays (9%), OLED lighting (7%) and optical switches (6%) make up the remainder of specific product types with a greater than 5% share. The category 'other' coves 11% of the total.

Products for photonics through nanotechnology, by application market

The products identified are divided as follows:

- Diode lasers;
- Light-emitting diodes (LEDs);
- Organic light-emitting diodes (OLEDs);
- Anti-scratch and anti-stick coatings;
- Optical recording media;

- Optical fibre cladding;
- High-pressure discharge lamp tubes;
- Near-field optical microscopes; and
- Advanced optical lithography tools.

In each case, details are given of the technology and its purpose, as well as market estimates and forecasts. Emerging applications are considered in a subsequent section. These are:

- Flat-panel displays using quantum dots;
- Digital image sensors;
- Transparent electrodes;
- Photonic add/drop filters;
- Optical switches;
- Optical amplifiers;
- Next generation lithography tools; and
- Holographic memory.

Products by existing application market

Diode lasers

Sales of quantum dots for use in semiconductor lasers are currently limited. However, quantum dot-based diode lasers show considerable long-term promise, particularly in the optical telecommunications market. The global consumption of semiconductor laser diodes in 2015 has been estimated as USD 1.3 million. The total global market for diode lasers was worth about USD 4.3 billion in 2015 and is projected to grow at a CAGR of 2% over the next five years. It has been forecast[387] that the market for quantum dot laser diodes will grow about twice as fast as the overall diode laser market (i.e., at an average annual rate of 4%). Given the difficulties of separating the cost of the quantum dot laser diodes from the rest of the solid-state laser diode, the numbers in the figure below reflect entire diode market.[388]

[387] BCC Research report NAN036B Nanotechnology for Photonics: Global Markets

[388] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.67

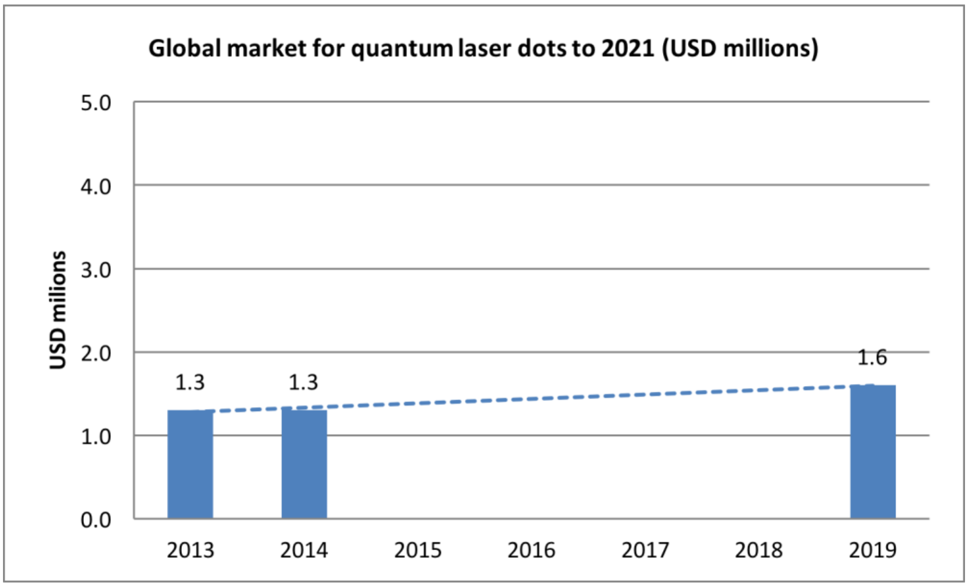

Figure A3.48. Global market for quantum laser dots to 2021 (USD millions)

Source: BCC Research

Light-emitting diodes (LEDs)

LEDs are used in an increasing number of lighting applications, replacing conventional light bulbs. Unlike conventional incandescent lamps (which convert electricity first into thermal energy and then to light), LED illumination is achieved when a semiconductor crystal is activated, directly producing visible light of a desired wavelength range[389]. Nevertheless, low-cost, mass-market white-light diodes with the potential to replace conventional incandescent bulbs and fluorescent tubes seem currently still out of the reach of LED researchers and manufacturers.

One possible solution is to use nanophosphors (i.e. semiconducting nanoparticles that emit light under excitation) in white LEDs. If the phosphor particles are smaller than 20 nm in diameter, according to Mie theory there will be less scattering of light waves and thus greater optical and energy efficiency[390].

The first commercial LED products incorporating nanoparticles were Nexxus Lighting's quantum dot-coated LED ceiling lamp fixtures, which began arriving on the market in small quantities in 2010. High-brightness LEDs may potentially use quantum dots or rare earth nanophosphors. The market for quantum dots used in LED applications could reach USD 50 million or more by 2021 and the demand for rare earth nanophosphors for LEDs is expected to be about the same[391].

Organic light-emitting diodes (OLEDs)

An OLED 'light bulb' is a thin film of material that emits light. OLED is currently the only technology that can create large area lighting panels (as opposed to the point or line lighting of LEDs and fluorescent bulbs). OLEDs can be used to make flexible and transparent panels, and can also be colour-tuneable, being the closest light source to natural light (with the exception of traditional incandescent lamps)[392].

Flexible signage and flexible lighting are being developed[393]: Philips Lighting's OLEDs

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

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

[391] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.72

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

[393] Michael Kanellos, "Start-up creates flexible sheets of light", CNet News.com, December 6, 2007

(brand name "Lumiblade") have been available online since 2009[394] and Novaled AG introduced a line of OLED desk lamps called "Victory" in September, 2011[395].

The market for OLED lighting was negligible in 2016, being mostly in niche applications such as high-end residential and commercial showroom installations. In the longer term, potential markets for OLED lighting include architectural lighting and backlighting for displays and signage, switches, keypads, instrument panels and automotive dashboards, the projected market in 2021 being forecast as USD 1 billion[396].

Backlighting applications are expected to represent the main market for OLED lighting between 2016 and 2021, with an initial emphasis on backlights on small displays, e.g. for mobile phones, later expanding into medium-sized and large flat-panel displays. The main competitor for OLED backlights comes from LEDs, which started replacing code cathode fluorescent lighting (CCFL) backlights around 2004. The global market for LED backlights in 2015 was estimated to be worth USD 4.3 billion, rising potentially to USD 1 billion by 2021, with the OLED thin film materials themselves accounting for about 50% of the total cost of the backlights, or USD 500 million[397].

OLED lights generally cast a diffuse light, which makes them more of a competitor for fluorescent tube lights than for directional lights. The global fluorescent lighting market is expected to reach at least USD 35 billion by 2021. As a benchmark for how large a share of the architectural lighting market OLEDs could capture by 2021, forecasters[398] looked at the market history of compact fluorescent lights' (CFLs). CFLs were introduced commercially in the early 1980s and by 2000 had captured about 3% of the residential lighting market. In view of the increased attention now being paid to energy-efficient lighting, OLEDs could capture a similar market share by 2021 and perhaps even take some market share from CFLs, which are encountering some resistance from buyers on aesthetic and performance grounds.

If OLED lamps succeed in capturing 3% of the global market that would otherwise be served by fluorescent lighting, their sales will be around USD 1.0 billion by 2021. If OLED thin film materials represent about 50% of the total cost of the lamps, their market value would be USD 525 million[399].

Types	Market in 2021 (USD million)
Backlighting	500.0
Architectural lighting	525.0

Table A3.7. Global market for OLEDs by type, 2021 (USD millions)

Source: BCC Research

OLED panel shipments were worth around USD 612.9 billion in 2015. Most of these panels were small-molecule displays used in mobile phones and small appliances. It has been estimated that, in 2015, the cost of the OLED thin film materials used in these

[394] http://oledworks.com/

[395] TMC NEWS: New OLED Luxury Luminaire Series Launched Under German Brand Name Liternity®, September 13, 2011

[396] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.128

[397] Ibid

[398] BCC Research

[399] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.129

displays was half of their total cost, or close to USD 6.5 billion. [400]

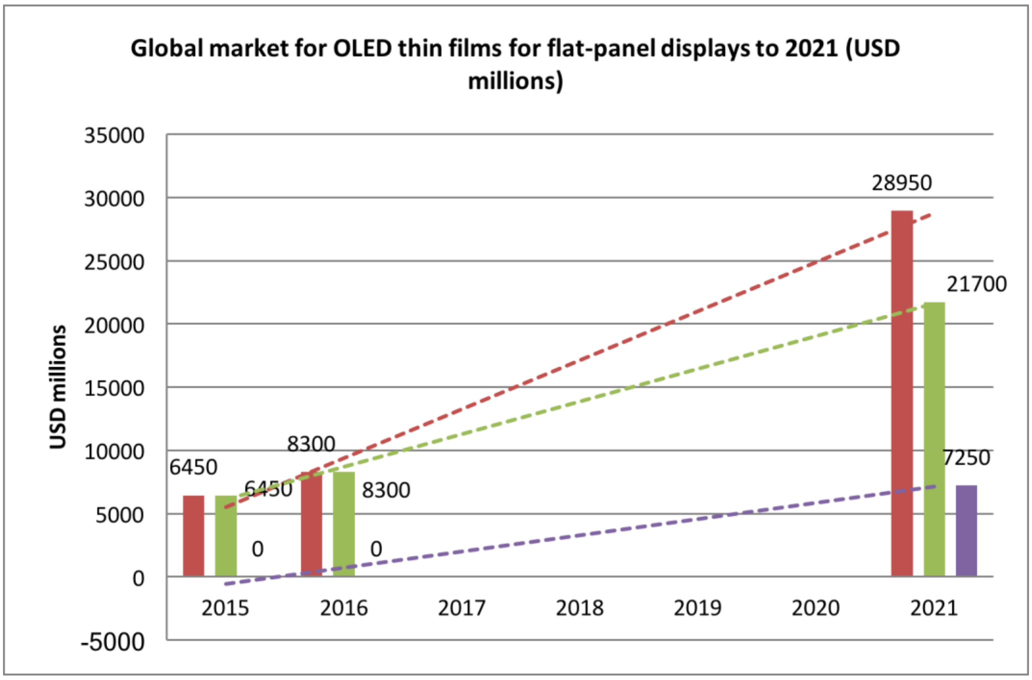

Table A3.8. Global market for OLED thin films for flat-panel displays to 2021 (USD millions)

Source: BCC Research 2016

Sales of polymer OLEDs were negligible in 2016. Manufacturing problems have prevented large-scale commercial production of polymer OLEDs. When these are solved, it is estimated that the polymer OLEDs will capture 25% of the market, worth USD 14.5 billion, by 2021. On this basis, sales of polymer OLED thin film materials should approach USD 7.3 billion by 2021. [401]

Anti-scratch/ anti-stick coatings

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

The total market for nanostructured anti-scratch coatings is estimated at 1,230 metric tonnes with a value of USD 93 million in 2015, growing to an estimated USD 104 million in 2016 and USD 202.2 million in 2021 (a CAGR of 14.2% between 2016 and 2021). The market for polyurethane/alumina nanocomposite floor finishes was estimated to be worth USD 56 million in 2015. The balance was divided between ophthalmic coatings (USD 23 million) and other miscellaneous applications (USD 14 million). [402]

Both ophthalmic coatings and floor finishes are relatively mature market segments that are expected to grow at a CAGR of around 8% from 2015 through 2021. The market for other types of anti-scratch coatings (especially auto clear-coat) is expected to grow much faster (at a CAGR of 32.7%) between 2016 and 2021[403]. The trends in global markets for alumina and other metal oxide nanoparticles use in anti-scratch coatings to 2021 are shown in the figure below.

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[400] BCC Research

[401] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.116-117

[402] BCC Research

[403] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.124

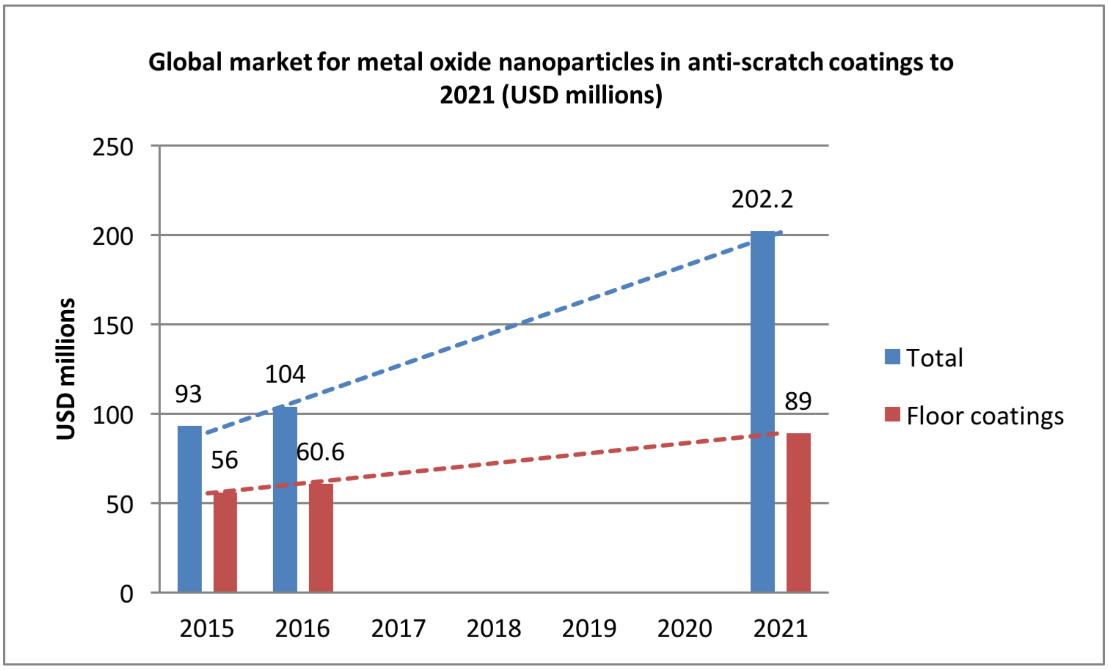

Figure A3.49. Global market for metal oxide nanoparticles in anti-scratch coatings to 2021 (USD millions)

Source: BCC Research

It is estimated[404] that sales in 2015 of polymer-based nanoscale thin film coating materials for eyeglasses, binoculars and cameras were about USD 32 million, based on sales figures for Nanofilm Ltd. Future sales of nanoscale optical coatings will depend on their ability to increase their penetration of the total eyeglass coating market, which, as shown in the table below, is slowly declining.

	2015	**2016**	**2021**	**CAGR% 2016-2021**
Eyeglass coating sales	832.7	831	822.7	-0.2

Table A3.9. Global eyeglass coating sales to 2021 (USD millions)

Source: BCC Research

Nanostructured polymer coatings' share of the total eyeglass coatings market was a little under 4% in 2015, with the potential to more than double their market share to about 8% by 2021, as shown in the figure below[405].

[404] BCC Research

[405] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.118-119

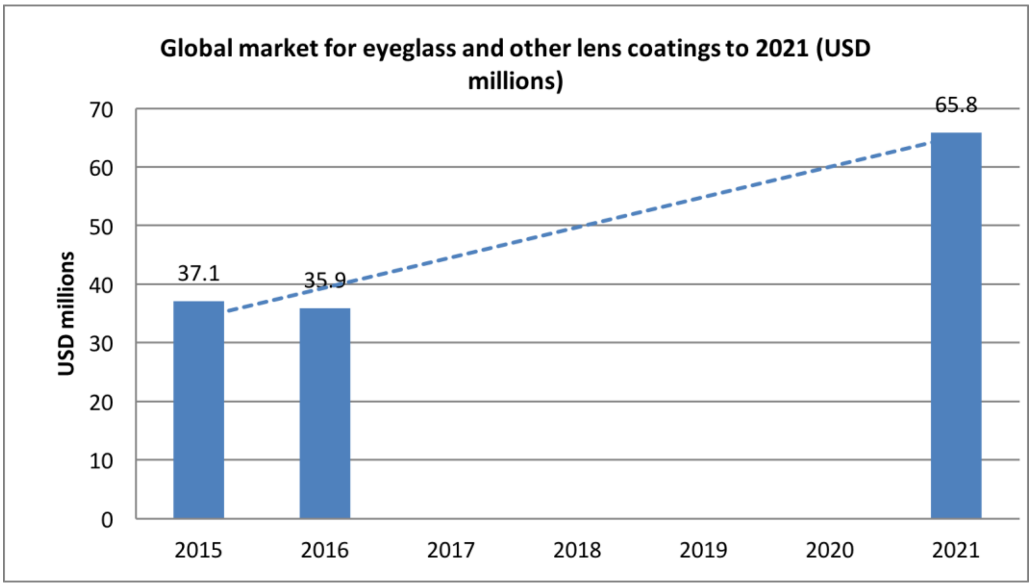

Figure A3.50. Global market for thin films coatings in eyeglass and other optical applications to 2021 (USD millions)

Source: BCC Research 2016

Optical recording media

In 2015, global consumption of nanostructured aluminium film materials used in the production of optical recording media (e.g. CDs and DVDs) was about 48 metric tonnes, with a value of USD 1.6 million. In the near- to mid-term, consumption will be driven by trends in unit sales. Data on total global shipments of optical recording media are hard to obtain, but the amounts are likely to decrease as alternative storage and delivery technologies gain market share. The figures in the table below assume that shipments of optical storage media are decreasing at a CAGR of -2.8%, with a proportional reduction in consumption of nanostructured aluminium thin film materials.

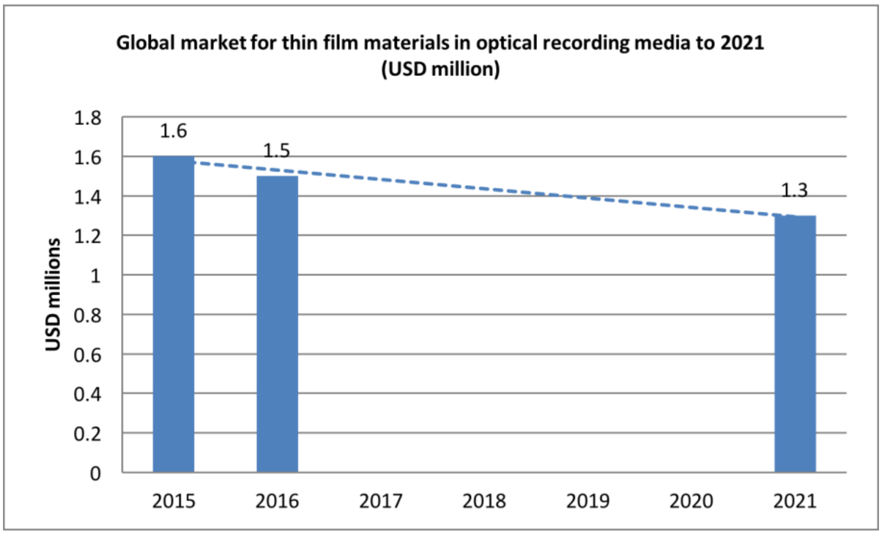

Figure A3.51. Global market for thin film materials in optical recording media to 2021 (USD millions)

Source: BCC Research 2016

Optical fibre cladding

Global consumption in 2015 of silica thin film nanomaterials used for fibre-optic cladding has been estimated at 1,820 tonnes and USD 28 million. Over the near- to mid-term, the market for silica-based nanoscale coatings will be driven chiefly by trends in output of fibre-optic cable. The latter is projected to grow from 182 million kilometres (km) in 2015 to 192.2 million km in 2016 and 252.4 million km in 2021, a CAGR of 5.6% over the next five years. The projections in the following figure assume that consumption of silica-based nano-thin-film materials grows in proportion to output of optical fibre cable[406].

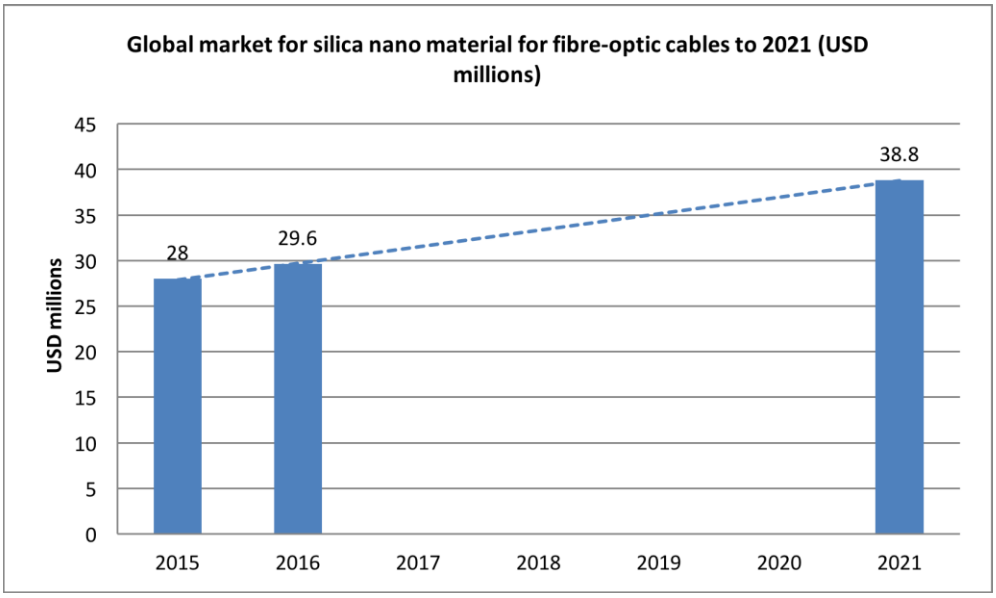

Figure A3.52. Global market for silica nanomaterials for fibre-optic cables to 2021 (USD millions)

Source: BCC Research 2016

High-pressure discharge lamp tubes

Nanostructured ceramic materials made using alumina nanopowders are being commercially produced for use in the translucent alumina arc tubes of high-pressure discharge (xenon) lamps, being normally used in conjunction with larger, submicron- or micron-scale powders to obtain the desired properties in the final sintered part. Each arc tube consumes about 3 g to 5 g of alumina powder, approximately 30% of which has nanoscale dimensions[407].

Total consumption of nanostructured ceramic materials in high-pressure discharge (xenon) lamp tubes in 2015 was 13 tonnes with a value of USD 3.3 million. The main market driver is forecast to be trends in transport i.e. sales of vehicles with this form of lighting. Once found only in luxury cars, xenon headlamps are available in a growing number of vehicles. The automotive market for xenon lamps to grow at a CAGR of 7.8% from 2016 to 2021, the same growth rate that is assumed for alumina consumption in the figure below[408].

[406] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.123

[407] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.75

[408] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.139

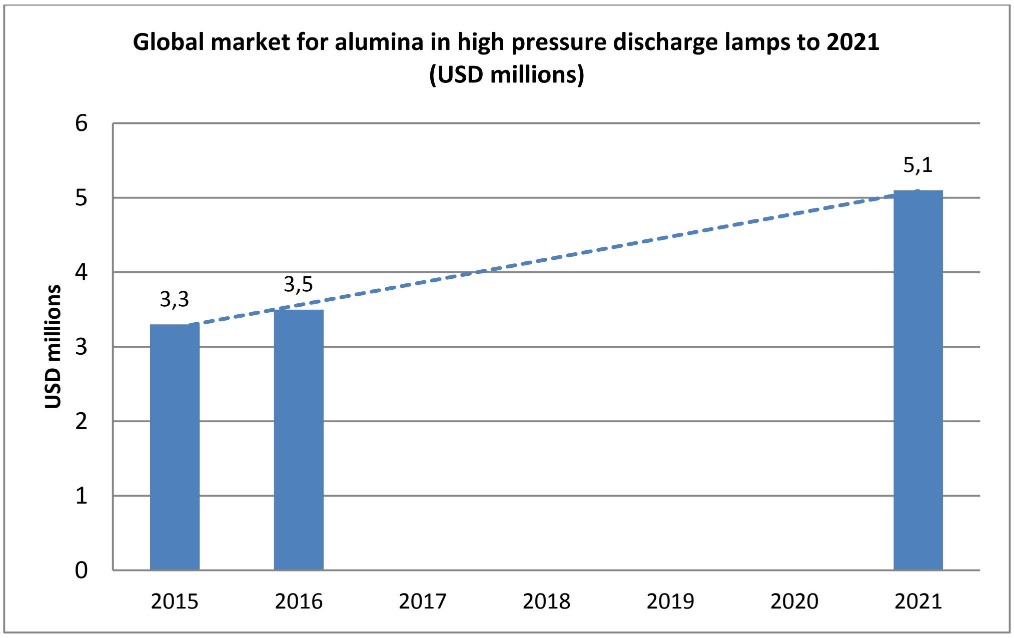

Figure A3.53. Global market for alumina in high pressure discharge lamps to 2021 (USD millions)

Source: BCC Research 2016

Near-field optical microscopes

Scanning near-field optical microscopy (SNOM), also known as near-field scanning optical microscopy (NSOM), is a scanning probe technique developed to overcome the spatial resolution constraints that traditionally limit conventional optical microscopy[409]. 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)[410] 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 lithography, and light-activated release of caged biochemical compounds[411] [412].

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 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

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

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

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

[412] "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

significant advantage of SNOM that remains is its ability to provide optical and spectroscopic data at high spatial resolution and with simultaneous topographic information[413].

The market for near-field optical microscopes was worth USD 68 million in 2015. Sales of SNOMs are expected to grow at a CAGR of 5.2% 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. [414]

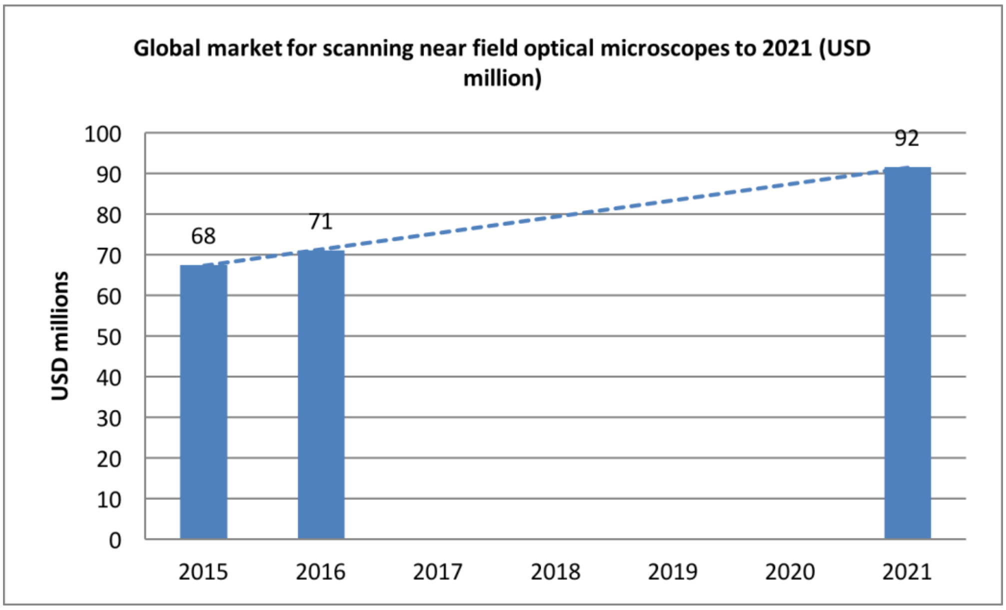

Figure A3.54. Global market for scanning near field optical microscopes to 2021 (USD million)

Source: BCC Research 2016

Advanced optical lithography tools

Optical lithography is the patterning of masks and samples with photoresist prior to other processing steps (e.g. deposition, etching, doping)[415]. The technology has enabled the size-reduction of semiconductor devices and integrated circuits[416]. 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[417].

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[418]. This technique effectively shortens the wavelength of the light involved while retaining resolution, and it has the potential to extend the capabilities of optical

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

[414] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.184

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

[416] Rothschild M et al. (2003), Recent Trends in Optical Lithography, Lincoln Laboratory Journal Volume 14, Number 2, 2003: 221

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

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

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[419]. The only manufacturers that are currently selling immersion lithography systems are ASML, Canon, and Nikon[420].

Mask-less optical lithography is enabling the development of a competing technology. In mask-less lithography, the radiation used to expose a photosensitive material is in the form of a narrow beam[421] and no mask is needed. The beam is used to 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)[422]. 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[423].

The FP7 project MAGIC (MAsk-less lithoGraphy for integrated circuits (IC) manufacturing) 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 use of these tools in an industrial environment[424].

Mapper Lithography[425] (Delft, Netherlands) has developed a 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.

It is estimated that optical immersion tool manufacturers delivered about 100 immersion lithography tools in 2015. At a cost of about USD 45 million each, these tools represented a USD 4.5 billion market in 2015. It is expected that the delivery of new optical immersion tools will peak at 127 units (USD 5.1 billion) in 2016, and then increase slightly by 2021, as next-generation nano-lithographic technologies such as nano-imprint and extreme ultraviolet lithography begin to come online[426].

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

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

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

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

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

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

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

[426] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.190

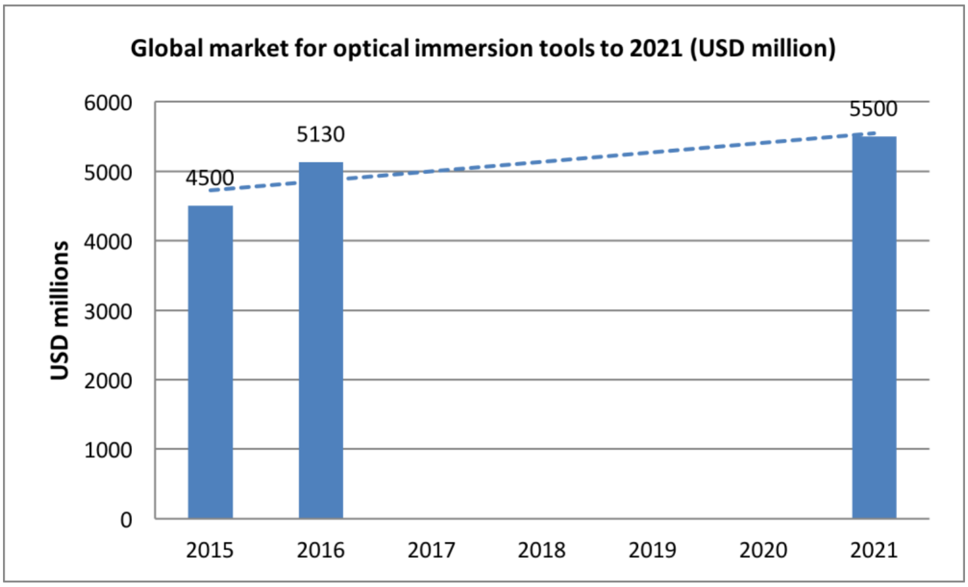

Figure A3. 55. Global market for optical immersion tools

Source: BCC Research 2016

Products by emerging market

Flat-panel displays using quantum dots

Quantum dots are nano-sized colloidal semiconductor particles with bandgaps that are tuneable based on the size of the colloid. They have been incorporated into display technology under development at QD Vision, Inc. There, the quantum dots are combined with organic molecules and processed into plastic electronics to create innovative solid-state displays. Organic materials are promising materials for light-emitting devices, including displays, because they can be made inexpensively, can be deposited on flexible substrates, and have good brightness levels[427].

QD Vision Inc. and Sony Corporation began to sell LCD TVs incorporating its so-called 'Color IQ™' fin the first half of 2013. QDEF™, jointly developed by Nanosys and 3M, has been used in Kindle Fire HDX tablets (by Amazon) since November 2013[428].

Meanwhile QD Vision is working on flat panel displays based on quantum dot LED (QD-LED) technology that could reach the market by 2019. The structure of QD-LED is similar to organic light-emitting diodes (OLEDs) but uses quantum dots (cadmium selenide (CdSe) nanocrystals) as its light source. If QD-LED becomes successfully developed, it is expected to compete strongly with existing technologies, particularly in the area of colour quality[429]. However, based on the experience of OLED displays, quantum dot displays are likely to remain a niche product through 2019[430].

Digital image sensors

Digital image sensors are used to record electronic images and are, for example, used in digital cameras to record images (in conjunction with a colour separation device and signal processing circuitry). The two main technologies used to fabricate digital image sensors are CCD (charge coupled device) and CMOS (complementary metal-oxide

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[427] Coe-Sullivan S (2006), The Application of Quantum Dots in Display Technology, Material Matters Volume 2 Issue 1

[428] IHS Technology – Abstract: - Quantum Dot Display Technology - 2014

[429] Headlines an Global News: New Research Improves QD-LED Displays by Using Engineered Quantum Dots, Oct 26, 2013

[430] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.137

semiconductor) technologies[431].

InVisage Technologies (Menlo Park, Calif.) is commercialising its 'QuantumFilm' technology with the aim of replacing conventional complementary metal-oxide semiconductor (CMOS) image sensors. It uses quantum dots suspended in a special polymer film that is "spun" or painted onto a traditional CMOS wafer. The quantum dot film captures the light that hits the top of the chip and sends it directly to the silicon chip, unlike a conventional CMOS image sensor in which light typically has to pass through layers with metal connections (leading to significant (50%) light loss) before it hits a photo detector. InVisage predicts that it can create a sensor that is four times more sensitive to light with twice the dynamic range of the typical CMOS sensor, leading to higher resolution for cameras and much better low-light performance, particularly relative to sensors used in current camera phones[432].

InVisage Technologies is targeting high-end mobile phone handsets with their QuantumFilm image sensors. Using Philips' Luxeon LED flashlight for mobile phones as a benchmark, it is estimated that 100 million QuantumFilm sensor-equipped handsets will be sold in 2021. Like QuantumFilm sensors, the Luxeon flash is targeted at smartphones and other high-end mobile phone handsets, to produce brighter, clearer images. QuantumFilm sensors are expected to cost the same as the CMOS sensors they replace (about USD 5 each) giving a total market of USD 500 million in 2021. The exact cost of the quantum dot film in a QuantumFilm sensor is not known, but according to InVisage, the incremental cost is minimal. For analytical purposes, if the quantum dot film adds 5% to the cost of the sensor, about USD 25 million worth of quantum dots will be required[433].

Transparent electrodes/ Transparent conducting oxides

Transparent conducting oxides (TCOs) are electrical conductive materials with low light absorption that are used in opto-electrical devices such as solar cells, displays, opto-electrical interfaces and circuitries. They are usually prepared using thin film technologies.[434]

To date, the industry standard in TCO is ITO, or tin-doped indium-oxide. Currently used in touch screens, LCD displays, solar cells, OLEDs and other electronic devices, the annual consumption of ITO is approximately USD 1 billion for the material alone (i.e., excluding deposition costs). Two nanomaterial-based thin film technologies are candidates to replace indium tin oxide (ITO): transparent carbon nanotube-based electrodes (such as the product Unidym is planning to launch in the near future) and graphene-based electrodes. Combined sales of these two transparent electrode materials could approach USD 116.5 million by 2021.

CNT-based transparent electrodes could capture one-sixth of the market from indium tin oxide electrodes within four years of commercialisation. If CNT electrodes reach the commercial market in 2017, sales could thus reach USD 167 million by 2021. If carbon nanotubes represent about half of the cost of the electrodes (similar to the figure for FED TV displays), the related market for CNTs could be close to USD 84 million by 2021.

Graphene is another promising material to replace ITO and has been investigated under the EU project GLADIATOR. The aim of the project is the cost-effective production of high quality graphene over a large area for electrode applications (e.g. integration in OLEDs)[435]. In terms of companies, the Chinese firm Chongqing Morsh Technology Co. Ltd is particularly active in the area, aiming to supply the Guangdong Zhengyang Technology

[431] https://illumin.usc.edu/101/the-digital-image-sensor

[432] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.42-43

[433] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.74

[434] Andreas Stadler (2012), Transparent Conducting Oxides — An Up-To-Date Overview. Materials 2012, 5: 661

[435] http://cordis.europa.eu/news/rcn/128114_en.html

Incorporated Company[436].

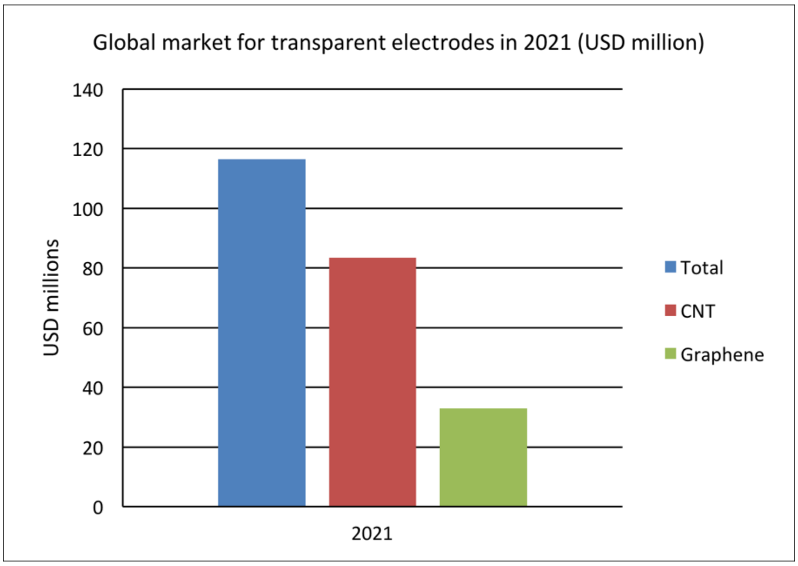

Figure A3.56. Global market for transparent electrodes in 2021 (USD millions)

Source: BCC Research 2016

In 2021, the market for graphene transparent electrodes is predicted to be at least USD 66 million. This projection is based on data that assume that the graphene accounts for half of the cost of the electrodes, or USD 33 million in 2021. Combined sales of CNT and graphene transparent electrode materials could approach USD 116.5 million by 2021. [437] [438]

Photonic add/drop filters

Starting with a collection of signals propagating down a waveguide (called the bus waveguide), a channel-drop filter picks out one small wavelength range (channel) and reroutes (drops) it into another waveguide (called the drop waveguide)[439]. Channel-drop filters are important for optical communications and other applications.

A number of technologies are used in today's channel add/drop filters, including Mach–Zehnder interferometers, grating-assisted mismatched couplers and multiport circulators. However, existing add/drop filters can only extract and redirect a few distinct, well-separated wavelengths. Accordingly, known drop filters are not fully satisfactory for use as an extraction device in a wavelength division multiplexing (WDM) system that requires the capability of extracting carrier signals carried by light having a large number of different wavelengths. The use of nanocomposites should make it possible to construct a channel add/drop filter that reroutes the desired channel into the drop waveguide with 100% transfer efficiency (i.e., no losses, reflection or cross-talk), while leaving all other channels in the bus waveguide to propagate unperturbed.

No nanocomposite add/drop filters are currently on the market, but they are being seen as one of the most promising applications of these materials in photonics[440]. The forecast is for sales of all types of optical add/drop filters to approach USD 1.6 billion by 2021[441]. If a commercial project can be brought to the market in the next few years, they could capture 10% of the total market by 2021, for total sales of USD 160 million, making a

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[436] Investorintel: Chinese Firms to launch First Mass Produced 15″ Single-layer Graphene Film, March 27, 2013

[437] BCC Research, AVM075D Graphene: Technologies, Applications and Markets

[438] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.129-130

[439] http://ab-initio.mit.edu/photons/ch-drop.html

[440] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.91

[441] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications

value of USD 53 million in 2021, material costs being about one-third of the total value in these types of electronics[442].

Optical switches

Optical switches (all-optical fibre-optic switching devices) maintain the signal in the form of light from input to output, traditional switches for optical fibre lines being electro-optic (converting light (photons) from the input side to electrons internally in order to do the switching and converting the electrons back to photons on the output side). Optical switches support all transmission speeds and unlike electronic switches which have specific data rates and protocols, optical switches direct the incoming bitstream to the output port no matter what the line speed or protocol (IP, ATM, SONET) and do not have to be upgraded to deal with any changes. Optical switches can also separate signals at different wavelengths and direct them to different ports[443].

Quantum dots (nano-sized semiconductor particles) can help to improve the performance of all-optical switches by allowing for higher switching, although no quantum dot optical switches are yet on the market and it is uncertain when they will be. Given their advantages over competing technologies, through concerted efforts quantum dot switches could reach the market before 2021. Optical switches are forecast to achieve a market value of over USD 1.3 billion by 2021, of which quantum dot switches have been forecast to potentially capture 2% to 5% (USD 26 million to USD 65 million, or a mean of USD 45.5 million) by 2021. Again using the estimate that material costs represent nearly one-third of the total cost of such devices, the market for PBG nanocomposites in optical switches could reach USD 15 million by 2021. [444]

Optical amplifiers

To be able to transmit signals in optical communication systems over long distances (>100 km) attenuation losses within the fibre must be compensated, conventionally using an optoelectronic module consisting of an optical receiver, a regeneration and equalisation system, and an optical transmitter, a system limited by the optical-electrical and electrical-optical conversions. Optical amplifiers have been developed to overcome these drawbacks, the two types most commonly in use being semiconductor optical amplifiers (SOA) and rare earth-doped fibre amplifiers (erbium – EDFA 1500 nm, praseodymium – PDFA 1300 nm)[445].

Optical amplifiers using quantum dots offer an ultrawide operating wavelength range, suppressed waveform distortion in high power output, and capability of noise reduction (signal regeneration) by limiting amplification.[446] With these features, quantum-dot devices have been developed targeting applications in optical communication systems such as inline, booster, and preamplifiers, and are currently in the commercialisation stage. The application is not limited to optical amplifiers, but also includes the light sources for sensors, gyroscopes, optical coherence tomography, etc., and the gain elements integrated into wavelength-tuneable lasers and mode-locked lasers[447]. While the development of quantum dot amplifiers has proceeded rapidly, commercialisation appears to be at least several years away. Reportedly there is still much room for improving the quality of the crystal to eliminate polarisation sensitivity and gain inequality. A further commercial obstacle to commercialisation of quantum dot amplifiers is telecommunications carriers' large investment in existing amplifier technologies,

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[442] Ibid

[443] http://www.pcmag.com/encyclopedia/term/48554/optical-switch

[444] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.172

[445] Kostuk R (2006), Optical Amplifiers, mimeo

[446] Akiyama T, et al. (2006), Quantum-Dot Semiconductor Optical Amplifiers, IEEE LEOS - Lasers & Electro-Optics Society Newsletter, February 2006 Volume 20, Number 1, p.11

[447] Akiyama T, et la. (2006), Quantum-Dot Semiconductor Optical Amplifiers, IEEE LEOS - LASERS & ELECTRO-OPTICS SOCIETY Newsletter, February 2006 Volume 20, Number 1, p.11

especially erbium amplifiers[448].

While nanoparticle-based optical amplifiers were not yet commercially available in 2016, it has been forecast that global sales of all types of optical amplifiers will reach USD 3 billion by 2021, and that quantum dot PBG nanocomposite devices could capture 10% of this market, or USD 300 million in total sales, by 2021. With the estimate that material costs represent nearly one-third of the total cost of such devices, the consumption of quantum dot PBG nanocomposites is projected to reach USD 100 million by 2021[449].

1. *Next-generation nanolithography tools*

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[450].

Extreme UV lithography (EUVL) is generally accepted as the leading candidate[451], extending optical lithography by using wavelengths in the range of 11 to 14 nm to shrink the size of features printed[452]. Repeated delays in the commercialisation of EUVL have made companies reluctant to pursue it in the short term.[453] 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 material is in the form of a narrow beam[454] and no mask is needed. The beam is used to 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)[455]. 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[456]. 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 lithography patterns from one run to the next, without incurring the cost of generating a new photomask. This may prove useful for double patterning[457].

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 principle makes NIL capable of

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[448] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.92

[449] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.173

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

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

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

[453] 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

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

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

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

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

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[458]. Canon recently acquired the semiconductor unit of Molecular Imprints (MII), a supplier of nanoimprint tools. That group is called Canon Nanotechnologies (CNT)[459].

Applications	**Global market (USD millions)**			**CAGR% 2016-2021**
	2015	2016	2021	
Extreme ultraviolet lithography	500	750	6,250	58.2
Mask-less optical lithography*	0.0	0.0	125	–
Nanoimprint lithography	50	50	50	0.0

Table A3.10. Global market for developmental nanotool applications, through 2021 (USD millions)

Source: BCC Research

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 2021. The market for these systems, including those sold for R&D purposes, was USD 550 million in 2015 and should reach USD 800 million in 2016, and more than USD 6.4 billion by 2021[460].

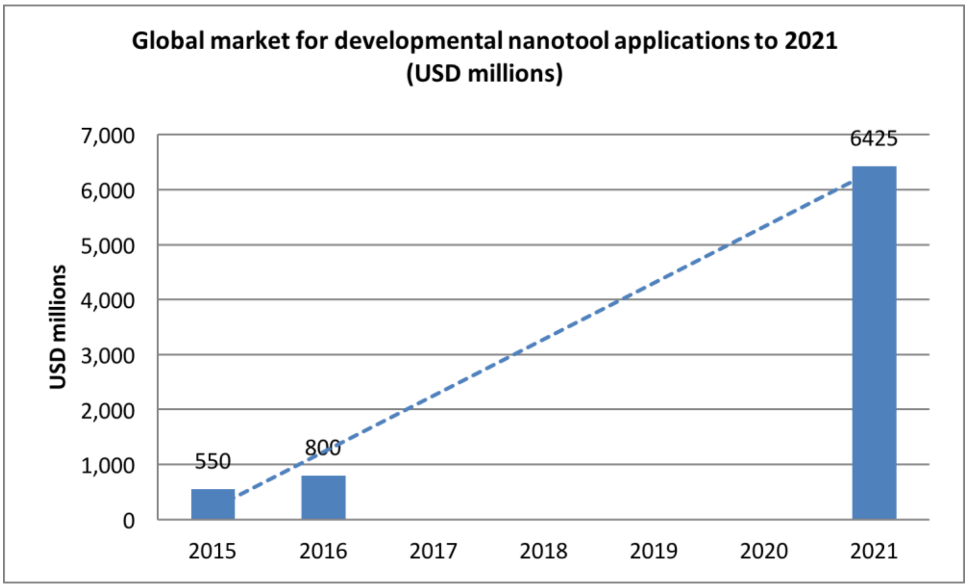

Figure A3.57. Global market for developmental nanotool applications to 2021 (USD millions)

Source: BCC Research

[458] Lan, H, Ding, Y (2010), Nanoimprint Lithography, in: Wang, M. (ed.), Lithography, pp. 656-657

[459] Semiconductor Engineering: What Happened To Next-Gen Lithography? September 3rd, 2014

[460] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications p.185

Holographic memory

In holographic data storage, a ‘data beam’ holding information is crossed with a ‘reference beam’ to produce an interference pattern that is recorded in a light-sensitive material. To retrieve data from a particular spot, a reference beam is shone onto it, and the combination of the reference beam and the patterned material reconstructs the original data beam, which is read and translated into a series of electrical signals. The recording material is typically either an inorganic crystal or a polymer. Polymers are more sensitive and require less powerful lasers, but they have disadvantages also, e.g. that they can deform, thereby corrupting the data[461]. Holographic memory offers the possibility of storing 1 terabyte (TB) of data in a sugar-cube-sized crystal. Data from more than 1,000 CDs could fit on a holographic memory system. Most computer hard drives only hold 10 to 40 GB of data, a small fraction of what a holographic memory system might hold[462].

Sales of nanodevices currently under development, primarily nanostructured holographic memory, are projected to reach USD 50 million by 2021[463].

The next section of this annex considers products and markets for environment through nanotechnology.

[461] MIT Technology Review: Holographic Memory, September 1, 2005

[462] How Stuff Works Tech: How Holographic Memory Will Work,

[463] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.192

6 Products and Markets for Environment through Nanotechnology

Commercialised products for environment through nanotechnology: Overview

To date, 40 products related to environmental remediation and using nanotechnology have been identified as being commercially available. Almost half (45%) of these are in the area of water remediation, filter systems and membranes are being used in the purification and remediation of water in particular. Products in air remediation account for the second largest share (32%) as shown in the figure below, comprising filter systems and photocatalytic coating applications.

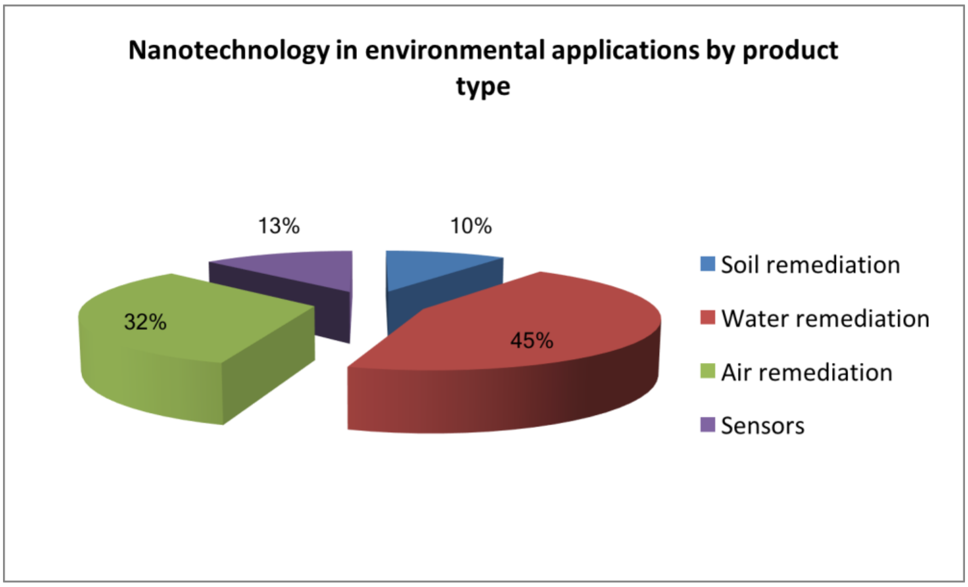

Figure A3.58. Nanotechnology products in environment, by product type

Source: JIIP, 2015

Products for transport through nanotechnology, by application market

The products reported on here are as follows:

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

Soil remediation[464]

There are three different types of use of nanomaterials in soil remediation: natural, incidental and engineered. Natural applications refer to the *in situ* use of nano-organic particles, such as bacteria, in remediation. In incidental remediation, the contaminated soil is removed and stored and/or treated *ex situ*. In engineered applications, remediation is done *in situ* with the help of engineered nanomaterials.

The market for natural applications of nanotechnology in soil remediation was forecast to grow by 5% from USD 2.4 billion in 2014 nearly USD 2.6 billion in 2015 and, at a five-year CAGR of 5.8%, to reach USD 3.4 billion in 2020.

[464] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market

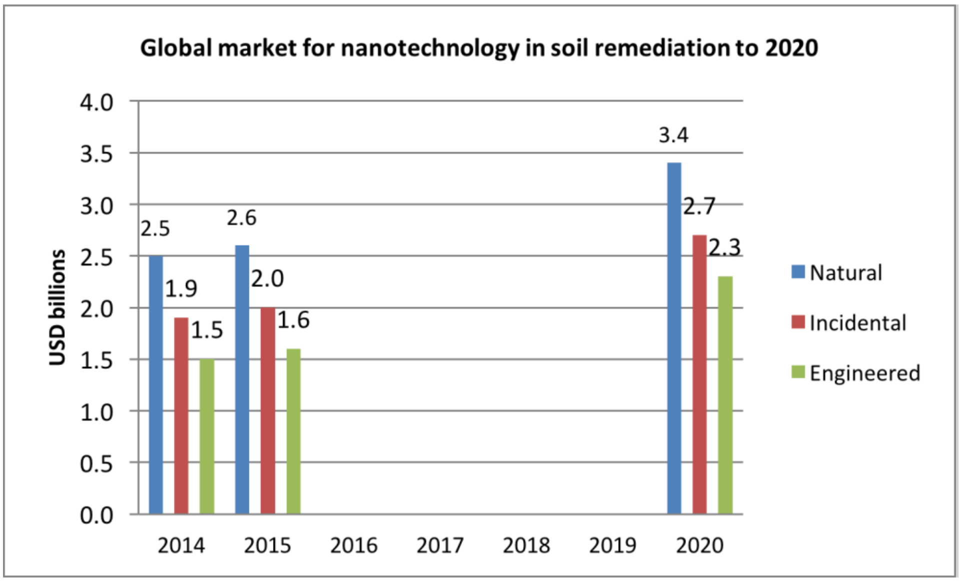

Figure A3.59. Global market for nanotechnology in soil remediation to 2020 (USD billions)

Source: BCC Research 2015

Nano-wires comprising potassium manganese oxide are being used in recent times for the cleaning up of oil spills and other organic pollutants, while making oil recovery possible. The market for incidental applications of nanotechnology in soil remediation is expected to rise from nearly USD 2 billion in 2015 to USD 2.7 billion in 2020 (CAGR 6.5%). It is forecast that the nanotechnology market for engineered applications in soil remediation will increase from USD 1.6 billion in 2015 to reach nearly USD 2.3 billion in 2020 (CAGR 7.2%).

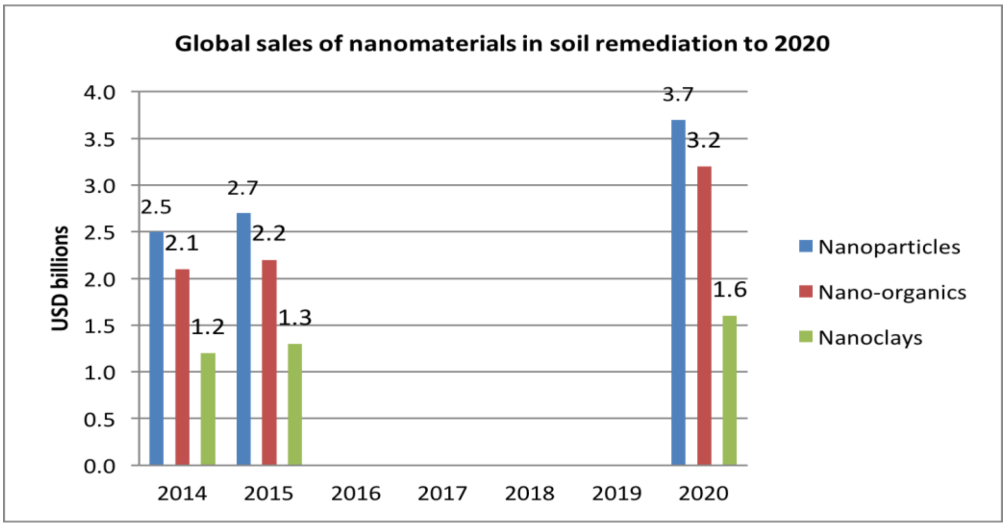

Figure A3.60. Global market for nanomaterials in soil remediation to 2020 by type of material (USD billions)

Source: BCC Research 2015

The nanotechnology market for nanoparticles used in soil remediation is forecast to rise from nearly USD 2.7 billion in 2015 to USD 3.6 billion in 2020 (CAGR of 6.5%).

The market for nano-organics used in soil remediation is forecast from USD 2.2 billion in 2015, to USD 3.1 billion in 2020 (CAGR 7.1%) while the market for nanoclays is forecast to be USD 1.6 billion in 2020, up from nearly USD 1.3 billion in 2015 (CAGR 5%).

Air remediation [465]

The nanotechnology market for adsorption of dioxins is expected to increase from USD 1.9 billion in 2015 to around USD 3 billion in 2020 (CAGR 9.2%). Acetaldehyde, toluene, and hexane are the three major components of organic air pollution, effectively removed from air and degraded by the nanocatalyst.

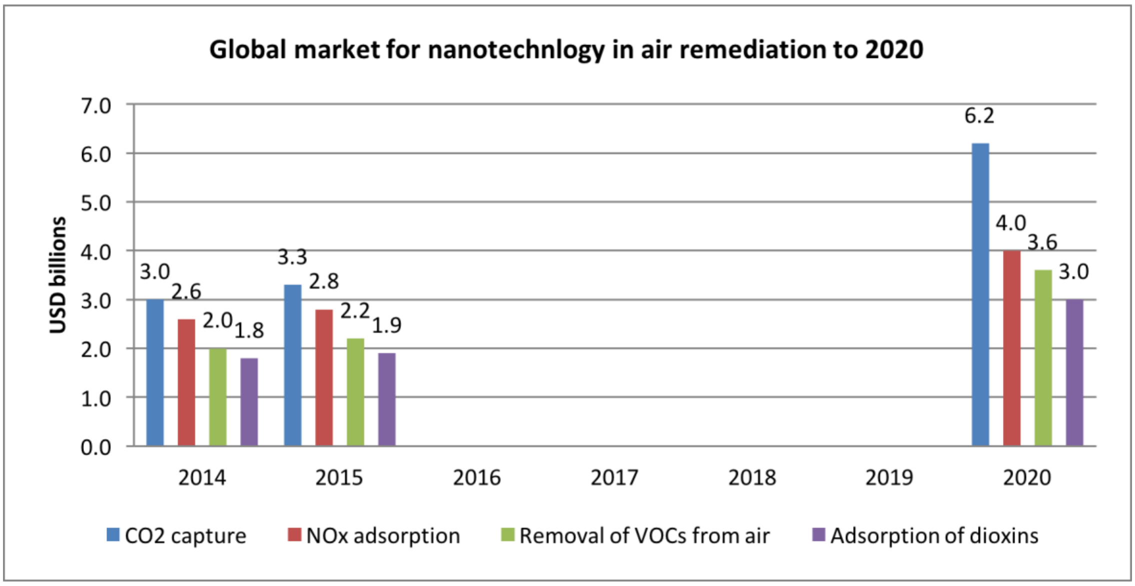

Figure A3.61. Global market for nanotechnology in air remediation to 2020 (USD billions)

Source: BCC Research 2014

The nanotechnology market for NOx adsorption is expected to rise from USD 2.8 billion in 2015 to USD 4 billion in 2020 (CAGR 7.5%). Porous manganese oxide nanomaterials embedded with gold nanoparticles are being used for the removal of volatile organic compounds (VOCs), nitrogen oxides and sulphur oxides from air at room temperature. These VOCs are potentially hazardous to human health and the environment.

The market for CO_2 capture using nanotechnology is expected to increase from USD 3.3 billion in 2015 to around USD 6.2 billion in 2020 (CAGR of 13.1%).

The forecast is for the nanotechnology market for removal of VOCs from air to rise from 10% to USD 2.2 billion in 2015 to USD 3.5 billion in 2020 (CAGR of 10.4%). Nanotechnology materials are being used to remove VOCs as well as nitrogen and sulphur oxides from air at room temperature, which in turn is driving the market for nanotechnology used in air remediation.

It is also expected that the nanotechnology market for titanium dioxide used in air remediation will increase from around USD 5.3 billion in 2015 to USD 8.9 billion in 2020 (11.1% CAGR).

The nanotechnology market for zinc oxide used in air remediation is expected to reach nearly USD 1.8 billion in 2015, up 10.7% from USD 1.6 billion in 2014, and is projected to show further growth at 12.2% CAGR in the five-year period to reach USD 3.1 billion in 2020. Site-selective deposition (SSD) of metal oxide thin films has been developed to fabricate nano/microstructures of metal oxide such as TiO_2, Fe_3O_4, ZnO, and Y_2O_3, Eu, etc. Several conceptual processes for SSD using self-assembled monolayers (SAMs) as templates were proposed, and nano/micropatterns of ceramic thin films were successfully fabricated. These different nano compounds are being successfully used for air remediation, which in turn is driving the market.

[465] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market

The forecast is for the nanotechnology market for tungsten oxide used in air remediation to increase to USD 892.3 million in 2015, up 5.9% from USD 842.4 million in 2014, and is expected to further grow at a five-year CAGR of 6.3%, to reach USD 1.2 billion in 2020. This report expects the nanotechnology market for ferrosoferric oxide used in air remediation to rise 6.9% to USD 400.3 million in 2015, from USD 374.4 million in 2014. In addition, the category is expected to grow at a five-year CAGR of 7.3%, to reach USD 568.4 million in 2020.

It is expected that the nanotechnology market for other compounds used in air remediation will increase from about USD 1.9 billion in 2015 to USD 2.9 billion in 2020 (CAGR 8.8%). Catalysts work by speeding up chemical reactions that transform harmful vapours from cars and industrial plants into harmless gases and those currently in use include nanofibre catalysts made of manganese oxide that removes VOCs from industrial smokestacks.

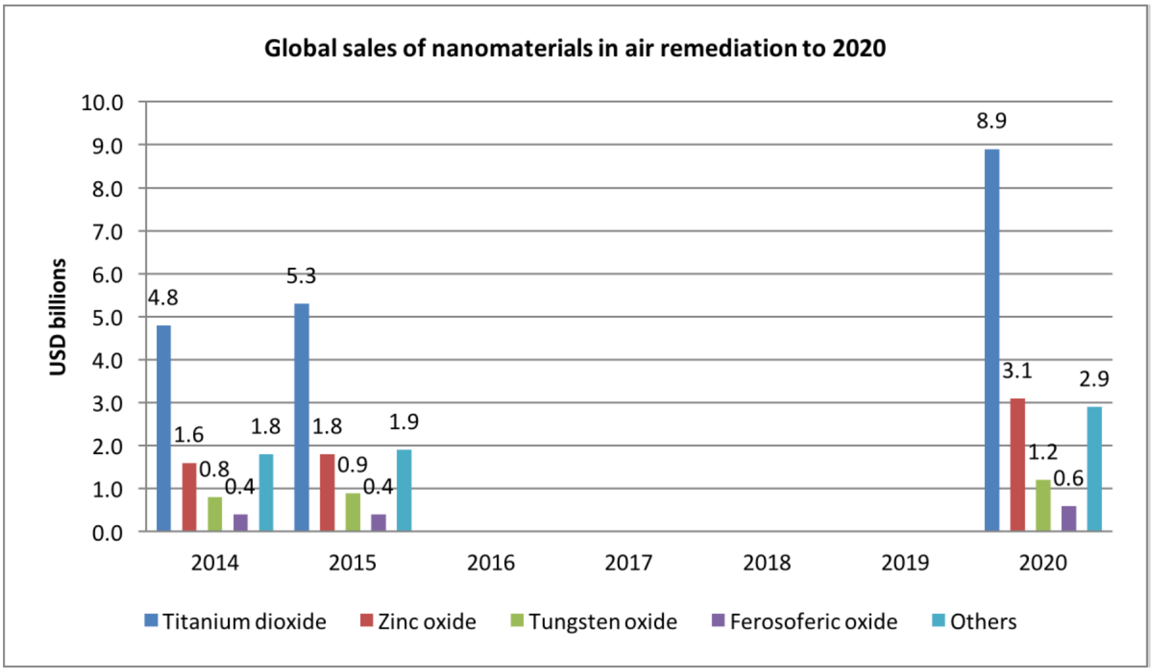

Figure A3.62. Global market for nanomaterials in air remediation to 2020 by type of material (USD billions)

Source: BCC Research 2015

Photocatalytic coatings

The surfaces of building facades are under the constant corrosive influence of weathering, traffic exhaust fumes or micro-organisms. Nanotechnology offers interesting ways to counteract these unwanted effects: e.g. via self-cleaning coatings. Self-cleaning coatings using nanotechnology can be applied to substrates ranging from natural stone and concrete to ceramics, composite material, metal, plastics or wood[466]. Such coatings can actively degrade organic pollutants or micro-organisms (e.g. fungi, algae or bacteria) using small amounts of zinc oxide (ZnO) or titanium dioxide particles (TiO_2) in a photocatalytic process, the photocatalytic activity increasing significantly with reducing particle size[467]. In addition to a photocatalytic effect, TiO_2 forms a hydrophobic, water-repellent coating that enhances the self-cleaning characteristics as water (rain) easily slides down the surface, washing any loose dirt away[468].

Nanoscale titanium dioxide thin films are used as photocatalytic coatings in a variety of products, ranging from anti-fogging mirrors, self-cleaning ceramic tiles and pollution-

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[466] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.36

[467] Ibid

[468] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.37

controlling construction materials. Estimates of the total consumption of nanoscale TiO_2 thin film materials in 2015 at 7,200 tonnes with a value of USD 147 million.

Projections for the global market for thin film catalytic coatings assume that the market will continue to grow at a CAGR of 10.4% from 2016 to 2021[469] (see figure below).

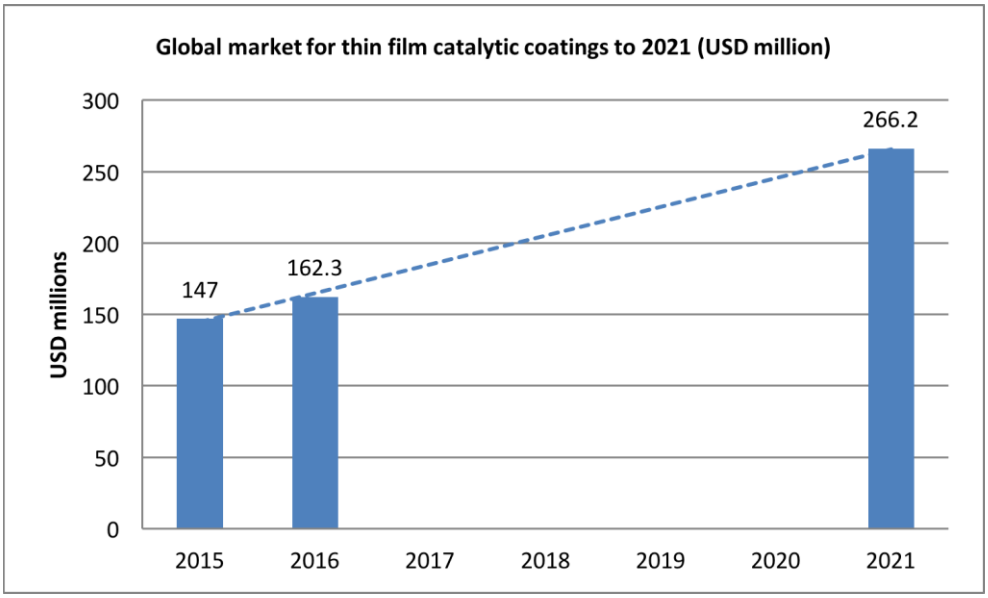

Figure A3.63. Global market for thin film catalytic coatings to 2021 (USD millions)

Source: BCC Research

Catalytic converters

Catalytic converters are used to reduce the toxicity of emissions from internal combustion engines, converting toxic combustion exhausts and their by-products into safer substances[470]. Current petrol (gasoline) vehicles are fitted with a "three-way" converter, so named because it converts the three main pollutants in automobile exhaust, as follows: an oxidising reaction converts both carbon monoxide (CO) and unburned hydrocarbons; and a reduction reaction converts oxides of nitrogen (NOx). The resultant substances emitted are carbon dioxide, nitrogen and water.

The first widespread introduction of catalytic converters was in the US market where, from 1975, petrol cars were so equipped to meet tightening EPA regulations on car exhaust emissions. These "two-way" converters targeted waste carbon monoxide and unburned hydrocarbons (HC) producing carbon dioxide and water. Two-way catalytic converters of this type are now considered obsolete, having been replaced, except on lean burn engines, by three-way converters.[471]

Most catalytic converters contain a nanoscale thin film of a noble metal (platinum, palladium, and/or rhodium) catalyst dispersed over a high-surface-area refractory aluminium oxide support. The support is designed to maximise the surface area and the thermal stability of the catalyst.[472] The nanocatalyst film is typically formed *in situ* by decomposition or reduction of salts impregnated on the oxide support material, a nanoscale alumina thin film. The support is made either by depositing a washcoat containing the oxide particles onto the carrier, followed by drying to form a porous

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[469] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.123-124

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

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

[472] BCC Research (2014), Nanotechnology, a realistic market assessment, p.59

coating, or by chemical precipitation in which the particles are formed *in situ* from an aqueous solution, both well-established technologies. Three-way catalytic converters have a stainless-steel body. Research is currently in progress, amongst other things, to minimise the amount of noble metal while maintaining the same catalytic performance[473].

Catalytic converters are used mainly in light motor vehicles, but also in non-vehicular emission control applications such as power lawn mowers and forklifts. These catalytic converters are a major market for platinum group nanocatalysts (i.e., platinum, palladium and rhodium) and for nanoscale alumina, as shown in the table below.

Applications	Global market (USD millions)			CAGR% 2016-2021
	2015	2016	2021	
Platinum group nanocatalysts	12,752.2	13,453.6	17,583.3	5.5
Nano alumina	16.8	17.7	23.1	5.5
Total	12,769.0	13,471.3	17,606.4	5.5

Table A3.11. Global market for thin film materials in catalytic converters to 2021 (USD millions)

Source: BCC Research 2016

The overall weight ratio of alumina support materials to nanocatalysts used in catalytic converters is about 41:1. The total consumption of platinum group metal (PGM) nanocatalysts (new as well as recycled) was 306,720 tonnes in 2015. Thus, 7,481 tonnes of alumina were consumed in the production of catalytic converters (including non-vehicular converters) in 2015. At an estimated average price of USD 2,240 per tonne, the value of these alumina support materials was USD 16.8 million in 2015. Based on projected trends in the number of vehicular and non-vehicular catalytic converters, consumption of alumina support materials is projected to reach USD 17.7 million in 2016 and USD 23.1 million in 2021[474].

Water remediation

Overview[475]

It is forecast that the nanotechnology market for groundwater remediation applications will increase to USD 3.9 billion in 2015, from USD 3.4 billion in 2014, and further rise at 12.4% CAGR over the five-year period to reach nearly USD 7.1 billion in 2020.

The nanotechnology market for surface water treatment should rise from about USD 2.4 billion in 2015 to USD 4.4 billion in 2020 (CAGR 12.6%). The forecast is for the nanotechnology market for trace contaminant detection to increase 11.5% to USD 2.9 billion in 2015, from USD 2.6 billion in 2014, and further rise at five-year CAGR of 12.1%, to reach nearly USD 5.2 billion in 2020.

The market for nanotechnology zero-valent iron used in water remediation is expected to grow from USD 1.5 billion in 2015 to USD 3.2 billion in 2020 (CAGR 16.1%) while the market for calcium carbonate is forecast to rise from nearly USD 1.2 billion in 2015 to USD 1.7 billion in 2020 (CAGR 8.4%). Different types of water remediation processes

[473] Federal Environment Agency of Germany (2010): Applications of Nanomaterials in Environmental Protection

[474] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.115

[475] BCC Research (2015), Nanotechnology in Environmental Applications: The Global Market

that utilise calcium carbonate include reverse osmosis, nanofiltration, ultrafiltration and microfiltration. Growth is also expected in the water remediation nanotechnology market for iron oxide (from USD 623.3 million in 2015 to USD 801.7 million in 2020 (CAGR 5.2%)), titanium dioxide (from USD 2.5 billion in 2015 to nearly USD 4.4 billion in 2020 (CAGR of 11.6%)) and carbon nanotubes (from USD 3.4 billion in 2015 to USD 6.5 billion in 2020 (CAGR 13.5%). Sensors using carbon nanotube detection elements are capable of detecting a range of chemical vapours. These sensors work by reacting to the changes in the resistance of a carbon nanotube in the presence of the vapour.

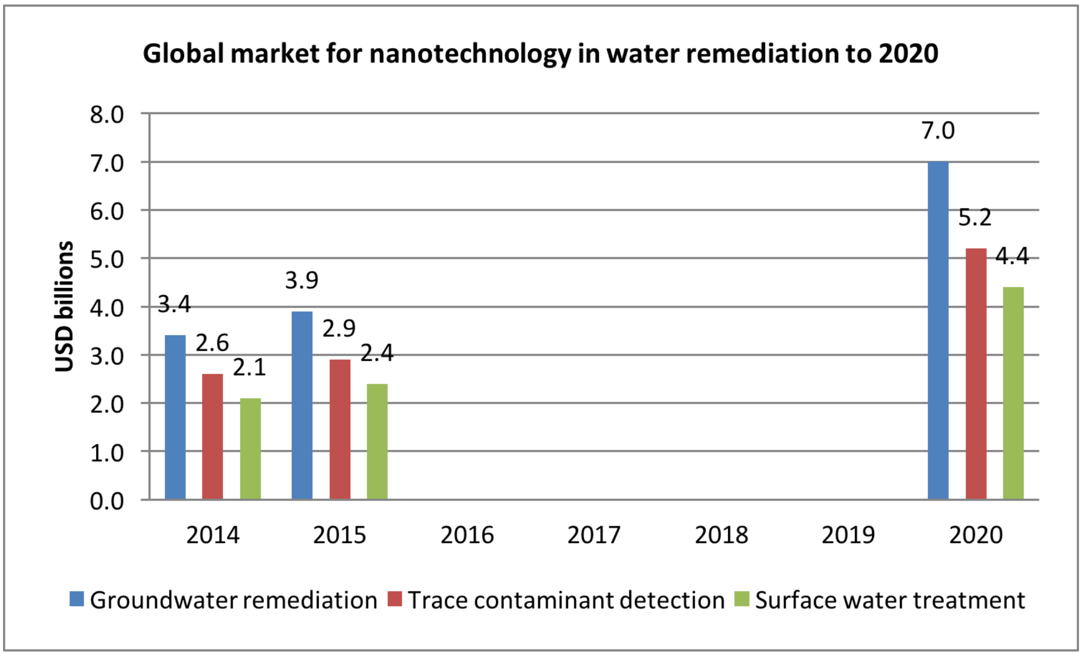

Figure A3.64. Global market for nanotechnology in water remediation to 2020 (USD billions)

Source: BCC Research 2015

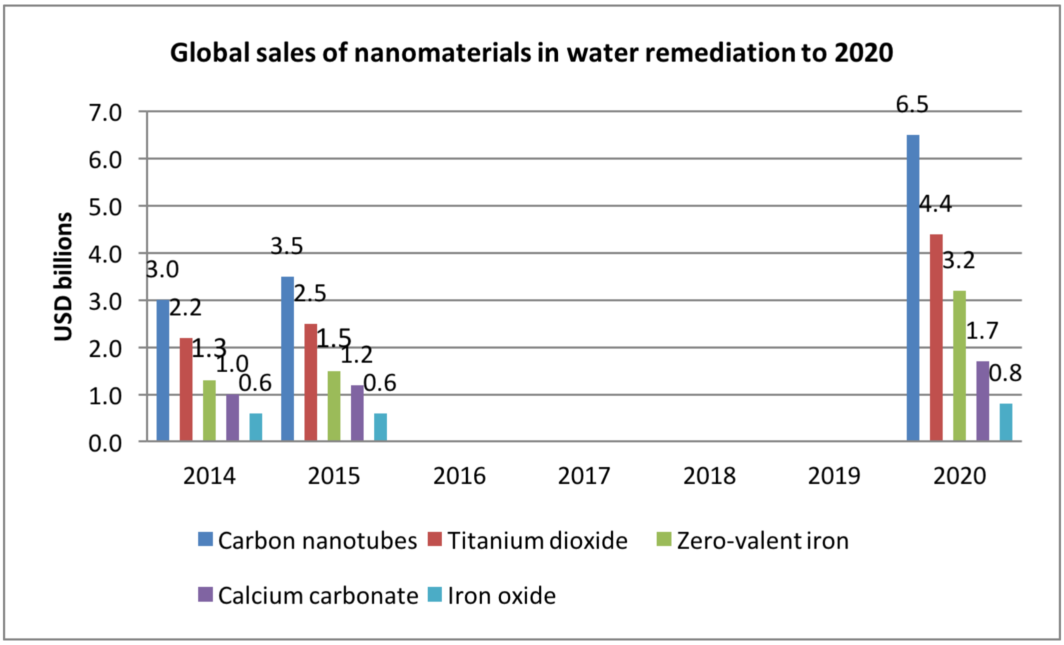

Figure A3.65. Global market for nanomaterials in water remediation to 2020 (USD billions)

Source: BCC Research 2015

Products in water filtration

Filtration systems based on nanoparticles

Ferritin, an iron-containing protein with the cage-like form of a protein network, is able to regulate the creation of mineralised structures. In the network cavity, iron molecules are transformed into ferrihydrite nanoparticles. Developers have been working on using the ability of the ferritins to remediate harmful metals and organic compounds under UV or solar radiation. The ferritins are more stable than traditional iron catalysts, because they do not react in photoreduction. Researchers from the Netherlands and Saudi Arabia have explored the characteristics of ferritins and their use against arsenate and phosphate pollutants, finding it to be effective in fast phosphate and arsenate transformation from water solution to reduce the concentrations of pollutants to picomolar level. Due to this low concentration level, ferritins are an excellent tool in industrial biofouling to overcome phosphate and arsenate limitations in drinking water[476].

Consumption of nanoparticulate alumina for ultrafiltration applications has been estimated at approximately USD 200,000 in 2015. The ultrafiltration market as a whole is projected to grow at a CAGR of 8.4% through the end of the decade. At this rate, consumption of nanoparticulate alumina ultrafiltration media should be USD 300,000 by 2021[477].

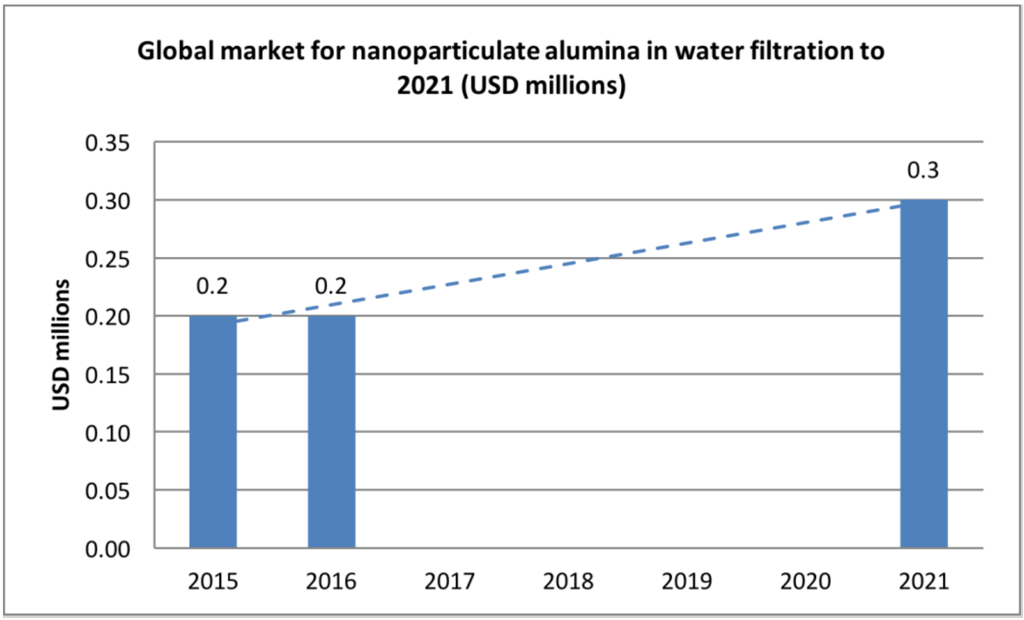

Figure A3.66. Global market for nanoparticulate alumina in water filtration to 2021 (USD millions)

Source: BCC Research 2016

Nanoporous membranes

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

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[476] http://www.sciencedirect.com/science/article/pii/S0043135415001359

[477] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.117-118

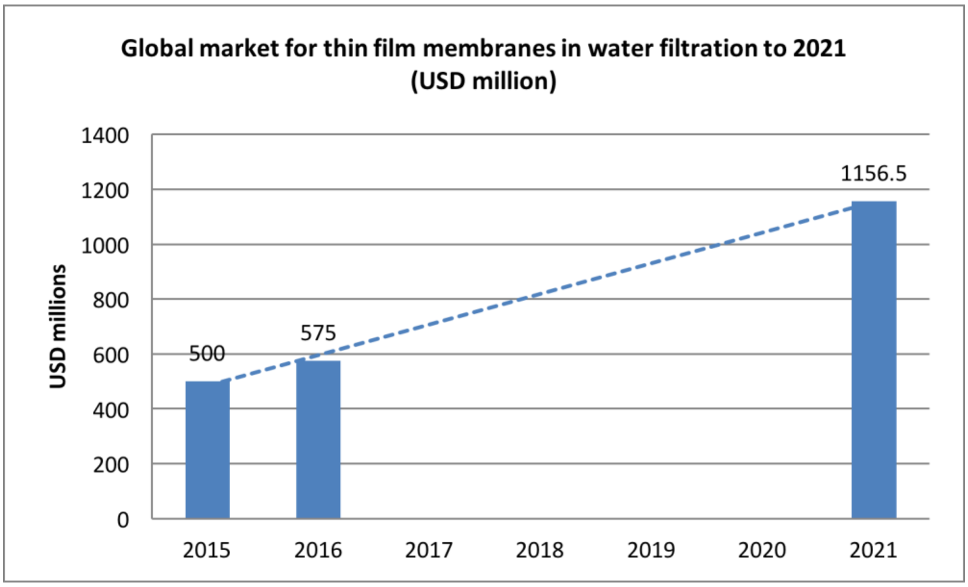

Figure A3.67. Global market for thin film membranes in water filtration to 2021 (USD millions)

Source: BCC Research 2016

Increasing global demand for potable water is driving growth in sales of water filtration membranes: the number of people without reliable access to water of good enough quality to be safe for human consumption is at least 1.8 billion, and possibly significantly more. Between 2011 and 2050, the world population is expected to increase by 33%, (from 7.0 to 9.3 billion) and the number living in urban areas will almost double (from 3.6 billion in 2011 to 6.3 billion in 2050).[478]

Dow does not disclose sales data on Filmtec nanoporous polymer filtration media, but 2015 sales were estimated to have been around USD 500 million with year-on-year growth of about 15%. At this rate, sales should reach USD 575 million in 2016 and over USD 1.1 billion by 2021[479].

Nanostructures water desalination membranes

In 2010, Dais Analytic Corp. (Odessa, USA) signed a USD 48 million contract to supply its NanoClear water treatment technology to China. This was the first major commercial sale of the NanoClear technology. NanoClear uses a proprietary nanostructured polymer membrane that rejects dissolved solids, organics and biologics while allowing the permeation of water molecules from one face of the membrane to the other. Warm water at atmospheric pressure impinges on one face of the membrane, while the other face of the membrane is held at a pressure less than atmospheric. Water vapour absorbed by the membrane permeates across into the vacuum where a regenerative blower directs it onto a cold surface, where it condenses into ultraclean water.

The 2015 Annual Report of Dais Analytic describes its water purification technology as developmental. However, it has been estimated that sales of such membranes could grow to as much as USD 150 million by 2021, based on sales of Dow Filmtec nanoporous thin film polymer filtration media for potable water plants in 2005, five years after the Filmtec technology was introduced to the market.[480]

Water filtration with nanocomposites

Polymer nanoparticles, due to their expanded structure, exhibit both hydrophobic and hydrophilic properties. After water treatment, a polymer will form a cell of several

[478] The United Nations World Water Development Report 2016

[479] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.64

[480] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.145

nanometres diameter which is hydrophobic inside and hydrophilic outside. These polymer nanoparticles can be used as surfactants in remediation of hydrophobic organic pollutants remediation although their uses in purification systems is still in the research stage.

LG NanoH2O[481] (Los Angeles, USA) has developed a nanocomposite technology designed to increase the efficiency of membrane-based water desalination and other purification systems by increasing water throughput at a given pressure[482]. LG NanoH2O manufactures reverse osmosis (RO) membranes for seawater and brackish water that lower the cost of desalination. Based on breakthrough nanostructured materials and industry-proven polymer technology, LG NanoH2O RO membranes dramatically improve desalination energy efficiency and productivity. More than 400 commercial sites in over 50 countries have installed LG NanoH2O s RO membranes for their desalination systems. [483]

LG NanoH2O’s QuantumFlux nanocomposite water desalination membranes entered the market in 2011 and have since been installed in over 100 plants around the world. By 2019, LG NanoH2O’s membranes will compete with Dais Analytics’ NanoClear nanostructured polymer membranes (see above) and other non-nano technologies for a share of the reverse osmosis/nanofiltration membrane market, estimated to grow to as much as USD 1.5 billion per year by 2019. It has been forecast that sales of LG NanoH2O’s nanocomposite membranes will rival sales of NanoClear (i.e., USD 150 million) by 2019[484].

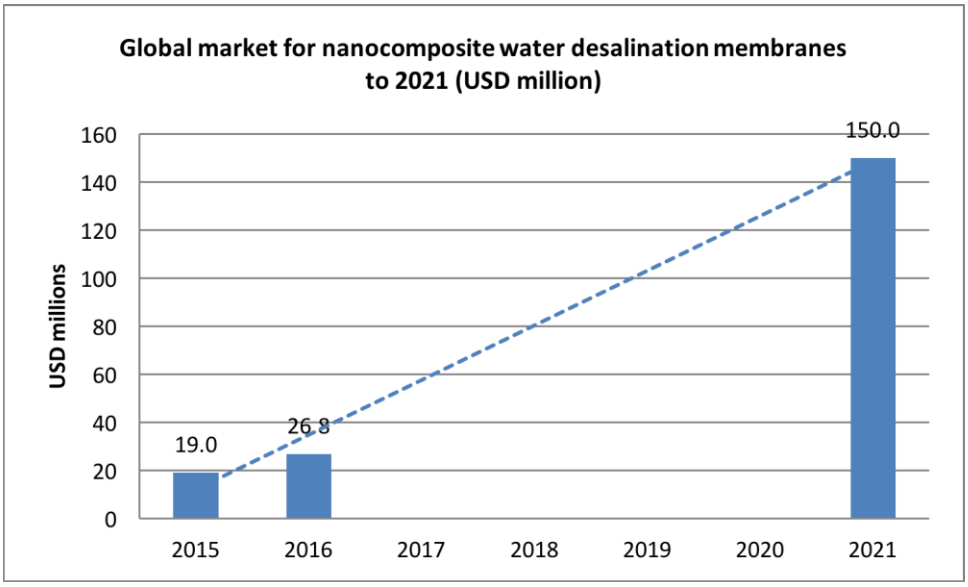

Figure A3.68. Global market for nanocomposite water desalination membranes to 2021 (USD millions)

Source: BCC Research 2016

Sensors

Products in application and emerging markets

Sensors based on nanoparticles

INanoBio LLC (Tempe, USA) has developed the FDEC FET nanosensor in collaboration with Arizona State University. The novel nano sensor technology is highly selective and capable of exponential capacitive transduction for ultra-high sensitivity molecular

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[481] NanoH2O was acquired by LG Chem in 2014

[482] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.88

[483] http://www.desalination.biz/59757/d/LG-NanoH2O-Inc

[484] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.64

detection. INanoBio LLC has strictly protected their technology but mention that the nanosensor can be used for both chemical as well as biological sensing activities. Industries wherein these sensors would positively impact include health care diagnostics, industrial leak detection systems and security[485]. It is estimated that the market for nanosensors could reach at least USD 60 million by 2021[486][487].

Sensors based on carbon nanotubes

Nanomix Inc. (Emeryville, USA) has developed a chemical sensing technology (called "Sensation") that integrates carbon nanotube sensing elements with CMOS technology on a silicon chip, with ultrahigh sensitivity in a small size and with cost and performance benefits relative to conventional chemical sensor technologies. Products of Nanomix that incorporate the Sensation technology include respiratory monitors and industrial gas leak detectors.[488] Based on revenue estimates for Nanomix, Inc, the main producer of carbon nanotube-based sensors, it is estimated that the market for nanotube-based sensors (not just the nanotubes) was around USD 4 million in 2015 and that the market for these sensors could approach USD 22 million by 2020, which would imply a CAGR of 38% between 2015 and 2020. At this rate, the market should reach USD 27.5 million by 2021.[489] [490]

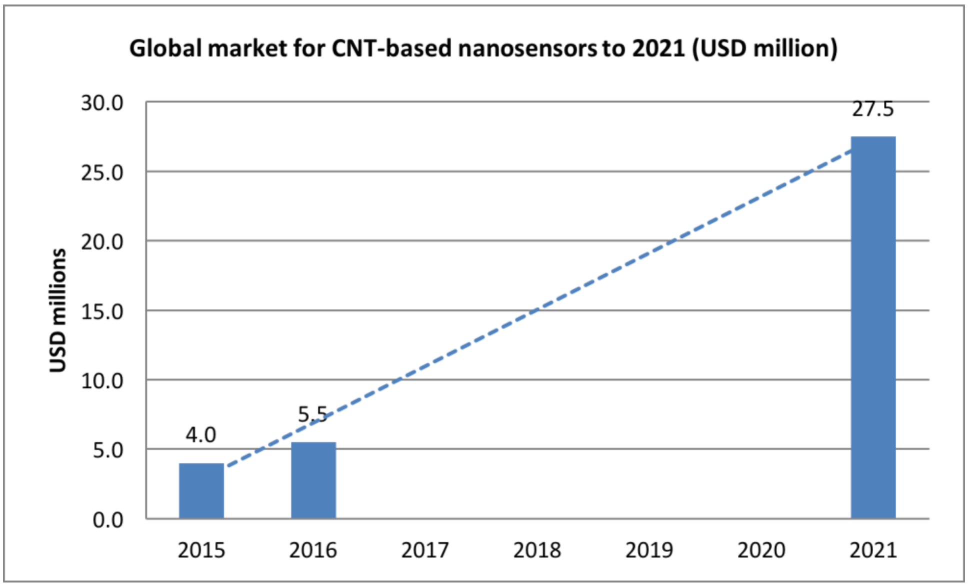

Figure A3.69. Global market for CNT-based nanosensors to 2021 (USD millions)

Source: BCC Research 2016

The next section of this annex looks at products and markets for transport through nanotechnology.

7 Products and Markets for Transport through Nanotechnology

Commercialised products for transport through nanotechnology: Overview

To date, 494 transport-related products using nanotechnology have been identified as being commercially available. One-fifth (20%) of those are in the area of anti-scratch and anti-stick coatings. Cleaning agents (13%) represent the third biggest group of commercially available products, after the mixture of products under the label 'Other'

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[485] http://www.inanobio.com/aboutus.php

[486] BCC Research, IAS027D MEMS: Biosensors and Nanosensors

[487] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.193

[488] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.102

[489] BCC Research, IAS027D MEMS: Biosensors and Nanosensors

[490] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.90

(17%) (ranging from coatings with IR radiation blocking properties to anti-corrosive coatings for marine and automotive applications and polishing slurries). Further types of products with more than a 5% share are lubricants (11%), nanocomposites (9%), batteries and hydrophobic/oleophobic nanocomposites (8% each).

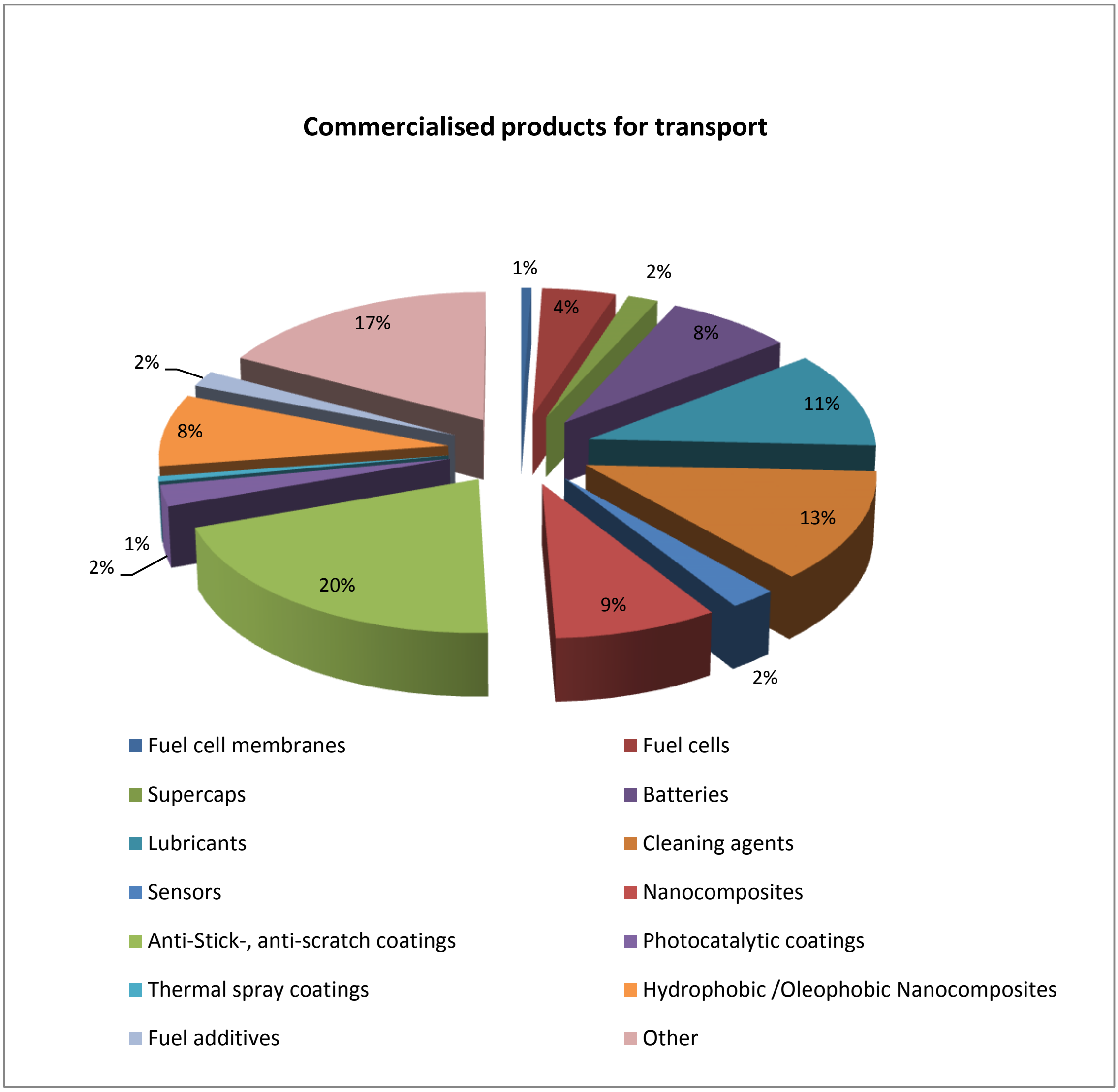

Figure A3.70. Nanotechnology products in transport, by product type

Source: JIIP, 2017

Products for transport through nanotechnology, by application market

The products identified are divided as follows:

- Batteries;
- Fuel cells;
- Coatings;
- Composites
- Conductive fibre; and
- Other products, e.g. diesel fuel additives, sensors.

Batteries

Products by application market

On-board energy storage forms a potentially large application area of nanotechnology in the transport sector and includes lithium-ion batteries, hydrogen storage materials and supercapacitors, and batteries for electric (EVs) and hybrid electric (HEVs) vehicles.

As the market for electric vehicles is growing, so too is the market for compatible batteries. New electric vehicle registrations in the EU rose from 22,500 units in 2014 to 58,689 units in 2015, a doubling in one year. Registrations of the new hybrid electric vehicles also rose substantially, from 47,000 up to 61,000 units in 2015, a growth of almost 30%[491]. The original equipment manufacturer (OEM) battery market for hybrid electric vehicles and plug-in hybrid electric vehicles in the EU was estimated by EUROBAT at 52,800 units in 2011 and 255,700 units in 2015, a CAGR of 48%. Each (plug-in) hybrid electric vehicle will have one or two batteries on-board[492].

Globally, over 750,000 new electric cars were sold in 2016. However, the growth rate for sales was lower than in previous years, being only 40%, 2016 being the first year since 2010 that the rate fell below 50% growth. European cars accounted for 215,000 electric cars in 2016, below China (336,000) and above the US (160,000). In Europe, the largest number of cars were sold in Norway, the United kingdom, France, Germany, the Netherlands and Sweden. 95% of electric cars sales took place in ten countries, these six European countries and China, the US, Japan and Canada.[493]

Rechargeable lithium ion batteries

Lithium ion batteries are generally based on the reversible transfer of lithium ions between two materials through an electrolyte. [494] The cathode (positive electrode) materials are lithium transition metal oxides represented by the general formula Li y MO 2 (y ≈ 1), whereas graphite is the most frequently used negative electrode (anode) material. With graphite, the battery operates at about 3.5 V during discharge, which makes the system very attractive for its high energy density[495].

With the arrival of the lithium ion technology in the 1990’s, cell energy density was boosted by a factor of three compared to lead acid batteries (35–40 Wh/kg) and two compared with Ni–Cd batteries (50–60 Wh/kg) and, more significantly, the energy density has doubled, from 100 Wh/kg to about 200 Wh/kg, over the past 25 years. However, even this falls short of meeting future application demands linked to the field of renewable energies and automotive transportation in terms of energy density, power and life span[496]. They eventually wear out, and they cannot discharge energy quickly enough for applications requiring power surges, such as camera flashes and power tools[497].

Lithium-titanate batteries (lithium titanium oxide or LTO) are one approach to overcome shortcomings of traditional lithium ion batteries. The LTO technology is based on modified lithium-ion batteries – the addition of lithium-titanate nanocrystals on the surface of the anode increases the surface area from 3 m^2/g to around 100 m^2/g and allowing electrons to enter and leave the anode far more quickly, resulting in faster charging times, increasing stability and making the batter safer[498]. A disadvantage of LTO

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[491] http://www.acea.be/press-releases/article/alternative-fuel-vehicle-registrations-20.0-in-2015-21.1-in-q4

[492] http://www.eurobat.org/sites/default/files/automotive_battery_market_outlook_-_update_2015_0.pdf

[493] https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

[494] Patrice Simon and Jean-Marie Tarascon (2013), Electrochemical Energy Storage: the Benefits of Nanomaterials, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.157

[495] Elzbieta Frackowiak and François Béguin (2013), Carbon-Based Nanomaterials for Electrochemical Energy Storage, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p. 194

[496] Ibid

[497] Graham-Rowe, Duncan (7 March 2005). "Charge a battery in just six minutes". New Scientist.

[498] Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015

batteries is that they have a lower inherent voltage (2.4 V), which leads to a lower energy density of about 30-110Wh/kg than conventional lithium-ion battery technologies (3.7 V)[499].

LTO batteries have applications in electric vehicles and charging stations, coaches, yachts, wind and solar energy storage power, traffic signals, solar hybrid street lighting, uninterruptible power supply, home power storage, weather radar, electricity, hospitals and telecommunications, as well as mobile and backup power systems[500].

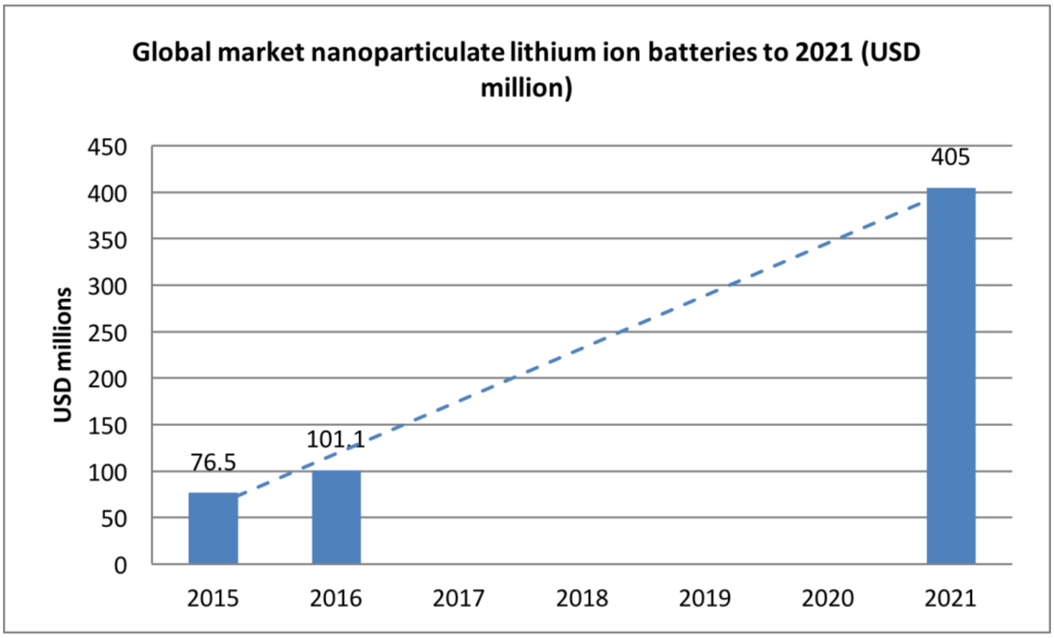

Figure A3.71. Global market for nanoparticulate lithium ion batteries to 2021 (USD millions)

Source: BCC Research 2016

The market in 2015 for advanced lithium ion batteries incorporating nanoparticulate electrode materials was estimated as USD 340 million, based partly on sales of major manufacturers such as A123 Systems and Valence Technology. Material costs represent about 45% of the value of all types of storage battery shipments, a percentage assumed to be characteristic of nanoparticulate lithium ion batteries as well. Materials used in fabricating the electrodes of these batteries in turn account for about half of the total material cost of lithium ion batteries, or USD 76.5 million in 2015 based on the projected value of nanoparticulate lithium ion battery sales.

In the longer term, the greatest potential market for nanoparticle-based lithium ion batteries is in electric vehicles. According to some estimates, the total market for automotive lithium ion batteries could approach USD 18 billion per year by 2021, with nanoparticle-based lithium ion batteries could capture 10% of the automotive market over the mid- to long term[501]. Based on a total market of USD 18 billion and following the cost-estimating logic described above, such a market implies a potential demand for nanoparticulate electrode materials of USD 405 million in 2021.[502]

Products by emerging market

Carbon nanotube batteries

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[499] Green Car Congress: Toshiba Developing 3.0 Ah High Power SCiB Li-Ion Cell for HEV Applications. 21 May 2008.

[500] Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015

[501] BCC Research

[502] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.71

By 2021, it has been forecast that CNT batteries will hold a market share of 2% to 3%, or USD 50 million, analogous to the share of the market of carbon nanotube ink-printed RFID tags. The electrode accounts for an estimated 45% of the cost of the battery, while the carbon nanotubes account for about half of the cost of the electrodes, or 22.5% of the total cost of the battery. This percentage, applied to projected sales of USD 50 million, yields a potential market for carbon nanotube battery electrode materials of USD 11.3 million in 2021.[503]

Carbon nanotube supercapacitors

It is equally difficult to project the market for carbon nanotube supercapacitor materials in 2019, when FastCAP's supercapacitors or their equivalents are expected to be on the market. Assuming that the supercapacitor market will roughly equal the battery market for nanotube electrodes, it value is forecast as USD 11 million in 2021[504].

Graphene supercapacitors[505]

The global market in 2015 for electronic and capacitive energy storage devices (including supercapacitors, supercapacitors and air capacitors) has been estimated at about USD 2 billion in 2015, rising to USD 2.4 billion in 2016 and almost USD 6 billion in 2021. There are several competing technologies that are further advanced in their development, as well as technical and cost versus manufacturability issues that need to be resolved for graphene supercapacitors to significantly enter the market so they seem to be unlikely to capture more than 1% (USD 60 million) of the supercapacitor market by 2021. The graphene electrode accounts for an estimated 45% of the cost of the battery, while the graphene materials account for about half of the electrodes' cost, or 22.5% of the total cost of the battery, making for an estimated value in 2021 for graphene materials in supercapacitors at USD 13.5 million.

Aerogel supercapacitors

Potential electrochemical device applications of nanotechnology include aerogel capacitors. The global market for electronic and capacitive energy storage devices (including supercapacitors, supercapacitors and aerocapacitors) was estimated at USD 2 billion in 2015. This figure is expected to rise to USD 2.4 billion in 2016 and almost USD 6 billion in 2021, a CAGR of 20% from 2016 through 2021.As with graphene supercapacitors, the future market value is hard to forecast but aerogels are seen as unlikely to capture more than 5% of the electronic and capacitive energy storage market (about USD 300 million) by 2021.[506]

Fuel cells

Products by application market

Fuel cells

A fuel cell is an electrochemical energy converter in which a fuel (e.g. hydrogen, methanol) reacts with an oxidant (e.g. oxygen, air) at electrodes separated by an electrolyte (e.g. a liquid or a polymer membrane). The electrodes act as catalysts, promoting oxidation at the anode and reduction at the cathode. Electrons released at the anode pass through an outer circuit to do useful work.[507]

Nanostructured fuel cell electrodes increase the surface area (per unit weight) for catalysis to take place, increasing contact between the fuel and the catalysts, thereby

[503] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.93

[504] Ibid

[505] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.131

[506] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.144

[507] Elena Serrano, Kunhao Li, Guillermo Rus, and Javier García – Martínez (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.22

enhancing cell efficiency. The preparation of nanoscale electrocatalysts for fuel cells typically starts from either supported or unsupported colloidal nanomaterial precursors, for example, colloidal platinum (Pt) sols[508]. Nanoscale thin film platinum catalyst material is currently used in proton exchange membrane fuel cells (PEMFCs), phosphoric acid fuel cells (PAFC), and direct methane fuel cells (DMFCs).

The 2013 market for platinum nanocatalyst thin film materials used in PAFC, PEMFC and DMFC fuel cells was worth over USD 20 million. It is expected that the combined sales of PAFC, PEMFC and DMFC fuel cells will rise from about USD 1.9 billion in 2015 to almost USD 2.6 billion in 2016 and nearly USD 16.8 billion by 2021, a CAGR of 45.3% from 2016 through 2021. Taking the estimate that platinum thin film catalysts represent between 1.3% and 1.9% of the total cost of fuel depending on the type of fuel cells, an estimate the related consumption of platinum nano thin film catalyst materials is shown in the table below.[509]

Types	**Market to 2021 (USD million)**			**CAGR%**
	2015	2016	2021	2016-2021
PEMFCs				
Total sales	1,635.0	2,107.5	7,449.6	28.9
Pt consumption at 1.9%	31.1	40.0	142.5	28.9
PAFC				
Total sales	70.0	83.6	202.8	19.4
Pt consumption at 1.8%	1.3	1.5	3.7	19.8
DMFC				
Total sales	215.0	401.2	9,076.3	86.6
Pt consumption at 1.3%	2.8	5.2	118.0	86.7
Total Pt catalyst consumption	35.1	46.8	264.1	41.3

Table A3.12. Global market for fuel cells and platinum thin film catalysts to 2021 (USD millions)

Source: BCC Research 2016

Fuel cell membranes

[508] Elena Serrano, Kunhao Li, Guillermo Rus, and Javier García – Martínez (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.24

[509] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.115-116

A key performance limitation in polymer electrolyte fuel cells (PEMFCs) is the so-called "mass transport loss". Typically, perfluorosulphonic polymer electrolyte membranes (for example, Nafion™) are used in PEMFCs because of their electrochemical stability and conductivity. Unfortunately, methanol cross–over and membrane dehydration processes hinder the efficiency of the cells. Nanostructured membranes can help to address some of these issues[510].

DuPont™ Nafion® perfluorosulphonic acid (PFSA) membranes are non-reinforced films based on chemically-stabilised perfluorosulphonic acid/PTFE copolymer in the acid (H+) form. Nafion® PFSA membranes are chemically-resistant and durable and are widely used for Proton Exchange Membrane (PEM) fuel cells and water electrolysers. The membrane acts as a separator and solid electrolyte in a variety of electrochemical cells that require the membrane to selectively transport cations across the cell junction.[511]

However, Nafion suffers from chemical crossover and fuel cell operation is limited to 80^{O} Celsius because of its inability to retain water at higher temperatures. Therefore there is a need for new proton-conducting materials in order to improve the commercialisation of PEMFCs.[512]

Sales of Nafion fuel cell membrane materials were estimated at about USD 92.5 million in 2015, and sales of PEMFC and DMFC USD 1.8 billion, with Nafion being used in the majority. DuPont estimates that the Nafion membrane represents about 5% of the total cost of a fuel cell. Future sales of Nafion will be driven in part by sales of PEMFC and DMFCs, in addition to competition from alternative (non-nano and well as nano-) materials. As shown in the following table, total sales of PEMFC and DMFC fuel cells are expected to approach USD 16.6 billion annually by 2021.[513]

Types	Market to 2021 (USD million)			CAGR%
	2015	2016	2021	2016-2021
PEFMC	1,635.0	2,107.5	7,499.6	28.9
DMFC	215.0	401.2	9,076.3	86.1
Total	1,850.0	2,508.7	16,575.9	45.9

Table A3.13. Fuel cell sales by type of technology to 2021 (USD millions)

Source: BCC Research

The prospect of increasing competition from alternative (nanoscale and non-nanoscale) fuel cell membrane materials makes it difficult to project the future market for nanoporous polymer membranes like Nafion. It has been forecast that fuel cells equipped with Nafion and similar nanoporous polymer membrane materials will drop from being most of the market in 2016 to about half of the global market by 2021[514].

[510] Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.22.

[511] DuPont Fuel Cells: DuPont™ Nafion® PFSA Membranes, product information

[512] Jurado J, et al. (2002), Protonic Conductors for Proton Exchange Fuel cells: an overview, Chem. Ind. 56 (6): 265

[513] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.141

[514] BCC Research (2014), Nanotechnology, a realistic market assessment p.169

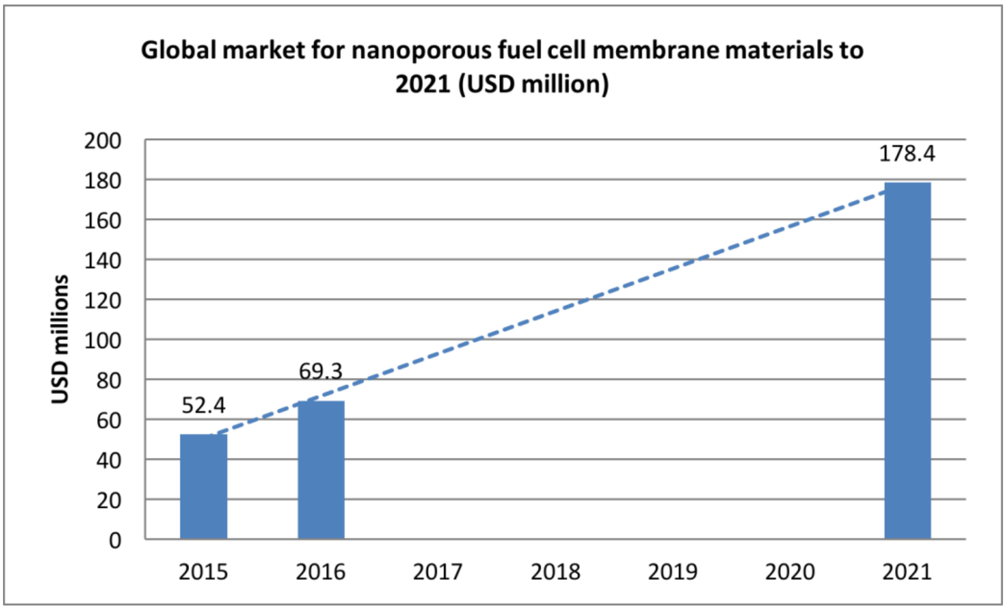

Figure A3.72. Global market for nanoporous fuel cell membrane materials to 2021 (USD millions)

Source: BCC Research 2016

Products by emerging market

Nanocomposite fuel cell membranes

Nanocomposite membranes are being developed for use in PEMFCs and DMFCs as a potential replacement for existing polymer membranes (such as DuPont's Nafion mentioned above). To overcome the limitations of existing technology, a variety of nanocomposite membranes incorporating inorganic nanoparticles such as clay, ZrO_2, SiO_2, TiO_2 and zeolites have been developed. As a group, these nanocomposite membranes show higher conductivity and water uptake than unmodified Nafion as well as better thermomechanical properties[515].

By 2021, it is forecast that sales of PEMFCs and DMFCs will reach USD 16.6 billion and will use more than 82 million m^2 of membrane material. It is difficult to predict the potential share of the market that will be taken by nanocomposite membranes as they are still under development and face competition from other non-nano membrane technologies that may be under development, such as the now-defunct PolyFuel's hydrocarbon membranes. It is conservatively forecast that nanocomposite membranes may capture 10% of the market by 2021, that is, 8.2 million m^2. At an average cost of USD 35/m^2, this implies a market worth around USD 287 million[516].

Coatings

Products by application market

Coating can be used during manufacture as well as for repair and maintenance of vehicles. It has been estimated that about half of nanocoatings are applied by original equipment manufacturers (OEM), the other half in refinishing[517]. Nanocoatings are also used for the maintenance of infrastructure.

Research on companies active in the global nanocoating market indicated that, as of November 2011, out of the 250 nanocoating companies surveyed, 50 companies were

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[515] BCC Research (2014), Nanotechnology, a realistic market assessment, p.124

[516] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.170

[517] BCC research CHM075A http://www.bccresearch.com/market-research/chemicals/automotive-coatings-chm075a.html

targeting the automotive industry, 35 the aerospace market and 20 the marine market [518]. Based on these figures, since nanocoating companies can serve multiple markets, the percentage of nanocoating companies targeting the transport sector lies in the range of 20%-42%. Based on other figures[519], almost 40% of the nano/smart coatings market was being applied in the transport sector (automotive, airline and marine).

High-strength Coatings (Nanostructured Steel)

The trade-off between steel strength and ductility is a significant issue for steel; the forces in modern construction require high strength, whereas safety and stress redistribution require high ductility. The presence of very hard nanometre-sized particles in the steel matrix can lead to a combination of these properties, effectively matching high strength with exceptional formability. However, when the particles become too small, this effect can be reversed[520].

The range of possible properties available via nanostructuring include steels with the hardness of alumina ceramics and the strength of carbon-based fibres. Other potential attributes may be superior corrosion resistance over nickel-based superalloys, higher strength-to-weight ratios than titanium alloys, and better weldability than cobalt-based satellites[521].

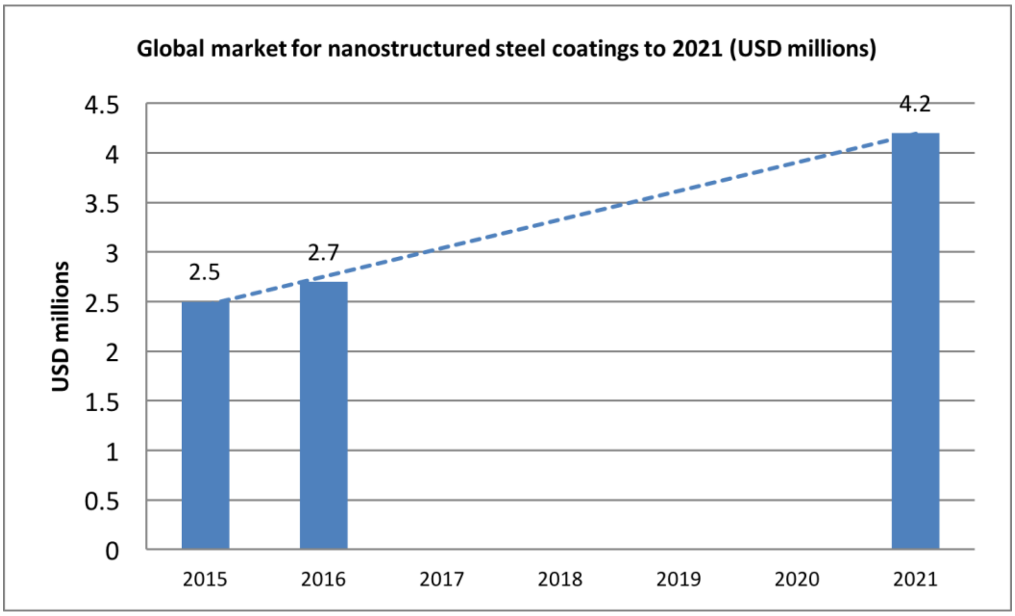

Figure A3.73. Global market for nanostructured steel coatings to 2021 (USD millions)

Source: BCC Research 2014

The market for nanostructured steel coatings was valued at around USD 2.5 million in 2015 and is forecast to reach USD 4.2 million in 2021, a CAGR of 9.2% over the next five years[522]. NanoSteel Inc. is currently the main vendor of nanostructured steel coatings, other providers including Sandvik. While NanoSteel does not publish separate sales data on its different product lines, it is estimated that coatings accounted for nearly all of the company's 2015 revenues of USD 2.1 million.[523]

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[518] http://www.nanowerk.com/news/newsid=23444.php Future Markets (2011)

[519] BCC research (2014), Global markets and advanced technologies for paints and coatings: http://www.bccresearch.com/report/download/report/chm049d

[520] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.32

[521] BCC Research (2014), Nanotechnology, a realistic market assessment, p.64

[522] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.127

[523] Ibid.

Photocatalytic coatings

The surfaces of transport infrastructure (such as buildings (bus and train stations), as well as bridges and roads) are under the constant corrosive influence of weathering, traffic exhaust fumes or micro-organisms. Nanotechnology offers interesting ways to counteract these unwanted effects: e.g. via self-cleaning coatings. Self-cleaning coatings using nanotechnology can be applied to substrates ranging from natural stone and concrete to ceramics, composite material, metal, plastics or wood[524]. Such coatings can actively degrade organic pollutants or micro-organisms (e.g. fungi, algae or bacteria) using small amounts of zinc oxide (ZnO) or titanium dioxide particles (TiO_2) in a photocatalytic process, the photocatalytic activity increasing significantly with reducing particle size[525]. In addition to a photocatalytic effect, TiO_2 forms a hydrophobic, water-repellent coating that enhances the self-cleaning characteristics as water (rain) easily slides down the surface, washing any loose dirt away[526].

Nanoscale titanium dioxide thin films are used as photocatalytic coatings in a variety of products, ranging from anti-fogging mirrors, self-cleaning ceramic tiles and pollution-controlling construction materials. Estimates of the total consumption of nanoscale TiO_2 thin film materials in 2015 at 7,200 tonnes with a value of USD 147 million.

Projections for the global market for thin film catalytic coatings assume that the market will continue to grow at a CAGR of 10.4% from 2016 to 2021[527] (see figure below).

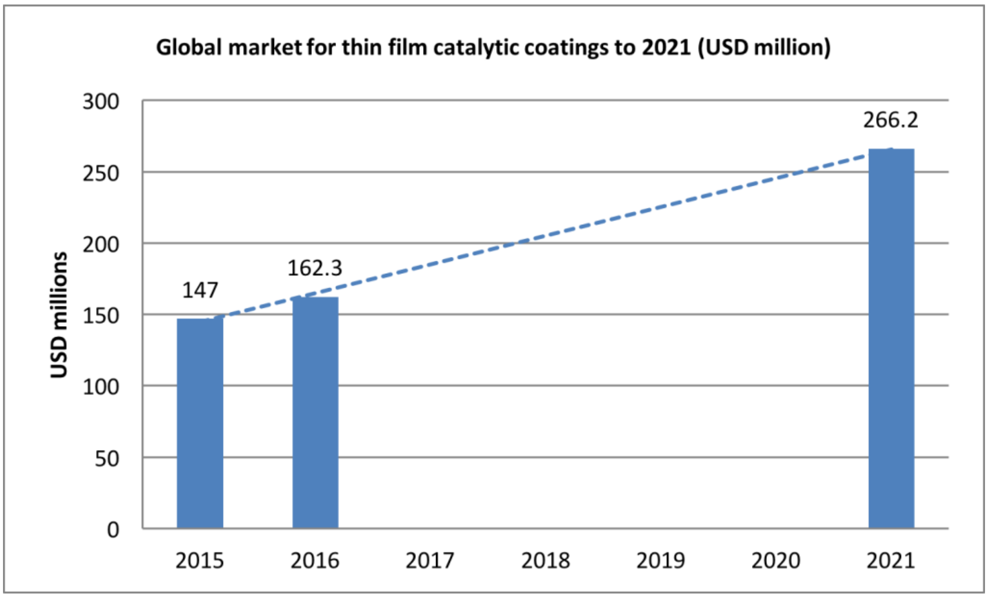

Figure A3.74. Global market for thin film catalytic coatings to 2021 (USD millions)

Source: BCC Research

Anti-scratch/ Anti-stick Coatings

Highly scratch-resistant lacquers for wooden flooring systems (e.g. boat decking) form an upcoming market and include several types of coating systems. One is based on the addition of (amorphous) nano-silica ($SiO_{2)}$ to an acrylic binder material. During the drying of the lacquer, the SiO_2 reacts chemically with the acrylic binder forming a highly-branched and very strong network of silane polymers, the basis of the high scratch resistance[528]. Another lacquer is based on the addition of nano-sized alumina ($Al2O_3$)

[524] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.36

[525] Ibid

[526] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.37

[527] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.123-124

[528] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.41

particles, which seem to improve the elasticity of the coating matrix, although the mechanism is not fully clear[529].

In addition to these, various other types of coatings are being developed to protect or treat wood surfaces. One of the main issues in this context is to preserve the initial (fresh) wood aesthetics: wood changes appearance over time under the influence of e.g. UV irradiation, moisture and temperature fluctuations. The nano-coatings protect against, or delay, the effects of such processes, so such that the wood retains its original appearance for a longer period of time. Protection of wood surfaces can be achieved using various metal oxides and organic chemicals that work by selectively filtering, i.e. blocking, UV radiation but leaving the visible light spectrum intact as much as possible (to maintain the natural wood appearance)[530].

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

The total market for nanostructured anti-scratch coatings is estimated at 1,230 tonnes with a value of USD 93 million in 2015, growing to an estimated USD 104 million in 2016 and USD 202.2 million in 2021 (a CAGR of 14.2% between 2016 and 2021). The market for polyurethane/alumina nanocomposite floor finishes was estimated to be worth USD 56 million in 2015. The balance was divided between ophthalmic coatings (USD 23 million) and other miscellaneous applications (USD 14 million). [531]

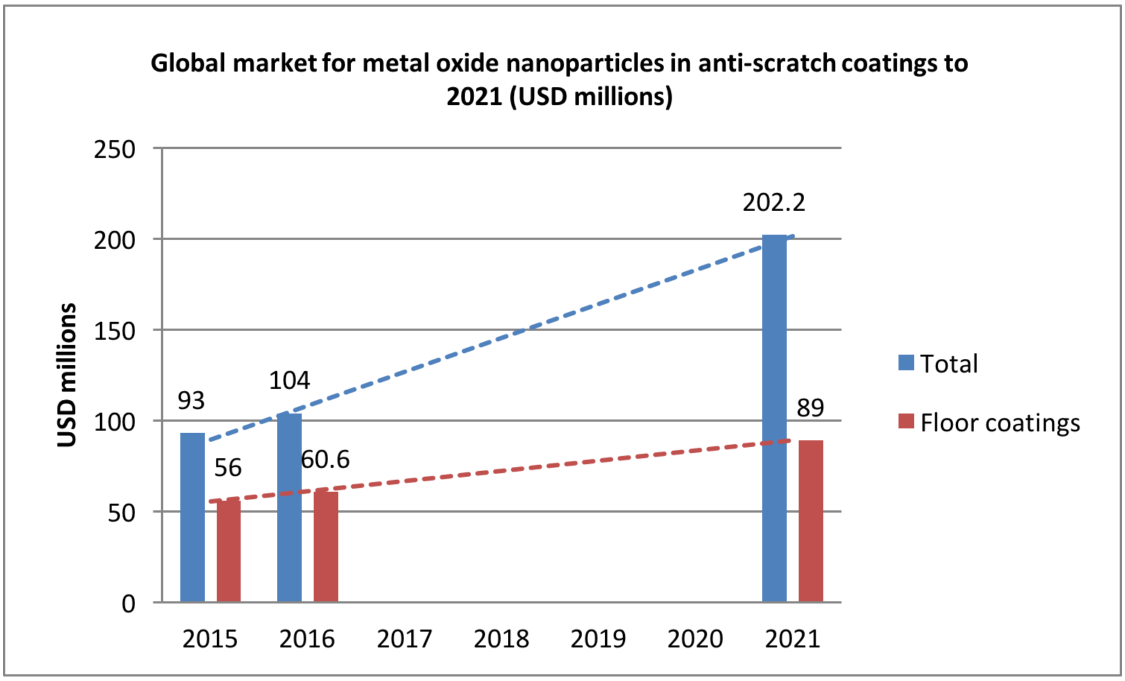

Figure A3.75. Global market for metal oxide nanoparticles in anti-scratch coatings to 2021 (USD millions)

Source: BCC Research 2016

Floor finishes is relatively mature market segment that is expected to grow at CAGRs of 8.0% from 2015 through 2021. The market for other types of anti-scratch coatings (especially auto clear-coat) is expected to grow much faster (at a CAGR of 32.7%) between 2016 and 2021[532]. The trends in global markets for alumina and other metal

[529] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.42

[530] Ibid

[531] BCC Research

[532] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.124

oxide nanoparticles use in anti-scratch coatings to 2021 are shown in the figure above.

Thermal-spray coatings

Thermal-spray metallic coatings (e.g. of zinc, copper or brass) are applied by melting a wire feedstock and propelling the molten droplets in a stream of compressed air onto the surface to be treated. They can be used in applications including the treatment of marine vessels to reduce corrosion resistance and reduce fouling, e.g. adherence by zebra mussels which they repel through the slow dissolution of metal ions into the water. There are limitations in their use, e.g. that copper and brass applied directly to steel will corrode it. While they are not suitable for use on non-ferrous metal substrates, surface preparation enables their use on materials such as concrete.[533]

Global consumption of nanoscale thermal spray coating materials in 2015 was estimated at about 317 tonnes or USD 28 million with forecast rises to USD 47.8 million in 2021. [534] [535]

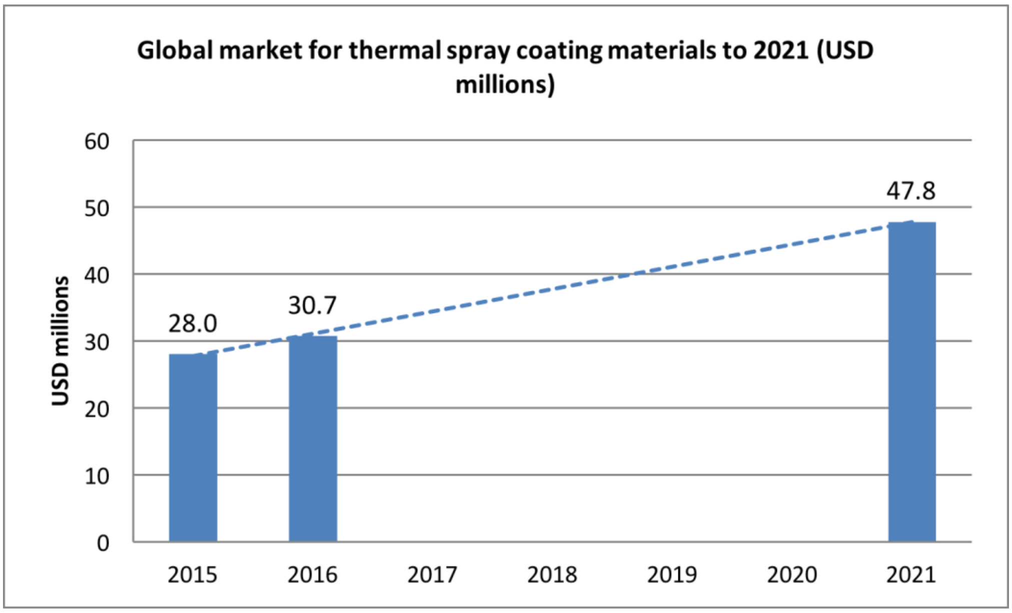

Figure A3.76. Global market for thermal spray coating materials to 2021 (USD millions)

Source: BCC Research 2016

Nanocomposites

Products by application market

Automotive parts

A nanocomposite material is a solid multiphase material where at least one or more phases have dimensions of less than 100 nanometres (nm), giving it unique properties relative to conventional composite materials, e.g. including improved mechanical properties, chemical resistance, gas permeability, electrical conductivity and processing capabilities. In most nanocomposites, a nanoscale filler material (e.g. clay, carbon black, carbon nanotubes, silicon carbide or graphene) is embedded in a matrix material (e.g. polymers such as polyester, epoxy or polyamide).[536]

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[533] http://el.erdc.usace.army.mil/zebra/zmis/zmishelp/antifouling_foul_release_and_thermal_spray_coatings.htm

[534] BCC Research, NAN021G Global Markets for Nanocomposites, Nanoparticles, Nanoclays, and Nanotubes

[535] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.126

[536] Observatory Nano (2013), Nanocomposite Materials, BRIEFING No.30

Nanocomposites used in the automotive and aircraft sector can significantly reduce vehicle weight through lighter mechanical and electronic components. Increasingly, filler materials of carbon nanotubes are being used in the automotive market mainly for fuel system components and body parts. The interest in using epoxy resin systems in the automotive and aircraft industry is also increasing[537]. Polymer-based nanocomposites are finding uses, for example, in tyres, fuel systems, seat textiles, mirror housings, door handles, engine covers, intake manifolds and timing belt covers, with porous materials also used in air filters. Sensors are another significant area.[538]

Polymer/carbon nanotube nanocomposites containing 2% to 5% nanotubes are used in fuel lines and exterior painted parts, with virtually all cars produced in the US since the 1990's having nanotubes in applications such as fuel lines. Because carbon nanotubes are highly conductive, they protect against any static build-up caused, for example, by the movement of fuel, even at low loadings that preserve the tensile elongation of the polymer, important in minimising the potential for fuel line rupture at low temperatures.[539] In body panels and other painted parts, the conductivity provided by the nanotubes enable the parts to be electrostatically spray-painted.

Cellulose nanofibre-reinforced bioplastics have a wide range of potential applications and may be applied in biodegradable parts for "green vehicles"[540].

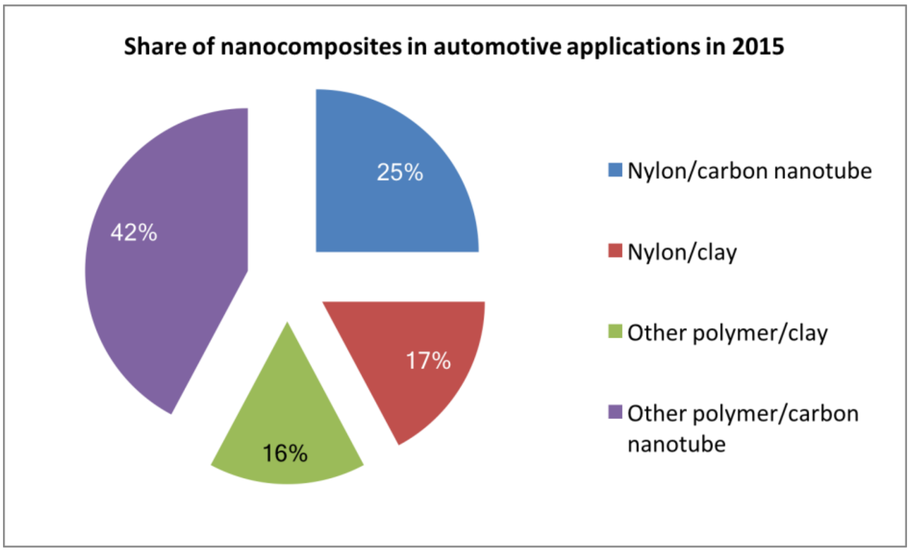

Figure A3.77. Global market for nanocomposites in automotive parts in 2015 by type of composite (USD millions)

Source: BCC Research 2016

The market in 2015 for all types of nanocomposites used in manufacturing automotive components was estimated at USD 320 million. Carbon nanotube-based nanocomposites accounted for the bulk of the market[541].

Factors driving the automotive nanocomposite market vary by sub-segment. It is estimated that the automotive market for nanocomposites will grow (in value terms) at an average annual rate of close to 13.5% from 2016 through 2021 (see figure below)[542].

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[537] Ibid

[538] Camargo, et al. (2009), Nanocomposites: synthesis, structure, properties and new application opportunities, Materials Research, 12(1)

[539] BCC Research (2014), Nanotechnology, a realistic market assessment, p.84

[540] Ibid

[541] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.165

[542] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.165

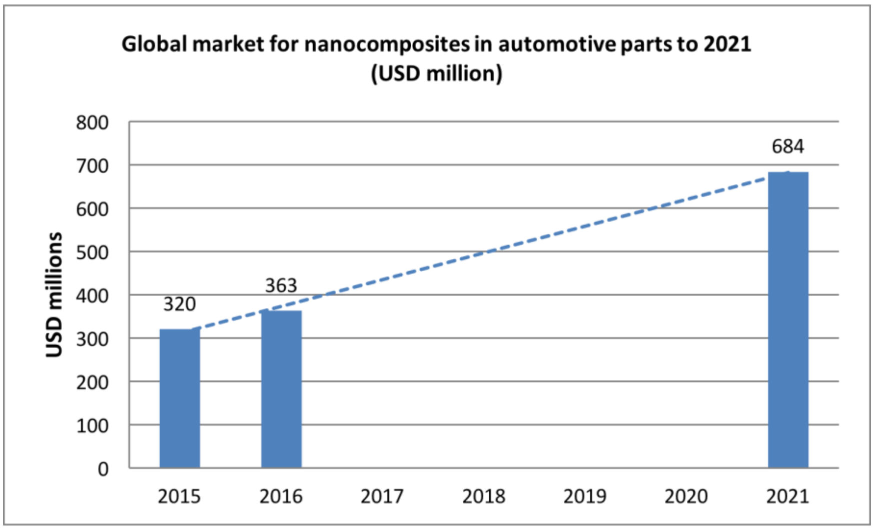

Figure A3.78. Global market for nanocomposites in automotive parts to 2021 (USD millions)

Source: BCC Research 2016

Hydrophobic/ Oleophobic Nanocomposites

Hydrophobic surfaces have established themselves as candidates for various engineering applications, such as self-cleaning, anti-biofouling, anti-icing, anti-corrosion and drag reduction at micro- and macro-scales. Superhydrophobicity helps in protecting surfaces potentially affected by environmental factors such as rain and dirt[543].

Nanogate GmbH, the main supplier of hydrophobic/oleophobic nanocomposites, had sales of USD 84.8 million in 2015. Nanogate's sales increased at a CAGR of 24.8% between 2001 and 2015. At this rate, total sales of hydrophobic/oleophobic nanocomposites are expected to reach USD 105.8 million in 2016 and USD 320.4 million by 2021. The cost-per-ton of the nanocomposites is projected to remain relatively constant at around USD 75,000 in real terms[544].

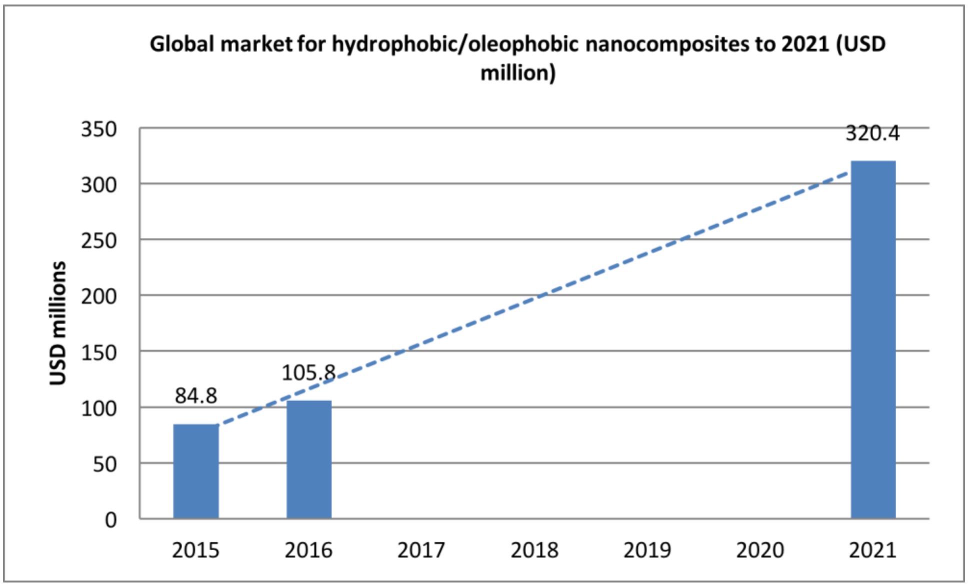

Figure A3.79. Global market for hydrophobic/ oleophobic nanocomposites to 2021 (USD millions)

Source: BCC Research 2014

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

[544] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.169

Products by emerging market

Graphene-based composites

Dispersing a small amount of graphene in polymers, many properties of the resulting composites (such as tensile strength and elastic modulus, electrical and thermal conductivity, thermal stability, gas barrier, and flame-retardance) can be significantly improved. These properties make graphene-based polymers composites good candidates for structural materials for the automotive sector and aerospace sectors[545].

Graphene-based composites are already reaching prototype or product applications in aerospace and other aspects of transport, e.g. for protective clothing. Being strong but also light (very important in transport applications), graphene-based composites are being developed for thermal management, drag-reduction and electrical conductivity, e.g. protecting aircraft from lightning strikes. Products using graphene-based composites that are currently on the market include helmets[546] that use a graphene composite coating for better heat distribution and to protect from damage to the helmet by enabling better distribution of impact forces. They are also being developed for their mechanical and thermal properties, e.g. for propeller blades of drones. Other applications are also reaching prototype stage, e.g. the world's first graphene-skinned aircraft, a model aircraft called 'Prospero', was flown at the Farnborough International Air Show in the UK in 2016[547]. Graphene additive for resins are being used in corrosion-resistant tanks and pipes for storage and transport of potentially explosive chemicals where the electrical conductivity and mechanical strength of the graphene complements the corrosion resistance of the resin replacing the traditional metallic systems, an application that may be applicable in transport applications in the future. [548]

Various graphene-filled polymer composites have been developed, including graphene-polystyrene composites. These are alternatives to carbon nanotube- and fullerene-polymer composites that have also been developed or investigated. The properties of graphene-polymer composites compare favourably with those of nanotube-polymer composites, with potential performance-related advantages over nanotubes as a filler material. Graphene-polymer composites have many of the same potential applications as carbon nanotube composites, including automotive components (e.g., fuel lines, exterior painted parts)[549].

It has been estimated that graphene-polymer nanocomposites could reach a market value of USD 94 million by 2021.[550] [551]

Other products

Products by application market

Conductive fibres

Thread spun from polyvinyl alcohol (PVA) in which single-wall nanotubes have been

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[545] Elmarakbi, A. et al (2015), Novel Composite Materials for Automotive Applications: Concepts and Challenges for Energy-efficient and Safe Vehicles, paper presented at the 10th International Conference on Composite Science and Technology

[546] https://phys.org/news/2016-11-graphene-coated-motorcycle-helmet.html

[547] https://phys.org/news/2016-11-world-graphene-enhanced-aircraft.html

[548] Several examples such as this are given on the website of the Graphene Flagship http://graphene-flagship.eu/graphene-shows-promise-for-composite-applications

[549] BCC Research (2014), Nanotechnology, a realistic market assessment, p.93-94

[550] BCC Research, AVM075D Graphene: Technologies, Applications, and Markets, the global market for these materials

[551] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.174

dispersed may meet some of the growing demand for conductive fibre in smart and interactive textile applications such as controls built into seats and other furnishings[552].

The global market for conductive fibre is expected to grow from approximately USD 500 million in 2015 to more than USD 1.6 billion in 2021. Polyvinyl alcohol–single-walled nanotube composites could capture 10% of the market for conductive fibres, worth at least USD 160 million, by 2021. [553]

Diesel fuel additives

Efforts to reduce diesel particulate emissions include the use of oxidation catalysts; diesel particulate filters (DPFs); low-sulphur diesel fuels; and fuel additives; some additives also improve fuel economy. One class of diesel fuel additives gaining acceptance comprises engineered nanomaterials composed of cerium compounds (nCe). These fuel additives also reduce fine particulate matter (PM2.5) emissions and alter the emissions of carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbon (HC) species, including several HAPs[554].

Energenics Ltd. does not publish sales data for its Envirox diesel fuel catalyst, which it acquired from Oxonica Ltd. in 2009. However, Envirox sales in 2015 were certainly much lower than they had been prior to 2007, when Oxonica had a contract to supply Petrol Ofisi (the Turkish national oil and gas company) with USD 12 million worth of Envirox per year. BCC Research estimates 2015 sales of Envirox at around USD 4 million, requiring the input of about USD 600,000 worth of cerium oxide nanocatalysts. For analytical purposes, BCC Research assumes that Energenics by 2021 will be able to restore sales of Envirox to at least the level it enjoyed before the loss of the Petrol Ofisi contract. Total Envirox sales in 2021 should thus be around USD 12 million, which would represent a 300% increase since 2015, or a CAGR of 19.4%. Such a level of Envirox sales could generate nearly USD 1.7 million in consumption of ceria nanopowders on a proportional basis in 2021[555].

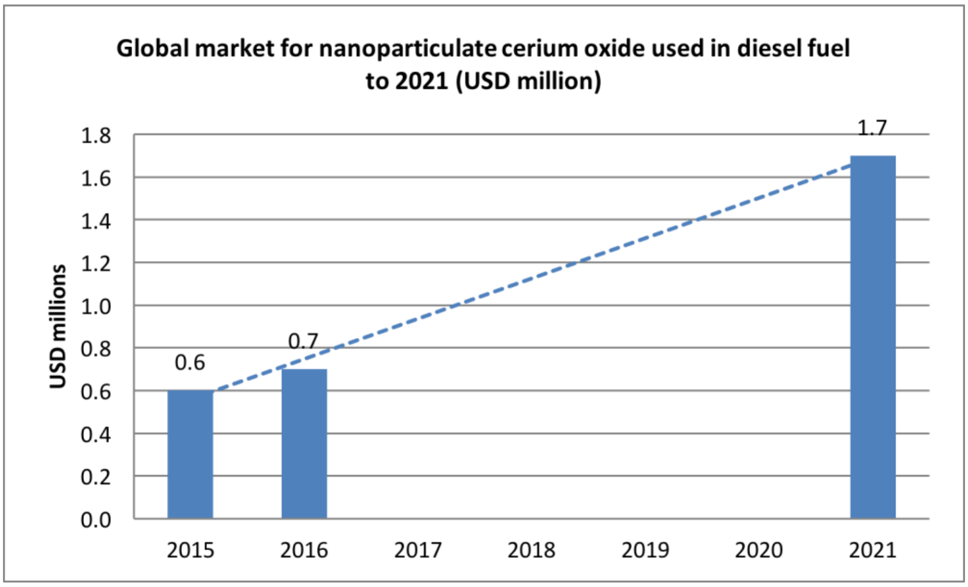

Figure A3.80. Global market for nanoparticulate cerium oxide used in diesel fuel to 2021 (USD millions)

Source: BCC Research

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552 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.144

553 BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.174

554 Green Car Congress: EPA researchers find widespread use of nano cerium diesel fuel additives could have measurable impact on air quality, 21 October 2014

555 BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.66

Catalytic converters

Catalytic converters are used to reduce the toxicity of emissions from internal combustion engines, converting toxic combustion exhausts and their by-products into safer substances[556]. Current petrol (gasoline) vehicles are fitted with a "three-way" converter, so named because it converts the three main pollutants in automobile exhaust, as follows: an oxidising reaction converts both carbon monoxide (CO) and unburned hydrocarbons; and a reduction reaction converts oxides of nitrogen (NOx). The resultant substances emitted are carbon dioxide, nitrogen and water.

The first widespread introduction of catalytic converters was in the US market where, from 1975, petrol cars were so equipped to meet tightening EPA regulations on car exhaust emissions. These "two-way" converters targeted waste carbon monoxide and unburned hydrocarbons (HC) producing carbon dioxide and water. Two-way catalytic converters of this type are now considered obsolete, having been replaced, except on lean burn engines, by three-way converters.[557]

Most catalytic converters contain a nanoscale thin film of a noble metal (platinum, palladium, and/or rhodium) catalyst dispersed over a high-surface-area refractory aluminium oxide support. The support is designed to maximise the surface area and the thermal stability of the catalyst.[558] The nanocatalyst film is typically formed *in situ* by decomposition or reduction of salts impregnated on the oxide support material, a nanoscale alumina thin film. The support is made either by depositing a washcoat containing the oxide particles onto the carrier, followed by drying to form a porous coating, or by chemical precipitation in which the particles are formed *in situ* from an aqueous solution, both well-established technologies. Three-way catalytic converters have a stainless steel body. Research is currently in progress, amongst other things, to minimise the amount of noble metal while maintaining the same catalytic performance[559].

Catalytic converters are used mainly in light motor vehicles, but also in non-vehicular emission control applications such as power lawn mowers and forklifts. These catalytic converters are a major market for platinum group nanocatalysts (i.e., platinum, palladium and rhodium) and for nanoscale alumina, as shown in the table below.

Applications	**Global market (USD millions)**			**CAGR% 2016-2021**
	2015	2016	2021	
Platinum group nanocatalysts	12,752.2	13,453.6	17,583.3	5.5
Nano alumina	16.8	17.7	23.1	5.5
Total	12,769.0	13,471.3	17,606.4	5.5

Table A3.14. Global market for thin film materials in catalytic converters to 2021 (USD millions)

Source: BCC Research 2016

The overall weight ratio of alumina support materials to nanocatalysts used in catalytic

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

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

[558] BCC Research (2014), Nanotechnology, a realistic market assessment, p.59

[559] Federal Environment Agency of Germany (2010): Applications of Nanomaterials in Environmental Protection

converters is about 41:1. The total consumption of platinum group metal (PGM) nanocatalysts (new as well as recycled) was 306,720 tonnes in 2015. Thus, 7,481 tonnes of alumina were consumed in the production of catalytic converters (including non-vehicular converters) in 2015. At an estimated average price of USD 2,240 per tonne, the value of these alumina support materials was USD 16.8 million in 2015. Based on projected trends in the number of vehicular and non-vehicular catalytic converters, consumption of alumina support materials is projected to reach USD 17.7 million in 2016 and USD 23.1 million in 2021[560].

High-pressure discharge lamp tubes

Nanostructured ceramic materials made using alumina nanopowders are being commercially produced for use in the translucent alumina arc tubes of high-pressure discharge (xenon) lamps, being normally used in conjunction with larger, submicron- or micron-scale powders to obtain the desired properties in the final sintered part. Each arc tube consumes about 3 g to 5 g of alumina powder, approximately 30% of which has nanoscale dimensions[561].

Total consumption of nanostructured ceramic materials in high-pressure discharge (xenon) lamp tubes in 2015 was 13 tonnes with a value of USD 3.3 million. The main market driver is forecast to be trends in transport i.e. sales of vehicles with this form of lighting. Once found only in luxury cars, xenon headlamps are available in a growing number of vehicles. The automotive market for xenon lamps to grow at a CAGR of 7.8% from 2016 to 2021, the same growth rate that is assumed for alumina consumption in the figure below[562].

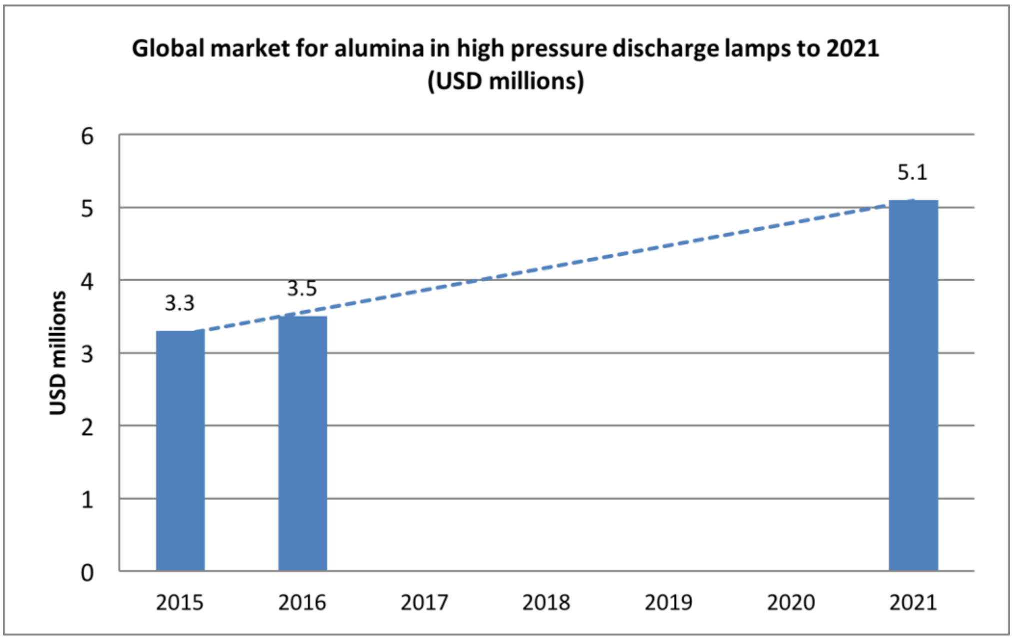

Figure A3.81. Global market for alumina in high pressure discharge lamps to 2021 (USD millions)

Source: BCC Research 2016

Products by emerging market

Nanosensors

A sensor is a device that responds to a physical, chemical, or biological parameter and converts its response into an output or signal, with complexity ranging from a door bell

[560] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.115

[561] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.75

[562] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.139

to a minute resistance change across a functionalised nanowire when a single protein attaches to it[563]. Sensors are basic components of mechatronic systems in vehicles, both for monitoring and for changing parameters in the vehicle. In moving systems, position and angle sensors play a key role. In order to improve the reliability of mechatronic systems, contactless magnetic field sensors that operate on the magnetoresistive principle are increasingly being applied. These convert position or movement information of a magnet into an electric signal using the giant magnetoresistive effect (GMR)[564]. The GMR effect only takes place in extremely thin layers of only a few nanometres[565]. Examples of automotive applications include ABS braking, door windows, sun roofs, control of driving dynamics and steering angle sensors.

The market for nanosensors is at a nascent stage, with negligible sales in 2015 and 2016 but a forecast value of at least USD 60 million by 2021[566] [567].

The next part of this annex looks at construction products and markets through nanotechnology.

8 Products and Markets for Construction through Nanotechnology

Commercialised products for building and construction through nanotechnology: Overview

To date, 156 building and construction-related products using nanotechnology have been identified as being commercially available on the market. About one-fifth of those are in the area of coatings and adhesives (20%), followed by anti-stick and anti-scratch coatings (17%). Insulation products have a share of 12% as shown in the figure below.

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[563] Report of the National Nanotechnology Initiative Workshop (2009), Nanotechnology-Enabled Sensing, Arlington, Virginia, May 5–7, 2009

[564] http://iopscience.iop.org/article/10.1088/0022-3727/41/9/093001

[565] Hessian Ministry of Economy, Transport, Urban and Regional Development (2008), Nanotechnologies in Automobiles, p.26

[566] BCC Research report IAS027D MEMS: Biosensors and Nanosensors

[567] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.193

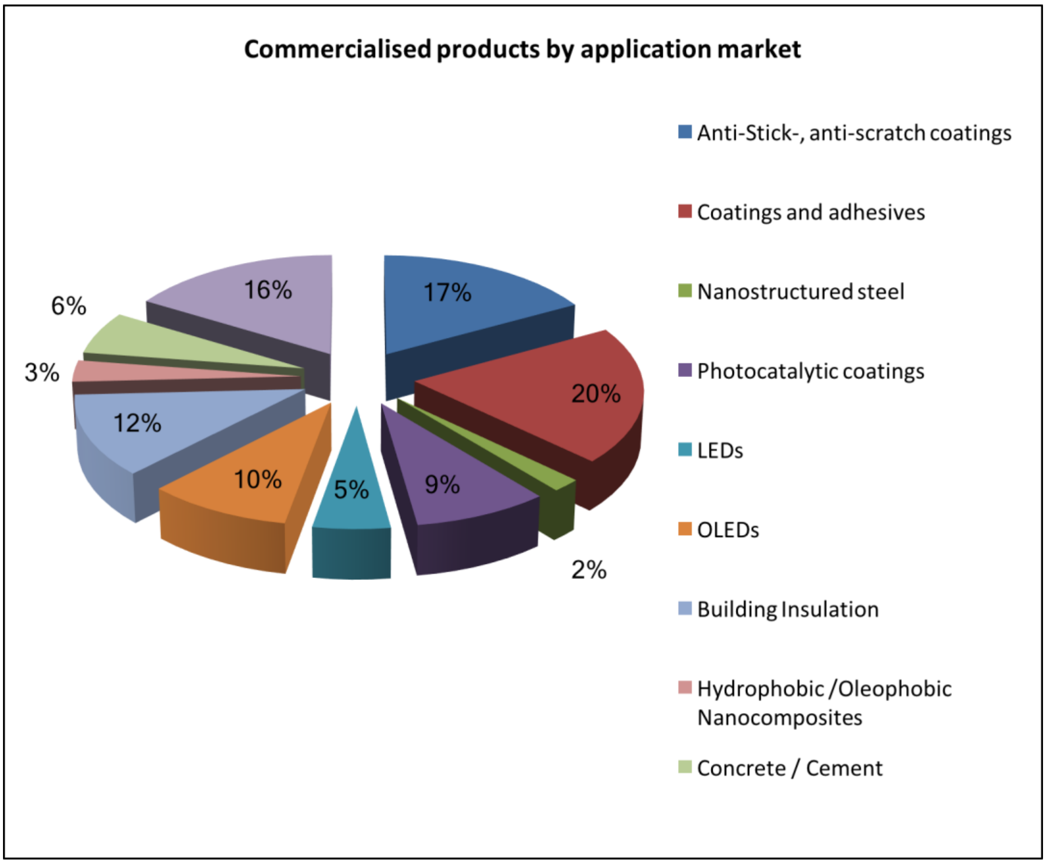

Figure A3.82. Nanotechnology in building and construction by product type

Source: JIIP, 2017

Products for construction through nanotechnology, by application market

The products identified are divided as follows:

- Coatings;
- Lighting; and
- Other products, e.g. energy recovery systems for buildings.

Coatings

Products by application market

Coatings and adhesives

Of all the nano-products introduced in the construction industry, coatings and paints have, up to now, been probably the most successful in achieving market success[568]. Paint is a pigmented chemical liquid that is applied to a substrate, in the case of construction to interior and exterior walls / roofs and pipes, to protect the surface and to give a colour to the surface. Paint is also used for energy preservation by modifying light reflection or heat radiation of a surface and, on metal surfaces, to prevent corrosion. Paint is composed of pigments, adhesives, binder, solvent and other additives[569].

Aqueous polymer dispersions have widespread applications in exterior paints, coatings and adhesives as well as in the finishing of paper, textiles and leather. They can be both

[568] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, Amsterdam

[569] ObservatoryNano (2009), Economical Assessment / Construction sector, Final report, p.30

decorative and protective against weathering, as binders in paint or plaster work and as coatings for concrete roofing tiles. If the dispersions are made soft and tacky, they can be used as pressure-sensitive adhesives for labels or adhesive tape. As binders for paper coatings, they can enhance brilliance in a wide variety of printed products. However, not all of the polymer particles used in these dispersions have truly nanoscale dimensions, ranging up to 800-nm in diameter, with it being estimated that about 10% of the polymer particles measure less than 100 nm.[570]

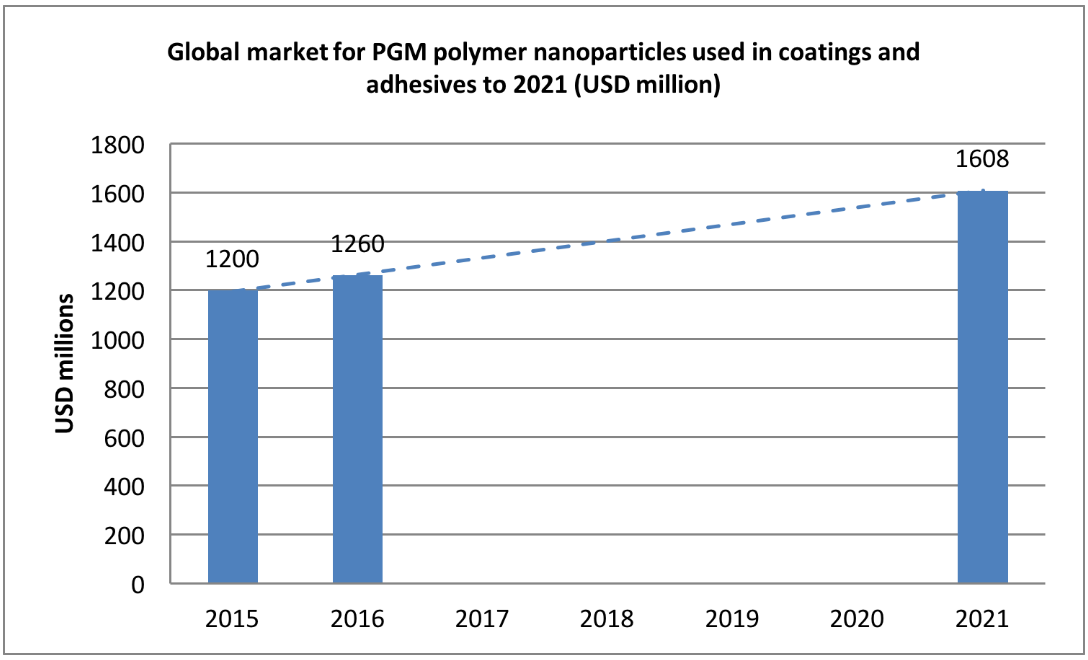

Figure A3.83. Global market for polymer nanoparticles used in coatings and adhesives to 2021 (USD millions)

Source: BCC Research 2016

Global consumption of polymer nanoparticles used to produce paints and other coatings was around 60,000 tons, with a value of USD 1.2 billion in 2015. These figures were estimated as follows. The worldwide market for aqueous polymer dispersions was worth an estimated USD 24 billion in 2015. In general, material costs for paints and coatings represent about half of the value of the product. Since water is the other major ingredient in these dispersions, the cost of the polymer ingredients was around USD 12 billion. However, not all of these particles have truly nanoscale dimensions; some range up to 800 nm in diameter. Lacking data on the average-size distribution of polymer particles used in the suspensions, it has been assumed that about 10% of the polymer particles measure less than 100 nm. The 2015 market for nanoscale particles used in aqueous polymer suspensions is thus an estimated USD 1.2 billion. [571]

The overall global coatings market is projected to grow at about 5% per year through 2021. Using this growth rate yields the projections in the figure above for platinum group metal (PGM) polymer nanoparticles used in coatings and adhesives to 2021.

High-strength Coatings (Nanostructured Steel)

The trade-off between steel strength and ductility is a significant issue for steel; the forces in modern construction require high strength, whereas safety and stress redistribution require high ductility. The presence of very hard nanometre-sized particles in the steel matrix can lead to a combination of these properties, effectively matching high strength with exceptional formability. However, when the particles become too

[570] BCC Research

[571] BCC Research

small, this effect can be reversed[572].

The range of possible properties available via nanostructuring include steels with the hardness of alumina ceramics and the strength of carbon-based fibres. Other potential attributes may be superior corrosion resistance over nickel-based superalloys, higher strength-to-weight ratios than titanium alloys, and better weldability than cobalt-based satellites[573].

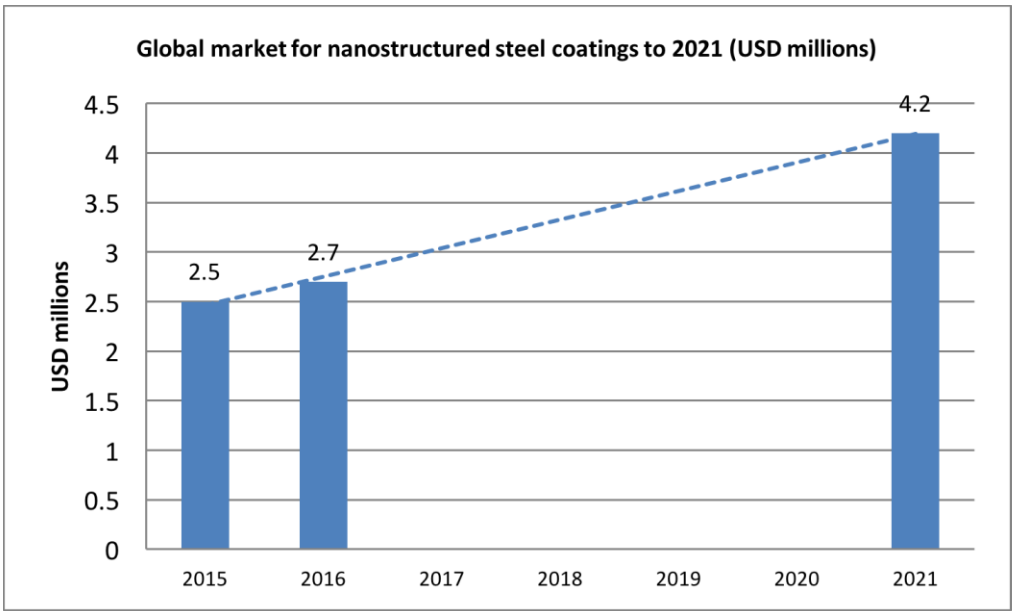

Figure A3.84. Global market for nanostructured steel coatings to 2021 (USD millions)

Source: BCC Research 2014

The market for nanostructured steel coatings was valued at around USD 2.5 million in 2015 and is forecast to reach USD 4.2 million in 2021, a CAGR of 9.2% over the next five years[574]. NanoSteel Inc. is currently the main vendor of nanostructured steel coatings, other providers including Sandvik. While NanoSteel does not publish separate sales data on its different product lines, it is estimated that coatings accounted for nearly all of the company's 2015 revenues of USD 2.1 million.[575]

Anti-scratch/ Anti-stick Coatings

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

The total market for nanostructured anti-scratch coatings is estimated at 1,230 metric tonnes with a value of USD 93 million in 2015, growing to an estimated USD 104 million in 2016 and USD 202.2 million in 2021 (a CAGR of 14.2% between 2016 and 2021). The market for polyurethane/alumina nanocomposite floor finishes was estimated to be worth USD 56 million in 2015. The balance was divided between ophthalmic coatings (USD 23 million) and other miscellaneous applications (USD 14 million). [576]

Both ophthalmic coatings and floor finishes are relatively mature market segments that

[572] van Broekhuizen et al. (2009), Nano-products in the European Construction Industry, p.32

[573] BCC Research (2014), Nanotechnology, a realistic market assessment, p.64

[574] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.127

[575] Ibid.

[576] BCC Research

are expected to grow at a CAGR of around 8% from 2015 through 2021. The market for other types of anti-scratch coatings (especially auto clear-coat) is expected to grow much faster (at a CAGR of 32.7%) between 2016 and 2021[577]. The trends in global markets for alumina and other metal oxide nanoparticles use in anti-scratch coatings to 2021 are shown in the figure below.

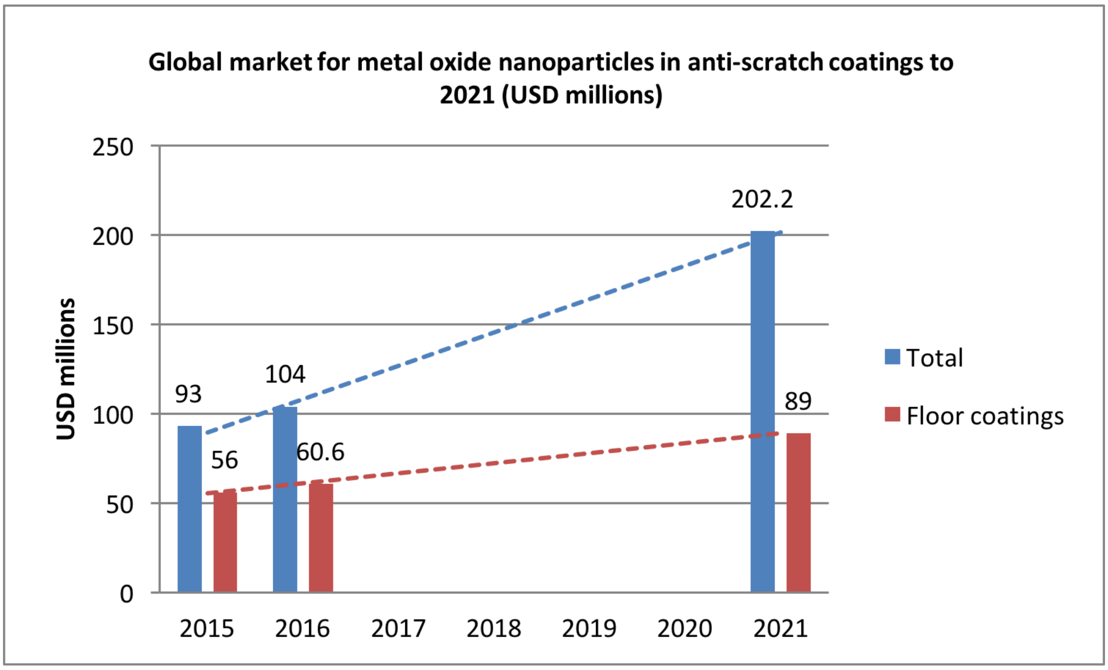

Figure A3.85. Global market for metal oxide nanoparticles in anti-scratch coatings to 2021 (USD millions)

Source: BCC Research

It is estimated[578] that sales in 2015 of polymer-based nanoscale thin film coating materials for eyeglasses, binoculars and cameras were about USD 32 million, based on sales figures for Nanofilm Ltd. Future sales of nanoscale optical coatings will depend on their ability to increase their penetration of the total eyeglass coating market, which, as shown in the table below, is slowly declining.

	2015	2016	2021	CAGR% 2016-2021
Eyeglass coating sales	832.7	831	822.7	-0.2

Table A3.15. Global eyeglass coating sales to 2021 (USD millions)

Source: BCC Research

Nanostructured polymer coatings' share of the total eyeglass coatings market was a little under 4% in 2015, with the potential to more than double their market share to about 8% by 2021, as shown in the figure below[579].

[577] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.124

[578] BCC Research

[579] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.118-119

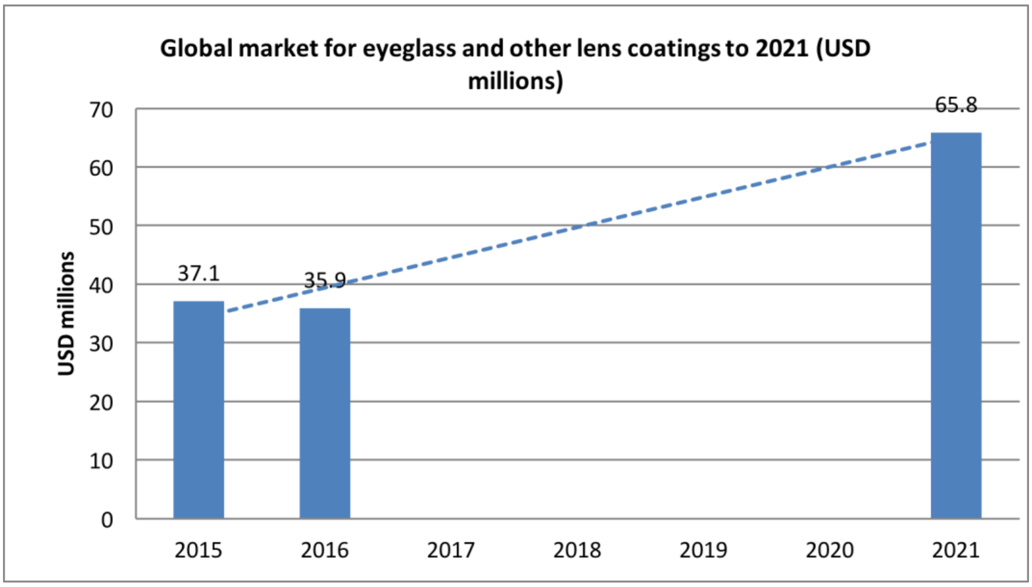

Table A3.16. Global market for thin films coatings in eyeglass and other optical applications to 2021 (USD millions)

Source: BCC Research 2016

Lighting

Products by application market

Light-emitting diodes (LEDs)

LEDs are used in an increasing number of lighting applications, replacing conventional light bulbs. Unlike conventional incandescent lamps (which convert electricity first into thermal energy and then to light), LED illumination is achieved when a semiconductor crystal is activated, directly producing visible light of a desired wavelength range[580]. Nevertheless, low-cost, mass-market white-light diodes with the potential to replace conventional incandescent bulbs and fluorescent tubes seem currently still out of the reach of LED researchers and manufacturers.

One possible solution is to use nanophosphors (i.e. semiconducting nanoparticles that emit light under excitation) in white LEDs. If the phosphor particles are smaller than 20 nm in diameter, according to Mie theory there will be less scattering of light waves and thus greater optical and energy efficiency[581].

The first commercial LED products incorporating nanoparticles were Nexxus Lighting's quantum dot-coated LED ceiling lamp fixtures, which began arriving on the market in small quantities in 2010. High-brightness LEDs may potentially use quantum dots or rare earth nanophosphors. The market for quantum dots used in LED applications could reach USD 50 million or more by 2021 and the demand for rare earth nanophosphors for LEDs is expected to be about the same[582].

Organic Light-emitting Diodes (OLEDs)

An OLED 'light bulb' is a thin film of material that emits light. OLED is currently the only technology that can create large area lighting panels (as opposed to the point or line lighting of LEDs and fluorescent bulbs). OLEDs can be used to make flexible and transparent panels, and can also be colour-tuneable, being the closest light source to

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

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

[582] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.72

natural light (with the exception of traditional incandescent lamps)[583].

Flexible signage and flexible lighting are being developed[584]: Philips Lighting's OLEDs (brand name "Lumiblade") have been available online since 2009[585] and Novaled AG introduced a line of OLED desk lamps called "Victory" in September, 2011[586].

The market for OLED lighting was negligible in 2016, being mostly in niche applications such as high-end residential and commercial showroom installations. In the longer term, potential markets for OLED lighting include architectural lighting and backlighting for displays and signage, switches, keypads, instrument panels and automotive dashboards, the projected market in 2021 being forecast as USD 1 billion[587].

Backlighting applications are expected to represent the main market for OLED lighting between 2016 and 2021, with an initial emphasis on backlights on small displays, e.g. for mobile phones, later expanding into medium-sized and large flat-panel displays. The main competitor for OLED backlights comes from LEDs, which started replacing code cathode fluorescent lighting (CCFL) backlights around 2004. The global market for LED backlights in 2015 was estimated to be worth USD 4.3 billion, rising potentially to USD 1 billion by 2021, with the OLED thin film materials themselves accounting for about 50% of the total cost of the backlights, or USD 500 million[588].

OLED lights generally cast a diffuse light, which makes them more of a competitor for fluorescent tube lights than for directional lights. The global fluorescent lighting market is expected to reach at least USD 35 billion by 2021. As a benchmark for how large a share of the architectural lighting market OLEDs could capture by 2021, forecasters[589] looked at the market history of compact fluorescent lights' (CFLs). CFLs were introduced commercially in the early 1980s and by 2000 had captured about 3% of the residential lighting market. In view of the increased attention now being paid to energy-efficient lighting, OLEDs could capture a similar market share by 2021 and perhaps even take some market share from CFLs, which are encountering some resistance from buyers on aesthetic and performance grounds.

If OLED lamps succeed in capturing 3% of the global market that would otherwise be served by fluorescent lighting, their sales will be around USD 1.0 billion by 2021. If OLED thin film materials represent about 50% of the total cost of the lamps, their market value would be USD 525 million[590].

Types	**Market in 2021 (USD million)**
Backlighting	500.0
Architectural lighting	525.0

Table A3.17. Global market for OLEDs by type, 2021 (USD millions)

Source: BCC Research

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583 http://www.oled-info.com/oled-light

584 Michael Kanellos, "Start-up creates flexible sheets of light", CNet News.com, December 6, 2007

585 http://oledworks.com/

586 TMC NEWS: New OLED Luxury Luminaire Series Launched Under German Brand Name Liternity®, September 13, 2011

587 BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.128

588 Ibid

589 BCC Research

590 BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.129

OLED panel shipments were worth around USD 612.9 billion in 2015. Most of these panels were small-molecule displays used in mobile phones and small appliances. It has been estimated that, in 2015, the cost of the OLED thin film materials used in these displays was half of their total cost, or close to USD 6.5 billion. [591]

Sales of polymer OLEDs were negligible in 2016. Manufacturing problems have prevented large-scale commercial production of polymer OLEDs. When these are solved, it is estimated that the polymer OLEDs will capture 25% of the market, worth USD 14.5 billion, by 2021. On this basis, sales of polymer OLED thin film materials should approach USD 7.3 billion by 2021. [592]

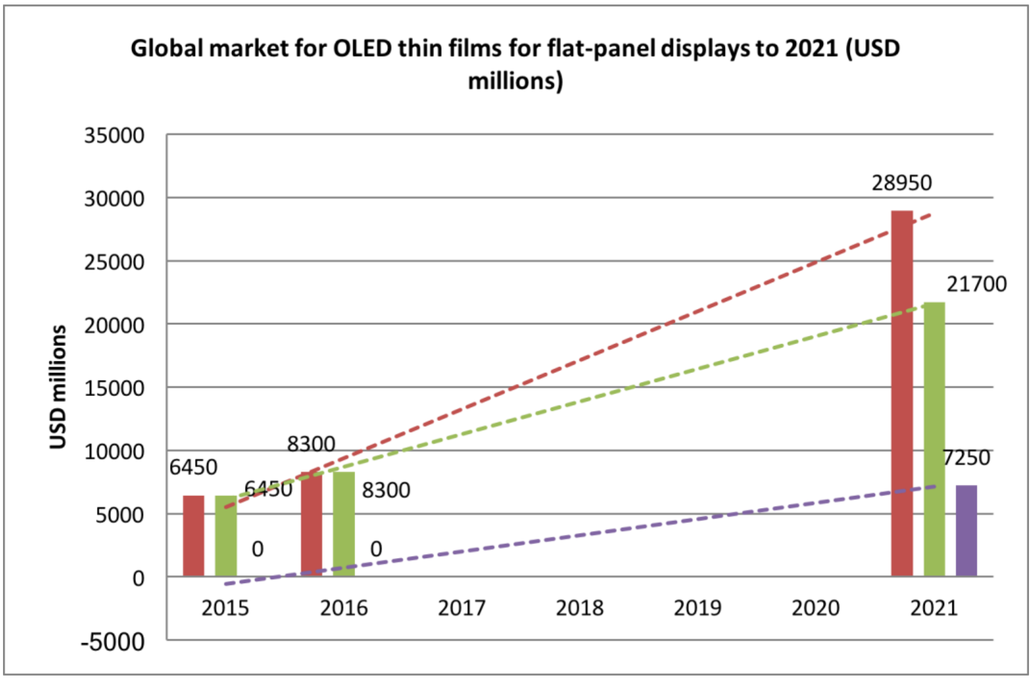

Figure A3.86. Global market for OLED thin films for flat-panel displays to 2021 (USD millions)

Source: BCC Research 2016

Other products

Energy Recovery Systems for Buildings

Energy recovery ventilation (ERV) is an energy recovery process in which the incoming air is treated (preconditioned) using the outgoing air of a building. Thus, for example, the incoming air can be pre-cooled and dehumidified in the summer or humidified and pre-heated in the winter[593]. The process leads to greater energy efficiency and reduced costs. A leader in the field is Dais Analytic Corporation, which uses nanotechnology in heating, cooling and refrigeration (NanoAir), energy storage (NanoCap supercapacitor) and water purification (NanoClear nanotechnology polymer), products that are at various stages of development and deployment (see https://daisanalytic.com) as well as in its ConsERV energy recovery ventilators using Aqualyte membranes.

While Dais Analytic Corp. does not publish separate data for its products, it has been estimated[594] that its energy recovery ventilator applications (ConsERV and Aqualyte membranes) were worth USD 50,000 in 2015 and projected that sales could approach USD 4 million by 2021. If the membranes account for 5% of the total cost of a ConSERV

[591] BCC Research

[592] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, pp.116-117

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

[594] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.142

system (similar to the share of nanostructured polymer membrane in a typical PEMFC or DMFC fuel cell), the revenue for the Aqualyte membrane could be as much as USD 200,000 by 2021.

Insulation for buildings

Aerogels are a porous, solid materials known for their extreme low densities (which range from 0.0011 to ~0.5 g cm^{-3}). In fact, the lowest density solid materials that have ever been produced are all aerogels, including a silica aerogel only three times heavier than air that could be made even lighter than air by evacuating the air out of its pores. In general, aerogels have densities of 0.020 g cm^{-3} or more (about 15 times heavier than air). Typically, aerogels are 95-99% air (or other gas) in volume, with the lowest-density aerogel ever produced being 99.98% air in volume[595]. Essentially an aerogel is the dry, low-density, porous, solid framework of a gel (the part of a gel that gives the gel its solid-like cohesiveness) with the liquid component removed. Aerogels are open-pored (that is, the gas in the aerogel is not trapped inside solid pockets) and have pores in the range of <1 to 100 nanometres (billionths of a metre) in diameter and usually <20 nm[596].

Aerogels have been prepared from many materials, including alumina, tungsten oxide, ferric oxide, tin oxide, nickel tartrate, cellulose, cellulose nitrate, gelatine, agar, egg albumen and rubber. However, most aerogels are formed from silica, hence their usual categorisation under that material. Aerogels reportedly have the highest thermal insulation value of any solid material[597].

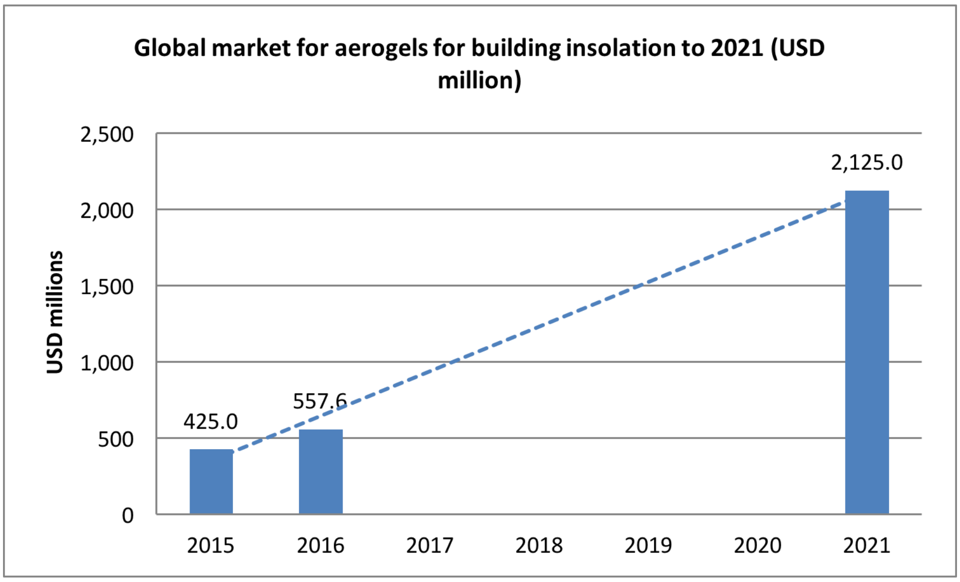

Figure A3.87. Global market for aerogels for building insolation to 2021 (USD millions)

Source: BCC Research 2016

The global consumption of aerogel insulation materials in 2015 was estimated[598] as USD 425 million. Silica aerogels are used commercially in a variety of applications, including oil and gas, aerospace, and cold-weather clothing. Over the next five years, the largest source of growth in the aerogel market is forecast for building insulation, which currently has a total market estimate of USD 23 billion, growing to close to USD 29 billion in 2021. At present, aerogel insulation has about a 1.85% share of this market. As a benchmark for the potential market penetration of aerogels by 2021 cellulose insulation took about

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[595] http://www.aerogel.org/

[596] Ibid

[597] BCC Research (2014), Nanotechnology, a realistic market assessment, p.76

[598] BCC Research

10 years after its introduction in the early 1990s to capture a 15% share of the U.S. market. It seems unlikely that aerogel sales could go from USD 425 million in 2015 to USD 4.4 billion (i.e., 15% of the projected world market for building insulation), a nearly ten-fold increase, in just six years. However, a fivefold increase, to some USD 2.1 billion, might be achievable[599].

Hydrophobic/ Oleophobic Nanocomposites

Hydrophobic surfaces have established themselves as candidates for various engineering applications, such as self-cleaning, anti-biofouling, anti-icing, anti-corrosion and drag reduction at micro- and macro-scales. Superhydrophobicity helps in protecting surfaces potentially affected by environmental factors such as rain and dirt[600].

Nanogate GmbH, the main supplier of hydrophobic/oleophobic nanocomposites, had sales of USD 84.8 million in 2015. Nanogate's sales increased at a CAGR of 24.8% between 2001 and 2015. At this rate, total sales of hydrophobic/oleophobic nanocomposites are expected to reach USD 105.8 million in 2016 and USD 320.4 million by 2021. The cost-per-ton of the nanocomposites is projected to remain relatively constant at around USD 75,000 in real terms[601].

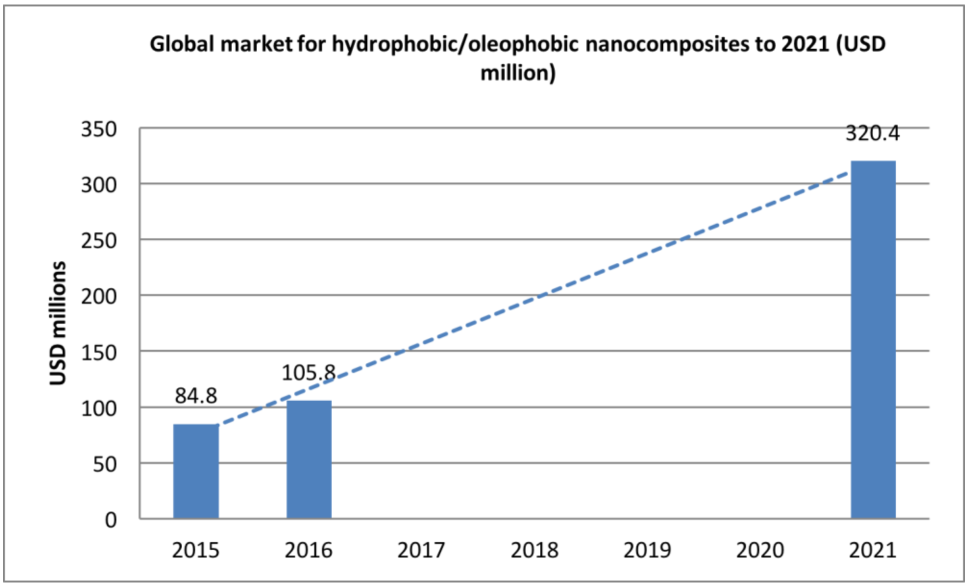

Figure A3.88. Global market for hydrophobic/ oleophobic nanocomposites to 2021 (USD millions)

Source: BCC Research 2014

Conductive Fibre

Thread spun from polyvinyl alcohol (PVA) in which single-wall nanotubes have been dispersed may meet some of the growing demand for conductive fibre in smart and interactive textile applications such as controls built into seats and other furnishings[602].

The global market for conductive fibre is expected to grow from approximately USD 500 million in 2015 to more than USD 1.6 billion in 2021. Polyvinyl alcohol–single-walled nanotube composites could capture 10% of the market for conductive fibres, worth at least USD 160 million, by 2021. [603]

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[599] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.139

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

[601] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.169

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

[603] BCC Research (2016), The Maturing Nanotechnology Market: Products and Applications, p.174

Wire and cable sheathing

One of the best-known commercial applications of clay nanocomposites is EVA/montmorillonite wire and cable sheathing materials (EVA being poly(ethylene-co-vinyl acetate) and montmorillonite being a smectite clay comprising single alumina sheets sandwiched between two silica sheets). A polypropylene (PP)/montmorillonite concentrate has also been developed (by Nanocor) to meet specific fire ratings, for use in heavy-duty electrical enclosures[604].

The estimated consumption of EVA/clay nanocomposite material for wire and cable sheathing and other fire-retardant applications in 2015 was USD 24.3 million (0.36% of the USD 6.8 billion global flame-retardant market). That global market is expected to grow at a CAGR of 9% over the next five years, reaching USD 11.4 billion by 2021. EVA/clay nanocomposites could increase their share of this market significantly, due to an environmentally-motivated switch away from halogenated fire retardants. To illustrate the market potential of EVA/montmorillonite fire retardants, if they succeed in doubling their market share from 0.36% in 2013 to just 0.72% in 2021, sales could reach USD 84.2 million by 2021[605].

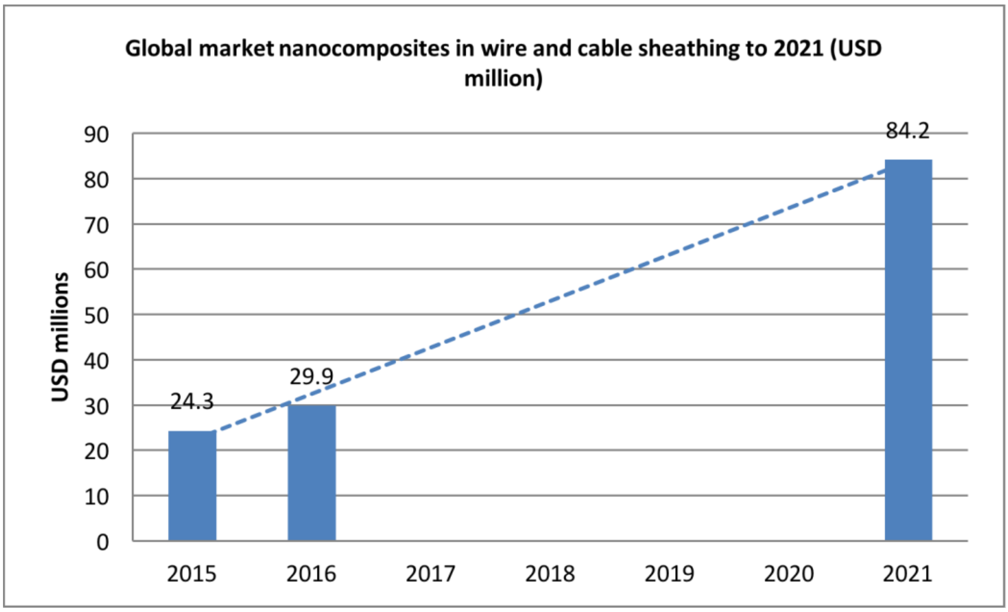

Figure A3.89. Global market for nanocomposite wire and cable sheathing to 2021 (USD millions)

Source: BCC Research 2016

The next annex looks at regulations and standards.

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

[605] BCC Research (2016), The Maturing Nano inst ology Market: Products and Applications, p.166

ANNEX 4: Regulations and standards by sector

This section covers sector-specific regulations and standards for each of the NanoData sectors in turn.

ICT

Overview

Regulatory frameworks applying to the ICT sector tend to focus on electronic communications and networks where nanotechnologies are not directly involved at the current stage of development.

Materials used in ICT are the highly regulated as environmental protection is paramount. Nanoscale materials used in ICT are also covered under nano-specific regulations such as the registers that have appeared in several countries.

European regulations affecting nanotechnology and ICT

In the European Union, ICT is regulated under the European framework directive for Electronic communications and is mostly oriented towards the provision of network services and international trade. This regulatory framework does not address the uses of nanotechnology in ICT.

Nanomaterials used to make or improve ICT must comply with the overarching regulatory framework in place for chemical substances. ICT innovations using nanotechnologies also fall under the scope of electronics regulations, such as the *Waste Electrical and Electronic Equipment Directive (WEEE) - 2012/19/EU and* the *Directive on the Restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS2) - 2011/65/EU.*

The WEEE directive refers to a 2009 Opinion of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) entitled '*Risk assessment of Products of Nanotechnologies*' stating that 'when nanomaterials are firmly embedded in large structures, for example in electronic circuits, they are less likely to escape this structure and no human or environmental exposure is likely to occur.' This directive also states that the European Commission should consider nanomaterials when reviewing Annex VII - Selective treatment for materials and components of waste electrical and electronic equipment referred to in Article 8(2) of the Directive. At the moment, nanomaterials have not been directly addressed in this annex.

The RoHS2 directive restricts the use of hazardous materials for electronic and electronical materials and mentions nanomaterials. In the absence of scientific evidence concerning nanomaterials hazardous properties, the European Institutions are invited to consider such substances during the process of reviewing Annex II – List of Restricted Substances. Between late 2012 and June 2014, Environment Agency Austria (Umweltbundesamt) had been tasked with writing up a methodology for the review of the List of Restricted Substances under RoHS2, under these methodology nanomaterials are not prioritised but assessors are still invited to be cautious when dealing with such substances. An exemption from restriction is ongoing for the use of cadmium quantum dots (CdQD) in illumination and display lighting applications, this exemption is however subject to debate in the European Parliament.

Some ICT applications may have both military and civil purposes; such goods are subjected to the EU Regulation setting up a Community regime for the control of exports, transfer, brokering and transit of dual-use items (428/2009). This text is set in the context of the international regime known as the Wassenaar Arrangement. Trade of dual use goods is restricted and requires an authorisation from national authorities, dual use goods are identified in a 'dual use list' where ICT is addressed in Categories 3 (Electronics), 4 (computers) and 5 (Telecommunications and information security). Some nanotechnology applications appear in the dual use list; under Electronics, 'nano-imprint lithography tools capable of producing features of 95nm or less (3.B)' are per example submitted to dual use rules.

Nano-specific regulations may also apply, e.g. REACH, as stated earlier.

The European RoHS2 and WEEE directives enacting restrictions for the use of certain hazardous materials are applied in ICT have been adapted in numerous countries outside of Europe (i.e. Argentina, China, Vietnam, the State of California, India, etc.). The Japanese authorities have taken a slightly different approach and did not introduce restrictions but labelling requirements. These do not specifically target nanomaterials.

Regulations for nanotechnology and ICT in the rest of the World

The European RoHS2 and WEEE directives enacting restrictions for the use of certain hazardous materials are applied in ICT have been adapted in numerous countries outside of Europe (i.e. Argentina, China, Vietnam, the State of California, India, etc.). The Japanese authorities have taken a slightly different approach and did not introduce restrictions but labelling requirements. These do not specifically target nanomaterials.

In the United States of America, the *Toxic Substances Control Act (TSCA)* is the main chemical regulation. The US Environmental Protection Agency (EPA) is in charge of adapting this regulation to nanoscale materials (the US authorities have decided not to write a binding definition of a nanomaterial). The latest regulatory initiative was taken by US EPA in April 2015 with the publication of a proposed rule for section 8 (a) of TSCA. This proposal would introduce reporting and recordkeeping requirements for nanoscale materials as well as a 135-days pre-notification requirement for the manufacturers of 'chemical substances as discrete nanoscale materials'. This new rule addressing nanomaterials under TSCA was promulgated in January 2017 and was initially intended to come into force in May 2017, this was however postponed to 14 August 2017.

In Canada, Health Canada and Environment Canada have been looking at similar approaches and requires manufacturers and importers to register information on a selection of 206 substances at the nanoscale under the *Canadian Environmental Protection Act (CEPA 1999*). Following the registration of those substances in 2015, Environment and Climate Change Canada have started prioritising the substances for further regulatory action.

European products are also subject to regulatory frameworks in other countries if they are to be marketed abroad. Marketing authorisations have to be applied for in each region or country and there are considerable differences between, for example, the US (implemented by the FDA[606]), Canada, Australia, China and Japan.

Standards

At the international level, the International Organisation for Standardisation (ISO) is responsible for the standardisation of nanotechnologies with its TC 229. ISO/TC 229 Nanotechnologies has not directly addressed ICT in its work. The TC has however worked on substances used in such products such as carbon nano-objects that were defined in *ISO/TS 80004-3:2010* and supported by a series of characterisation documents.

In Europe, the European Committee for Standardisation committee on nanotechnology (CEN/TC 352) has not developed standards relevant to the ICT sector but it does cover ICT and nanotechnology more generally through its working group on health safety and environmental aspects.

ICT is addressed by International Electrotechnical Commission (IEC) in IEC/TC113 – Nanotechnology standardisation for electrical and electronic products and systems. The technical committee has participated to joint terminology work with ISO/TC 229 and has

[606] US Food and Drug Administration http://www.fda.gov/

also produced technical specifications on key control characteristics for the manufacturing of electronics at the nanoscale (*IEC 62607* series). On EHS aspects, the IEC/TC 113 is currently developing Guidelines for quality and risk assessment for nano-enabled electrotechnical products *(IEC/TS 62844*).

IEC/TC 113 is mirrored in Europe by the European Committee for Electrotechnical Standardisation (CENELEC) committee CLC/SR 113; this committee has not produced standardisation documents.

Manufacturing

Overview

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

Standards

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:

Nanomanufacturing

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

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.

Health

Overview

Health and nanotechnology are covered by regulations and standards impacting nanotechnology (e.g. REACH) but also by many regulations and standards for health and patient safety.

European regulations affecting nanotechnology and health

In 2017, the European Institutions finalised the regulatory process for the review of the Medical Devices Directive. The new Regulation on Medical Devices (2017/745) introduces the definition of the term 'nanomaterial', and a new classification rule (in Annex VIII - Rule 19) specifically addressing the use of nanomaterials in medical devices and requiring higher risk classification for devices as follows:

Rule 19 - All devices incorporating or consisting of nanomaterial are classified as:

- class III if they present a high or medium potential for internal exposure;
- class IIb if they present a low potential for internal exposure; and
- class IIa if they present a negligible potential for internal exposure.

This regulation will enter into force on 26 May 2020.

The table below lists some key regulatory documents within the European Union and within its Member States. Nano-specific regulations often exclude medicinal products and medical devices from their scope due to the specific rules applying to the medical industry. These regulations are nevertheless relevant to the health sector as they may come into force at different stages of the production process (e.g. at the manufacturing stage of a batch of nanomaterials with uses in various sectors).

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
Published	Regulation on Medical Devices - 2017/745	EU	Medical devices	Yes
Implemented	European Commission Recommendation on the Definition of a Nanomaterial	EU	Substances at the nanoscale	Yes
Implemented	Nanomaterials in the Healthcare Sector: Occupational Risks & Prevention - E-fact 73	EU	Medical devices and pharmaceuticals (and wider healthcare)	Yes
Implemented	Decree on the annual declaration on substances at nano-scale - 2012-232	France	Substances at the nano-scale	Yes
Published	Guidance on the Determination of Potential Health Effects of Nanomaterials Used in Medical Device	EU	Medical devices	Yes
Implemented	Royal Decree regarding the Placement on the Market of Substances	Belgium	Substances manufactured at the nano-scale	Yes

Status	Name of the document	Country/ Region	Scope	Nano-specific
	manufactured at the Nano-scale			
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

Table A3.18. Overview of regulations for nanotechnology use in Europe

There are also efforts underway within the research community to develop a testing strategy for engineered nanomaterials such as those used in some health and cancer treatment applications. These include the ITS-NANO project under FP7-NMP which seeks to establish a roadmap for the development of advanced tools and databases that help to assess the risks through knowledge-based decision making.[607]

Regulations for nanotechnology and health in the rest of the World

A 2013 publication of the OECD on the *Regulatory Frameworks for Nanotechnology in Foods and Medical Products*[608] disclosed the results of a survey on 10 OECD delegations from the EU, France, Germany, the Netherlands, Poland, Canada, Japan, Norway, the Russian Federation and the USA. According to this survey, all the aforementioned delegations have frameworks 'governing the manufacture, importation and commercialisation/marketing for medical products relevant to nanotechnology'. All of them also stated that they had 'published (or articulated) a regulatory approach to nanotechnology'; these approaches are not systematically reported in the document. The OECD concluded that, in the countries of the responding delegations, the existing frameworks already cover medical products that may contain nanomaterials or involve the application of nanotechnology.

Standards and nanotechnology

Nanotechnologies in the field of medicine have also been considered by standardisation bodies. At European level, the European Standardisation Committee (CEN) has a dedicated technical committee TC 352 that has been working with nanotechnologies. While the organisation's working group WG3 is focussing on 'Health, Safety and environmental aspects', it has not yet published any document directly relating to nanomedicine.

At the international level, the International Organisation for Standardisation (ISO) is responsible for the standardisation of nanotechnologies with its TC 229. Similar to CEN/TC 352, the International Technical Committee comprises a working group on health safety and environmental aspects.

The seventh part of the ISO 80004 series on nanotechnology vocabulary is dedicated to nanomedicine (ISO/TS 80004-7:2011 Nanotechnologies - Vocabulary - Part 7:

[607] http://www.its-nano.eu

[608] OECD (2013), "Regulatory Frameworks for Nanotechnology in Foods and Medical Products: Summary Results of a Survey Activity", OECD Science, Technology and Industry Policy Papers, No. 4, OECD Publishing. http://dx.doi.org/10.1787/5k47w4vsb4s4-en

Diagnostics and therapeutics for healthcare). It defines general terms such as 'nanointervention' (i.e. manipulation at the cellular and subcellular level using nano-scale properties of materials or systems), as well as terms related to structural entities (e.g. 'stealth nano-object', 'nanoarray', 'nanopore sensor', 'nanocapsule', etc.).

While standardisation bodies have nanotechnology committees, nanotechnologies are cross-sectoral and are therefore relevant in other specific TCs of ISO. The EU FP7 project NanoSTAIR identified all ISO/TCs working with nanotechnologies. At the international level, the consortium identified several relevant technical committees working with health issues:

- ISO/TC 150 Implants for surgery;
- ISO/TC 150/SC2 Cardiovascular implants and extracorporeal systems;
- ISO/TC 194 Biological evaluation of medical devices; and
- ISO/TC 215 Health informatics.

ISO/TC 194 has also developed a specific guidance on nanomaterials for the biological evaluation of medical devices (ISO/ TR 10993-22).

Health product regulations

In order to protect the consumer, the health sector is highly regulated. There are three major health application areas each having different regulatory requirements attached to them: medicinal products, medical devices and advanced therapy medical products. Testing of the products is required and can greatly increase the cost and time to market of new or changed products. The process of testing, leading to a market authorisation, takes the form of a benefit and risk analysis which examines the three elements of quality, safety and efficacy of the medicine or medical device.

Following the acquisition of the market authorisation, the pricing of the product has to be negotiated and the terms for reimbursement set. These negotiations involve regional, national and private health insurance authorities.

In the EU, the framework under which these health products are brought to the market is based on the following EU Directives and Regulations, amongst others, are those shown in the table below.

Application	Directives and Regulations
Drugs Including Nano-Pharmaceuticals	Directive 2001/83/EC on Medicinal Products for Human Use Regulation No.141/2000 EC for new therapies for orphan diseases ('orphan drugs').
Medical Devices[609]	Regulation on Medical Devices - 2017/745Regulation on in vitro diagnostic medical devices - 2017/746
Advanced Therapy Medical Products	Advanced Therapy Medical Products (cell therapies and regenerative medicine). Regulation EC No 1394/2007 for gene and cell

[609] See also http://ec.europa.eu/growth/sectors/medical-devices/regulatory-framework/revision/index_en.htm

Application	Directives and Regulations
	therapies.
Clinical Trials	Clinical Trials Regulation (CTR) EU No 536/2014
Good Clinical Practice	The Good Clinical Practice Directive 2005/28/EC
Good Manufacturing Practice	Directive 2003/94/EC
Animal Testing (in vivo, pre-clinical testing)	European Directive 2010/63/EU ("Directive") on the protection of animals used for scientific purposes

Table A3.19. European directives and regulations for health products

In addition to different regulations and directives, the bodies responsible for accrediting new health products vary from one type to another.

- New pharmaceutical products require an application to be made to the EMA (European Medical Association), working in cooperation with national agencies, and the products follow a centralised procedure at the EU level.
- Approval of medical devices (including bandages, implants, medical instruments and equipment) must be obtained from authorised national 'Notified Bodies', which give the product a CE marking. There are four classes of medical devices depending on their intended purpose and inherent risks. Following the reporting of the supply of breast implants filled with sub-standard silicone by PIP, the EC proposed in September 2012 a new Regulation on Medical Devices, and the amendment of the previous Directive and regulations. The new regulation has been published in 2017 and requires stricter classification for devices incorporating or consisting of nanomaterials.
- The regulatory framework for advanced therapy medical products is under responsibility of EMA.

Regulations for nanotechnology and health products in the rest of the World

European products are also subject to regulatory frameworks in other countries if they are to be marketed abroad. Marketing authorisations have to be applied for in each region or country and there are considerable differences between, for example, the US (implemented by the FDA[610]), Canada, Australia, China and Japan. A product approved for the EU countries generally must be clinically tested again to gain approval in the US, incurring additional costs and time delays.

In order to harmonise regulation globally, the International Conference on Harmonisation of technical Requirements for Registration of Pharmaceuticals for Human Use (ICH)[611] convenes meetings of the regulatory authorities[612] and pharmaceutical industry to discuss scientific and technical aspects of drug registration. Members currently come from Europe, Japan, USA, Canada and Switzerland but expansion is being considered. ICH meetings aim to share regulatory understanding and activities, learn from existing regulatory frameworks and policy approaches, and promote regulatory convergence where appropriate. Confidentiality agreements are used to enable more open sharing of

[610] US Food and Drug Administration http://www.fda.gov/

[611] http://www.ich.org/home.html

[612] Participating organisations include the European Medicines Agency, European Commission, European Food Safety Authority, Health Canada, Japanese Ministry of Health, Labour and Welfare and Pharmaceuticals and Medical Devices Agency, United States Food and Drug Administration.

information among regulators.

Energy

Overview

Legislative frameworks for energy production and storage do not currently include nano-specific provisions. Nanomaterials used in energy production are nevertheless regulated similarly to other chemical substances in most countries. Nanomaterials may also require registration in country where nanomaterial reporting schemes have entered into force.

European regulations for nanotechnology and energy

Legislation applying to electronics and that include nano-specific provisions, such as the Waste Electrical and Electronic Equipment Directive (WEEE) - 2012/19/EU and the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS2) - 2011/65/EU, may also concern electronic devices used for energy. Under WEEE the European Commission reserves the right to amend Annex VII to eventually apply selective treatment to nanomaterials contained in waste electrical and electronic equipment. With RoHS2, European institutions keep on the possibility to add substances to Annex II – List of Restricted Substances and invited the reviewers of this annex to consider these materials.

Standards

Standards development on nano-enabled energy applications is mostly done via the International Electrotechnical Commission (IEC) Technical committee IEC/TC 113 Nanotechnology standardisation for electrical and electronic products and systems.

Several standards on of the IEC series on nano-manufacturing key control characteristics target the production and storage of energy. Cathode nanomaterials for lithium ion batteries are addressed in IEC/TS 62607-4-1, IEC/TS 62607-4-2, and IEC/TS 62607-4-3. IEC/TS 62607-4-4 Nano-manufacturing – Key Control Characteristics – Part 4-4: Nano-enabled energy storage - Thermal characterisation of nanomaterials, nail penetration method is also under development. Photovoltaics will be covered in Part 7 of this IEC series: experts are drafting the document Nano-manufacturing – Key Control Characteristics – Part 7-1: Nano-enabled photovoltaics measurements of the electrical performance and spectral response of tandem cells.

ISO has a number of technical committees dedicated to different types of energy production (e.g. ISO/TC 28 Petroleum and petroleum products, ISO/TC 180 Solar energy and ISO/TC 203 technical energy systems).

Photonics

Nanotechnology photonics are not regulated *per se,* being characterised by the wavelength of the emitted light being in the nanoscale rather than by the materials used.

European regulations affecting nanotechnology and photonics

Nanomaterials used for the realisation of photonic devices are nevertheless regulated under REACH in the EU and other national regulations (see above). Regulations applying to electronics, such as the Waste Electrical and Electronic Equipment Directive (WEEE) - 2012/19/EU and the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS2) - 2011/65/EU, may also concern electronic devices used for photonics.

Standards

The standardisation of photonics is shared amongst several technical committees (TC) of the International Standardisation Organisation. The dedicated ISO/TC for photonics is ISO/TC 172 Optics and photonics. The nanoscale aspects of photonics are however being covered by ISO/TC 229 Nanotechnologies and IEC/TC 113. The twin technical committees develop a joint vocabulary series for nanotechnologies that encompass nano photonics. A technical specification ISO/DTS 80004-10 Nanotechnologies -- Vocabulary -- Part 10: Nano-enabled photonic components and systems is currently under development. Other electronic aspects are covered by IEC/TC 76 Optical radiation safety and laser equipment.

In Europe, the European Standardisation Committee (CEN) has a dedicated technical committee TC 352 that has been working with nanotechnologies. CEN/TC 123 Lasers and photonics and CEN/TC 352 Nanotechnology are responsible for the same issues as mentioned above for ISO. They have however not developed standards relevant to nanotechnology photonics.

Environment

Overview

Environmental protection is the main driver for the development of regulation directed to nanomaterials.

European regulations affecting nanotechnology and environment

EU Biocidal product regulation

Nanomaterials are also covered in the Biocidal Product Regulation (BPR) (EU/528/2012). Applicable since 1 September 2013, it requires a dedicated risk assessment when a nanomaterial form of an active or non-active substance is used in a biocidal product. Such biocidal products must also be labelled and indicate the name the nanomaterial followed by the word "nano" in brackets. In addition, the simplified procedure for authorisation introduced in the BPR is not applicable for nanomaterials.

Other EU environmental regulations

While considering that 'all environmental regulation reviewed could be considered to address nanomaterials in principle', the second regulatory review states that classifications under the *Regulation for the Classification and Labelling and Packaging of Substances and Mixtures (CLP) EU/1272/2008* are the main trigger of pollutant identification.

The Second Regulatory Review was supported by a *Review of Environmental Legislation for the Regulatory Control of Nanomaterials*[613]*.* Conducted in 2011 by the environmental consultancy Milieu, the study had a specific look at nanomaterials in environmental regulation; a thorough analysis of the following pieces of legislation was undertaken:

- Waste Framework Directive 2008/98/EC
- Decision 2000/532/EC on the List of Waste
- Directive 2000/53/EC on end-of-life vehicles
- Landfill Directive 1999/31/EC
- WEEE Directive 2002/96/EC
- Directive 2002/95/EC on RoHS
- Packaging and Packaging Waste Directive 1994/62/EC

613 http://ec.europa.eu/environment/chemicals/nanotech/pdf/review_legislation.pdf

- Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when the sewage sludge is used in agriculture (Sewage sludge Directive)

- Water Framework Directive 2000/60/EC

- Directive 2008/105/EC on EQS in the Field of Water Pollution

- Directive 2006/118/EC on the protection of groundwater against pollution and deterioration

- Urban Waste Water Directive 91/271/EEC

- Drinking Water Directive 98/83/EC

- Directive 96/82/EC on the control of major-accident hazards involving dangerous substances (Seveso II Directive)

- Air Quality Directive 2008/50/EC

- Regulation (EC) No 66/2010 on the EU Ecolabel

In principle, the consultants found that nanomaterials fall under these regulations. However, the report notes that only a few of the aforementioned acts list or precisely refer to these substances; these are:

- *The WEEE Directive 2002/96/EC,* this directive requires the European Commission to consider nanomaterials when reviewing Annex VII - Selective treatment for materials and components of waste electrical and electronic equipment referred to in Article 8(2) of the Directive. At the moment, nanomaterials have not been addressed in this annex.

- The Directive 2002/95/EC on RoHS, this directive revised in 2011 as the Directive on the restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS2) - 2011/65/EU. RoHS2 restricts the use of hazardous materials for electronic and electronical materials and mentions nanomaterials. In the absence of scientific evidence that nanomaterials have hazardous properties, the European Institutions are invited to consider such substances during the process of reviewing Annex II – List of Restricted Substances. Between late 2012 and June 2014, Environment Agency Austria (Umweltbundesamt) had been tasked with writing up a methodology for the review of the List of Restricted Substances under RoHS2. This methodology does not prioritise nanomaterials, but assessors are still invited to be cautious when dealing with such substances.

- *The Regulation (EC) No 66/2010 on the EU Ecolabel* sets the rules for the award of the European environmental quality 'ecolabel'. It excludes products containing hazardous substances but has no rules regarding nanomaterials. However, in 2014, a decision by the European Commission excluded nanosilver from eligibility for the EU Ecolabel for rinse-off cosmetic products[614]. Other decisions[615] have added requirements for

[614] European Commission. 2014, Commission Decision of 9 December 2014 establishing the ecological criteria for the award of the EU Ecolabel for rinse-off cosmetic products (notified under document C(2014) 9302). Available at:
http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.354.01.0047.01.ENG

[615] European Commission. 2012. Commission Decision of 14 November 2012 establishing the ecological criteria for the award of the EU Ecolabel for Industrial and Institutional Automatic Dishwasher Detergents. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012D0720-20121201 and

European Commission. 2012. Commission Decision of 14 November 2012 establishing the ecological criteria for the award of the EU Ecolabel for Industrial and Institutional Laundry Detergents (notified under document C(2012) 8055). Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012D0721-20121201 information regarding the state and physical form of substances used in the final product.

In addition, a specific study was commissioned by the EU to tackle the coherence of waste legislation[616]. Compiled in 2011 by Bio Intelligence Service, the study lists nano-waste as one of the waste streams with potentially inadequate coverage. The report also features a section dedicated to nanomaterials and considers that "adaptation of EU waste policy might be required in the future to take into account possible new risks identified".

While regulations covering cosmetic products, food contact materials and novel foods also target nanomaterials, these do not address environmental issues.

Regulations for nanotechnology and environment in the rest of the World

Norway

Norway developed a register under its Pollution Control Authority (SFT). From 2013, chemical products must be registered in the Norwegian Product Register of Chemicals at the Norwegian Environment Agency, which includes chemicals that are classified as dangerous, and whose quantity produced in/imported to Norway and/or placed on the market each year is 100 kg or more. Registrants are required to provide information on chemicals containing "a substance in nano form" with a 'tickbox' system

If the chemical contains nanomaterials this must be declared in the registration, and information on any substance in nano form must be given for all mandatory declared chemicals, including the identity of the constituent that is in nano form. Only intentionally added nanomaterials need to be registered in the Norwegian Product Register of Chemicals, and the definition of nanomaterials follows the EC Recommendation 2011/696/EU.

Switzerland

The Swiss Secretariat for Economic Affairs (SECO) published a guideline document for the compilation of safety data sheet for synthetic nanomaterials, with as definition:

"A material whose particle size distribution includes over 1% nanoparticles (1-100 nm) in an unbound state, either as an aggregate or as an agglomerate. Fullerenes, graphene flakes and single-wall carbon nanotubes are classed as nanomaterials even if they have dimensions of less than 1 nm. Should the particle size distribution not be known, then any material with an average grain size less than 500 nm will be classed as a nanomaterial"

The definition adopted, as explained in the guideline, is mainly based on the definitions of nanomaterial of the 2011/696/EU Recommendation1 and on the ISO definition CEN ISO/TS 27687.8 The differentiation between nano-particles, nano-fibres and nano-plates and the definition of agglomerates and aggregates (not cited here) are adopted from the ISO definition.

Two important aspects of this definition: the percentage used for the particle size distribution (1% versus 50% of the EC recommendation) and the 500 nm upper size limit to be used when the PSD is unknown. The adoption of 500 nm as upper size limit is justified by the following considerations: a) in size distributions of manufactured nanomaterials (MNM) with a maximum at 500 nm, a large fraction of the MNM can still be in the low nm range; b) potential nano-specific interaction with cells can occur for sizes < 300 nm.

In 2016, Switzerland announced plans to reform its nanomaterial regulation framework.

[616] Bio Intelligence Service, 2011, *Study on coherence of waste legislation – Final Report*, DG ENV. Available at: http://ec.europa.eu/environment/waste/studies/pdf/Coherence_waste_legislation.pdf

Under the Swiss Chemical Ordinance (ChemO), the Federal Office for Public Health (Bundesamt für Gesundheit - BAG) proposed the introduction of communication requirements for nanomaterials, this reform is currently under discussion.

United States of America

In the United States of America, the *Toxic Substances Control Act (TSCA)* is the main chemical regulation. The US Environmental Protection Agency (EPA) is in charge of adapting this regulation to nanoscale materials (the US authorities have decided not to write a binding definition of a nanomaterial). The latest regulatory initiative was taken by US EPA in April 2015 with the publication of a proposed rule for section 8 (a) of TSCA. This proposal would introduce reporting and recordkeeping requirements for nanoscale materials as well as a 135-days pre-notification requirement for the manufacturers of "chemical substances as discrete nanoscale materials". This new rule addressing nanomaterials under TSCA was promulgated in January 2017 and was initially intended to come into force in May 2017, this was however postponed to 14 August 2017.

Canada

In Canada, Health Canada and Environment Canada require manufacturers and importers to register information on a selection of 206 substances at the nanoscale under the *Canadian Environmental Protection Act (CEPA 1999*). Following the registration of those substances, Environment and Climate Change Canada have started prioritising the substances for further regulatory action.

Health Canada published a "Policy Statement on Health Canada's Working Definition for Nanomaterials" (2011)[617].

Australia

The Australian National Industrial Chemicals Notification and Assessment Scheme (NICNAS) covers nanomaterials: nanoforms of substances in the Australian Inventory of Chemical Substances may be used and introduced in Australia while nanomaterials that are "new substances" are submitted to notification and assessment procedures. It is worth noting that the Australian regulations rely on a NICNAS working definition of "industrial nanomaterial" which reads as follows:

"…industrial materials intentionally produced, manufactured or engineered to have unique properties or specific composition at the nanoscale, that is a size range typically between 1 nm and 100 nm, and is either a nano-object (i.e. that is confined in one, two, or three dimensions at the nanoscale) or is nanostructured (i.e. having an internal or surface structure at the nanoscale)".

In 2016, NICNAS published a consultation on its reform initiative. The publication includes criteria for classifying materials as hazardous if it is a nanomaterial. This reform initiative also suggests that safety data sheets are provided to workers handling nanomaterials (even if they are not classified as hazardous substances) and that nanomaterials are labelled as *"caution: hazards unknown" or "caution: hazards not fully characterised"*.

South Korea

The Republic of South Korea has established the "National Nano-safety Strategic Plan (2012/2016)". The Ministry of Knowledge and Economy and the Korean Agency for Technology and Standards, published in 2011 a "Guidance on safety Management of Nano-based products", (Korean Agency for Technology and Science Public Notice No.2011-0108 of 12 May 2011).

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[617] http://www.hc-sc.gc.ca/sr-sr/pubs/nano/pol-eng.php

Taiwan (Chinese Taipei)

Under the Council of Labour Affairs, Taiwan addresses nanomaterials within the context of Chemical Substance Nomination & Notification (2012)[618].

OECD

Efforts to regulate nanomaterials are harmonised globally at the Organisation for Economic Co-operation and Development (OECD). Under the Working Party on Manufactured Nanomaterials, the OECD has a testing programme on manufactured nanomaterials. The organisation promotes its system of Mutual Acceptance of Data and develops Guidelines for the Testing of Chemicals that specifically address endpoints adapted to nanomaterials.

Standards

ISO

At the International Organisation for Standardisation (ISO), environmental issues are addressed in the ISO 14000 family of standards, developed in ISO/TC 207 Environmental Management. Nevertheless, these do not directly address the use of nanotechnologies.

In its scope ISO/Technical Committee (TC) 229 Nanotechnologies includes the development of "standards for: […] science-based […] environmental practices". Work package 3 of the TC specifically addresses Health, Safety and Environmental Aspects of Nanotechnologies. It has developed a number of technical specifications and technical reports addressing risks raised by nanomaterials for the environment and aiming at standardising test and toxicity assessment methods. For example, the technical committee has produced the following documents relevant to environmental protection:

- ISO/TR 13121:2011 Nanotechnologies — Nanomaterial risk evaluation.
- ISO/TR 16197:2014Nanotechnologies -- Compilation and description of toxicological screening methods for manufactured nanomaterials.
- ISO 29701:2010 Nanotechnologies -- Endotoxin test on nanomaterial samples for in vitro systems -- Limulus amebocyte lysate (LAL) test.

Work on environmental issues continues at ISO/TC 229. WG3 is currently working on an approved work item on *Nanotechnologies -- Considerations for the measurement of nano-objects, and their aggregates and agglomerates (NOAA)* in the environment and another one on *Nanotechnologies: Aquatic Toxicity Assessment of Nanomaterials in salt water lakes using Artemia sp.*

CEN

In Europe, the European Committee for Standardisation on nanotechnology (CEN/TC 352) mirrors the structure of ISO/TC 22: in WG3 - Health, safety and environmental aspects, the technical committee is currently developing a number of documents relevant to environmental protection, these are:

- CEN/TS (PWI 00352011) "Nanotechnologies – Guidelines for aspects of Life Cycle Assessment specific to nanomaterials"
- CEN/TS (PWI 00352012) "Nanotechnologies – Guidance on detection and identification of nano-objects in complex matrices"
- CEN/TS (PWI 00352013) "Nanotechnologies – Guidelines for determining protocols for

[618] This legislation was reformed in 2013 with the Toxic Chemical Substance Control Act (TCSCA) but, at the moment, it is not clear how nanomaterials will be affected

the explosivity and flammability of powders containing nano-objects (for transport, handling and storage)"

- CEN/TS (PWI 00352014) "Nanotechnologies – Guidelines for the management and disposal of waste from the manufacturing and processing of manufactured nano-objects"

- CEN/TS (PWI 00352023) "Manufactured nanomaterials (MNMs) in the construction industry. Guidelines for occupational risk management".

Transport

Overview

Legislation and regulation of transport is mainly based on a broad and well-established framework that covers all aspects of transportation from the manufacture of vehicles and the construction of infrastructure to the end of life of these vehicles. In this mature sector, the use of nanomaterials is not incorporated in the transport regulations of the relevant authorities. They rely rather on the adaptation of regulations for chemicals to the use of nanomaterials.

European regulations affecting nanotechnology and transport

Transport is one of the key policies of the European Union and is featured in *Title VI – Transport* of the *Treaty on the Functioning of the European Uni*on. The Directorate General for Mobility and Transport has the main responsibility for European transport policy, a dense package of directives and regulations. These never directly address the use of nanotechnologies in the final products.

The reuse and recycling of vehicles, for example, is mainly regulated by the *End of Life Vehicles Directive* (Directive 2000/53/EC - the "ELV Directive", amended in 2008) of the European Commission. It restricts the use of some substances and includes targets for the recycling and reuse of vehicles, but no provision in this directive targets nanomaterials. The ELV directive is supported *by Directive 2006/66/EU on Batteries and Accumulators and Waste Batteries and Accumulators*, amended in 2013, which also does not cover nanomaterials.

Nanomaterials used in transportation must comply with the overarching regulatory framework in place for chemical substances: *Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)*. Electronic items used in vehicles and incorporating nanomaterials may fall under the scope of electronics regulations, such as the *Waste Electrical and Electronic Equipment Directive (WEEE) - 2012/19/EU and* the *Directive on the restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS2) - 2011/65/EU.*

The WEEE directive refers to a 2009 Opinion of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) entitled '*Risk assessment of Products of Nanotechnologies*' stating that 'when nanomaterials are firmly embedded in large structures, for example in electronic circuits, they are less likely to escape this structure and no human or environmental exposure is likely to occur.' This directive also states that the European Commission should consider nanomaterials when reviewing Annex VII - Selective treatment for materials and components of waste electrical and electronic equipment referred to in Article 8(2) of the Directive. Currently, nanomaterials are not addressed in that annex.

The RoHS2 directive restricts the use of hazardous materials for electronic and electrical materials and mentions nanomaterials. In the absence of scientific evidence concerning any hazardous properties of nanomaterials, use can also be made of an associated annex: *Annex II – List of Restricted Substances*. Between late 2012 and June 2014, the Environment Agency of Austria (Umweltbundesamt) was tasked with formulating a methodology for the review of the *List of Restricted Substances* under RoHS2, under which methodology nanomaterials are not prioritised but assessors are still invited to be cautious when dealing with such substances.

For articles containing nanomaterials that are used in road vehicles, only electrical or electronic articles that can be bought separately and that are not specifically designed to be used in vehicles[619] would be covered by the RoHS2 Directive.

Nano-specific regulations may also apply, e.g. REACH, as stated earlier.

Similarly to Europe, other countries have not developed nano-specific regulations in their transport policy. The European legislation that may be applied to vehicles in Europe - the RoHS2 and WEEE directives enacting restrictions for the use of certain hazardous materials - have been adapted in numerous countries outside of Europe (i.e. Argentina, China, Vietnam, the State of California, India etc.), but do not specifically target nanomaterials.

Standards

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

At the ISO level, a number of technical committees however cover areas linked to transportation. These are: ISO/TC 8 Ships and marine technology; ISO/TC 22 Road vehicles; ISO/TC 20 Aircraft and space vehicles; ISO/TC 31 Tyres, rims and valves; ISO/TC 45 Rubber and rubber products; ISO/TC 110 Industrial trucks; ISO/TC 149/SC 1 Cycles and major sub-assemblies; ISO/TC 204 Intelligent transport systems; and ISO/TC 269 Railway applications. These do not provide for the use of nanotechnologies in these products.

The use of the nanomaterial carbon black in rubber components used in transportation has been the most heavily concerned by standardisation. In ISO TC 45 ISO/TC 45/SC 3 Raw materials (including latex) for use in the rubber industry, a series on carbon black in Rubber compounding ingredients is being developed and includes the following:

- ISO 1124:1988 Rubber compounding ingredients - Carbon black shipment sampling procedures;
- ISO 1125:2015 Rubber compounding ingredients - Carbon black - Determination of ash;
- ISO 1126:2015 Rubber compounding ingredients - Carbon black - Determination of loss on heating;
- ISO 1138:2007 Rubber compounding ingredients - Carbon black - Determination of sulphur content;
- ISO 1138:2007/Amd 1:2012 Clarification of digestion temperature in Subclause 3.4.5;
- ISO 1304:2006 and ISO/FDIS 1304 Rubber compounding ingredients - Carbon black - Determination of iodine adsorption number;
- ISO 1306:1995 Rubber compounding ingredients - Carbon black (pelletised) - Determination of pour density;

[619] European Commission, Frequently Asked Questions on Directive 2002/95/EC on the Restriction of the Use of certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) and Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE), available at http://ec.europa.eu/environment/waste/pdf/faq_weee.pdf

- ISO 1435:1996 Rubber compounding ingredients - Carbon black (pelletised) - Determination of fines content;
- ISO/DIS 1437 and ISO 1437:2007 Rubber compounding ingredients - Carbon black - Determination of sieve residue;
- ISO 3858:2008 Rubber compounding ingredients - Carbon black - Determination of light transmittance of toluene extract;
- ISO 4652:2012 Rubber compounding ingredients - Carbon black - Determination of specific surface area by nitrogen adsorption methods - Single-point procedures;
- ISO 4656:2012 Rubber compounding ingredients - Carbon black - Determination of oil absorption number (OAN) and oil absorption number of compressed sample (COAN);
- ISO 5435:2008 Rubber compounding ingredients - Carbon black - Determination of tinting strength.

In Europe, the European Committee for Standardisation committee on nanotechnology (CEN/TC 352) has not developed standards for transport applications. Similarly to the international level, a number of technical committees address issues related to transport, these are: CEN/TC 2 Shipbuilding details; CEN/TC 22 Rubber; CEN/TC 73 Methods of test for vehicle safety glass; CEN/TC 150 Industrial Trucks – Safety; CEN/TC 245 Leisure accommodation vehicles; CEN/TC 278 Intelligent transport systems; CEN/TC 301 Road vehicles; CEN/TC 320 Transport - Logistics and services; CEN/TC 326 Gas supply for Natural Gas Vehicles (NGV); and CEN/TC 354 Non-type approved light motorised vehicles for the transportation of persons and goods and related facilities. These, however, do not deal with the use of nanotechnologies in transport.

The International Electrotechnical Commission (IEC) in IEC/TC113 – Nanotechnology standardisation for electrical and electronic products and systems, mirrored in Europe by the European Committee for Electrotechnical Standardisation (CENELEC) committee CLC/SR 113 has not produced standardisation document relating to nanotechnologies in transport.

Construction

Overview

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

European regulations affecting nanotechnology and construction

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

CPR defines a construction product as follows:

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

This regulation evaluates the environmental impact of construction products but does not specifically cover nanomaterials. Nanomaterials used in construction must also comply with the overarching regulatory framework in place for chemical substances: *Regulation*

(EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), and CPR specifically refers to REACH. However, recital 25 of the CPR states that '*the specific need for information on the content of hazardous substances in construction products should be further investigated with a view to completing the range of substances covered so as to ensure a high level of protection of the health and safety of workers using construction products'.*

In France, the Decree[620] on the annual declaration on substances at nano-scale - 2012-232 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 grammes"*. The 2015 report of r-nano[621] identified 122 declarations referring to the use code su19, Building and Construction work. This represents 0.81% of the total registrations that year. In the 2016 report, figures drop to 84 declarations and 0.60% of the total registrations.

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

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

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

Regulations for nanotechnology and construction in the rest of the World

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

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

Standards

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

However, at ISO level, a number of technical committees cover areas linked to construction. The main committees are: ISO/TC 59 Buildings and civil engineering works,

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[620] 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

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

ISO/TC 195 Building construction machinery and equipment, and ISO/TC 205 Building environment design. Standards covering construction developed in these and other technical committees are gathered under the International Classification for Standards (ICS) code 91: Construction materials and building. At the moment, however, these do not provide for the use of nanotechnologies in these products.

In Europe, the European Committee for Standardisation (CEN) committee on nanotechnology (CEN/TC 352) is currently working on a technical report dealing with the construction sector. Tentatively entitled: '*Manufactured nanomaterials (MNMs) in the construction industry. Guidelines for occupational risk management'* this project is being developed under Working Group 3: Health, safety and environmental aspects. It originates from the SCAFFOLD[622] project of the European Union Seventh Framework Programme for Research (FP7), which aimed to develop 'innovative strategies, methods and tools for occupational risks management of manufactured nanomaterials in the construction industry'. The project produced a toolkit for risk management and is looking to translate its findings into a standardised guidance document.

Over 80 technical committees are dealing with construction at CEN[623]. However, these have not yet produced standards dealing with the use of nanotechnology in construction.

[622] SCAFFOLD ; http://scaffold.eu-vri.eu/

[623] See CEN website: https://www.cen.eu/work/areas/construction/products/Pages/default.aspx

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Eight NanoData Landscape Compilation studies covering the application of nanotechnology in the fields of construction, energy, environment, health, ICT, manufacturing, photonics and transport were published in 2017, based on data from 2015 and 2016. This report is an update of those studies and is based on data collected in 2016 and 2017.

Studies and reports

Publications Office