European Commission

NanoData Landscape Compilation

Information and Communication Technologies

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Contents

Figures

Tables

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EXECUTIVE SUMMARY

Background

This report offers a snapshot of the status of the environment for nanotechnology in the context of information and communications technologies (ICT). Analysis of that environment, trends in the data, and the effects of European policies and actions on nanotechnology, will be reported in the NanoData ICT Impact Assessment and are therefore not included in this report.

Role of nanotechnology

In using new methods and new technologies, the main goal of manufacturers of traditional ICT, such as chips for electronics, is to make smaller, faster and better devices. Reduced size means that more components and more functionalities can be put into a device. Faster and better devices are built with components with better computing speed and capacity. Better devices may also have the ability to process and/or store more data. Associated goals are to minimise costs of materials and manufacture, as well as to optimise performance, e.g. by controlling the heating of components. Nanotechnology can contribute to all these goals through coatings, particles and films but also, in the future, perhaps through radical changes in how ICTs work, though the use of spin (rather than charge) in technologies known as spintronics, quantum computing and DNA computing.

Policies

National policies to support nanotechnology tend to be generic at Member State level in that they may support nanotechnology within broad science and technology (S&T) initiatives (e.g. Innovate UK in the United Kingdom, which funds S&T across the board) or support it as a designated priority but usually do not single it out for specific measures (e.g. NanoNext in the Netherlands). Examples of initiatives in which nanotechnology and ICT (or related areas) have been specified together include the establishment of IMEC[1] in Belgium; the founding of the Iberian Nanotechnology Laboratory[2] in Portugal; and the thematic calls of the ANR[3] in France (on miniaturisation, new technologies and new devices for electronics and nano-photonics).

European supports are concentrated in the EU RTD Framework Programmes (see below under *EU R&D projects*) as these have the greatest role in EU funding of nanotechnology R&D (research and development). Other policies include those for industry and for ICT. There are many examples of collaborative and co-ordination mechanisms at European level including ERA-NET[4]s, European Technology Platforms (ETPs) and Networks of Excellence (NoEs), not least NANOFUNCTION, CHIST-ERA, ETP4HPC and ECSEL. In ICT policy, in addition to the Framework Programmes, there is the Digital Agenda for Europe, which aims to exploit the potential of ICT for jobs, growth and society.

Globally outside of the EU, countries that have specified nanotechnology and ICT (or related areas) as a priority within their policies and programmes at some point in the recent past include the Russian Federation (with the RUSNANO cluster on optoelectronics and nano-electronics); Japan (under its Second and Third S&T Basic Plans, 2001-2005 and 2006-2010, although Japan has now moved to more generic priority areas); and Korea (with national programmes and centres). Other countries include nanotechnology in policies and programmes but do not single out ICT (e.g. India's NanoMission).

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

EU R&D projects

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

[1] Interuniversitair Micro-Electronica Centrum, http://www2.imec.be/be_en/about-imec.html
[2] http://inl.int/
[3] http://www.agence-nationale-recherche.fr/
[4] Also ERA-NET plus

Mobility (Marie Curie Actions, EUR 219 million).

1307 projects (75% of them in FP7) were found to be related to nanotechnology and ICT, approximately 32% of all nanotechnology projects in the two Framework Programmes. They received EUR 2,655 million in funding, EUR 0.66 billion in FP6 and EUR 2 billion in FP7. The largest proportion of funding by theme was under the ICT-related theme of the Co-operation Programme in both FP6 (46.6%) and FP7 (56.6%). 25% of FP6 funding for ICT and nanotechnology was under the NMP theme, reducing to 10% in FP7. Marie-Curie Actions took around 10% of funding in both FPs.

Throughout FP6 and FP7, the top three countries (DE, FR and UK) received almost half of ICT nanotechnology funding and together have also taken over half of the total FP funding. Other countries (including Italy, the Netherlands, Switzerland, Belgium and Spain) follow at a distance.

Higher education establishments predominate in the FPs (receiving 45% of the funding), followed by research organisations (29%) and large companies (16%). SMEs are less strong in funding participation in ICT nanotechnology (7.5%) than for nanotechnology (12%) or FP overall (11%).

In terms of individual organisations in the EU28, the countries of France (CNRS[5], CEA[6]), Belgium (IMEC), Germany (Fraunhofer[7] and Max Planck[8] Gesellschaften) and the United Kingdom (the Universities of Cambridge and Manchester) are strongly represented in the top 20, which also includes organisations from the Netherlands, Sweden, Italy and Finland. Switzerland is the strongest non-EU28 country (EPFL[9] and ETHZ[10]) and Israel is represented by the Weizmann Institute.

Looking at companies by funding, branches of the French-Italian company group STMicroelectronics participate in 100 projects in FP6 and FP7, receiving funding of over EUR 80 million. Both Philips (NL, DE) and Infineon (DE, AT) with over 40 projects each received EUR 26 million. There are no SMEs in the top 25. In terms of location, the countries of these large companies are Germany (7), France (5), the Netherlands (3), Austria, Belgium and Italy (2 each), Spain, Finland, the United Kingdom and Switzerland (one each).

Publications

Of 1.8 million publications globally related to nanoscience and nanotechnology (NST) between 2000 and 2014, about 130,000 were related to ICT, 7% of the total output.

The strongest publishing countries in 2014 were the China and the US, followed by Korea, Japan, Germany, India and the United Kingdom. Of the EU28, the strongest in publications in 2014 were Germany, the United Kingdom, France, Italy and Spain, the top three being the same as for FP projects.

Thirteen of the top 25 publishing organisations are in China. Of the top ten, six are from China and two each from Singapore and Korea. There are no European organisations in the top 25.

Looking at EU&EFTA organisations in 2014, these are led by the University of Cambridge (UK), the University of Paris XI Sud and IMEC, each with over 100 publications. However, there has been no normalisation of the data to take into account factors influencing publication output such as the number of researchers/technicians/students or the research budgets. The companies with the most ICT publications globally in 2014 were IBM, Samsung Electronics and Nippon Telegraph (NTT).

Patenting

The strong presence of countries such as the US, Japan, Korea, Germany and the United Kingdom is also seen in patenting, with the omission of China and the addition of the Netherlands in the top six. However, the third placed Korea has less than a quarter of the patent families (422) of the US (2196) and Japan (1787). Using patenting families[11] as the measure, the top EU28 countries for ICT nanotechnology patenting between 1993 and 2011 were Germany, the Netherlands, the United

[5] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr
[6] Commissariat à l'énergie atomique et aux énergies alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[7] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[8] Max-Planck-Gesellschaft, the Max Planck Society www.mpg.de
[9] École Polytechnique Fédérale de Lausanne, the Swiss Federal Institute of Technology in Lausanne www.epfl.ch
[10] Eidgenössische Technische Hochschule Zürich, Swiss Federal Institute of Technology in Zurich www.ethz.ch
[11] At the European Patent Office, US Patent and Trademark Office or World Intellectual Property Office

Kingdom and France.

The top ten EU and EFTA countries by number of applications are the same as the top ten as measured by patents granted (DE, NL, UK, FR, BE, CH, SE, IT, ES and FI) with some changes in position but with the top five countries being the same in both. Germany, the United Kingdom and France also lead the table in FP projects and publications on nanotechnology and ICT (followed by Italy and Spain) but in patents the Netherlands also performs strongly.

Globally, the leading organisation for patents (by patent families) was the CEA in France, with the CNRS in France and IMEC in Belgium also in the top ten. Four out of the top ten organisations filing patents were in the US, and one each from Japan, Korea and Taiwan.

Of the top 15 universities and research organisations ranked by the highest number of EPO patents granted between 1993 and 2011, four are from the EU28/EFTA countries (CEA, CNRS, IMEC (ranked 1, 2 and 3 respectively) and the Fraunhofer Gesellschaft (ranked 10)). Seven are from the US.

Of the top ten companies with the highest number of patent families (with percentages for PCT, US and EP applications), five are in Japan and three the United States. Germany is the only EU28 country that features with the company Infineon, which is also very engaged in EU Framework Programmes. It should be noted that some may be holding companies rather than research companies or manufacturers.

Companies from the US and Korea lead the organisations with highest number of patents granted by the EPO. Infineon Technologies (DE) appears again at fourth place and is joined by Philips (NL), both strong FP performers. Another Dutch company (NXP) also has a significant number of EPO patents granted.

Products and markets for ICT through nanotechnology

The global market nanotechnology ICT products is expected to grow (USD 2 billion 2013, over USD 10 billion 2019). There is the potential for dramatic changes in computing but the markets for these cannot be quantified. It can only be forecast that 3-4% of the market in 2019 will come from applications of technology that do not already exist in some form. A relative decrease in exploitation of carbon nanotubes is expected by 2019 and the use of solid particles and thin films to increase.

The largest markets globally in 2014 were estimated[12] for low-k dielectric films for electrostatic protection (USD 870 million); sputtered magnetic coatings for hard discs (USD 429 million); nanoparticles in ceramic capacitors (USD 242 million); and nano-inks for printed electronics (USD 225 million). The highest growth for these products is forecast in low-k dielectric films, followed by nano-inks (and the silver nanoparticles they contain) and nanoparticles in ceramic capacitors. However, the market for new products such as transparent electrodes is expected to be very strong. In total markets in 2019, the forecast is for almost USD 7 billion for low-k dielectric, USD 1 billion for nano-inks for printed electronics, and almost USD 0.5 billion for sputtered magnetic coatings for hard disc applications. Market opportunities may also arise from the spintronics, quantum computing and valleytronics.

84 ICT-related products using nanotechnology have been identified as being commercially available on the market. Nanotechnology occurs mostly in components including data storage but also strongly in materials such as electrostatic dissipative coatings.

Regulation and standards

European regulations for nanotechnology are well-advanced with definitions and many regulatory documents. ICT is regulated under the European Framework Directive for Electronic Communications, which is mostly oriented towards the provision of network services and international trade and 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, the *Waste Electrical and Electronic Equipment Directive (WEEE*) and the *Directive on the Restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS2)*. In general, nanomaterials fall under REACH - the *Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)*.

[12] BCC Research

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 ICT may fall. In general, marketing authorisations must be applied for on a country by country basis.

The International Organisation for Standardisation (ISO) is responsible for the standardisation of nanotechnologies but has not directly addressed ICT. The European Committee for Standardisation committee on nanotechnology (CEN/TC 352) has not developed standards relevant to ICT but covers ICT and nanotechnology more generally through its working group on health, safety and environmental aspects. ICT and nanotechnology also fall under the International Electrotechnical Commission (IEC) and the European Committee for Electrotechnical Standardisation (CENELEC) committee.

1 BACKGROUND

The ability to measure and manufacture at the nanoscale is opening up many new avenues within industry and across society including information and communication technologies (ICT).

This report is a Landscape Compilation of facts and figures related to nanotechnology and ICT. It offers a snapshot of the status in 2015 of the environment for nanotechnology in the context of ICT. It documents past and current policies and programmes for nanotechnology (in particular, but not exclusively, those relating to ICT); the outputs of research (projects, publications and patents) and how those outputs are used in the application of nanotechnology to ICT (products and markets). Being a nanotechnology landscape, it does not provide detailed analysis of the data or its trends or draw policy conclusions. The analysis of the data in this report will be fully presented in the Impact Assessment report that accompanies it. The Impact Assessment considers the policies and practices at European level to date (an ex-post evaluation) and looks at gaps in the policies and practices, concluding with a review of what actions could be taken to enhance nanotechnology and ICT in the future (an ex-ante analysis).

The outline of this report is as follows:

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

The next section introduces ICT and the role of nanotechnology in addressing it.

2 INTRODUCTION TO ICT AND THE ROLE OF NANOTECHNOLOGY

2.1 Introduction to ICT

Information and communications technology (ICT) is an umbrella term applied to communication devices and systems (including computer and network hardware and software); telecommunications (e.g. telephones, mobile phones, radio and television); and satellite systems. It also covers the applications associated with them, such as video-conferencing, data management and distance learning. The devices and systems are often inter-linked, for example, satellites used by mobile phone networks.

Key applications of ICT

- Smart mobility: improve air quality, reduce congestion, sustain mobility for the elder generation and increase accident free mobility;
- Smart society: intelligent, secure and easy-to-use data systems;
- Smart energy: sustainable energy generation and conversion, reducing energy consumption, efficient community energy management;
- Smart health: long and healthy living through affordable care and well-being; improved food production, processing and delivery; and
- Smart production: manufacturing and process automation and new manufacturing and process technologies enabled by advanced electronics systems.

Adapted from http://www.ecsel-ju.eu/

ICT today is mainly semi-conductor and silicon-based, with integrated circuits driving ICT systems – here called **Traditional ICT**. Also of relevance in the context of nanotechnology is **Frontier ICT**, using new materials and novel systems (including the potential of quantum computing and organic electronics). The following paragraphs introduce traditional ICT and frontier ICT.

2.1.1 Traditional ICT

ICT has, following the age of the vacuum tube, relied largely on electronics composed of electronic components (e.g. resistors, capacitors, diodes and transistors[13]) and/or integrated circuits. Integrated circuits (ICs) are **semiconductor** wafers holding thousands or millions of miniature components - resistors, capacitors, transistors, etc. Integrated circuits can have many functions including being amplifiers, timers, actuators, counters, computer memories and microprocessors.

Semiconductors

A semiconductor is a substance that can conduct electricity under some conditions but not others, making it a good medium for the control of electric current. The ease with which a semiconductor conducts (its conductance) varies depending on the current or voltage applied to a control electrode, or on the intensity of irradiation by infrared, visible or ultraviolet light or X-rays.

The properties of a semiconductor depend on the impurities, or dopants, added to it. An N-type semiconductor carries current mainly in the form of negatively-charged electrons, in a manner similar to the conduction of current in a wire. A P-type semiconductor carries current predominantly as electron deficiencies (holes). A hole has a positive electric charge, equal and opposite to the charge on an electron. In a semiconductor material, the flow of holes is opposite in direction to the flow of electrons.

Elemental semiconductors include antimony, arsenic, boron, carbon, germanium, selenium, silicon, sulphur and tellurium. Silicon is the best-known of these, forming the basis of most integrated circuits (ICs). Common semiconductor compounds include gallium arsenide, indium antimonide and the oxides of most metals. *See: http://whatis.techtarget.com*

[13] Transistor: a device that regulates current or voltage flow in a circuit, acting as a switch or gate for electronic signals.

Advances in ICT have long been driven by the goal of miniaturisation, making smaller components in order to make smaller devices and systems and to incorporate a greater number of functionalities into devices. The rate of miniaturisation was predicted by Moore in 1965 in Moore's Law, which states that the number of components on an integrated circuit will increase exponentially over time i.e. double every year. In 1975, Moore revised his Law to state that the number of components on an integrated circuit would double every two years.

The Law proved to be accurate in large part, in that industry has delivered smaller and smaller and more and more powerful devices. The Law has long been used in goal-setting and long-term planning by the semiconductor and computer industries in the scenario called **More Moore**. The exponential trajectory of semiconductor manufacture, and hence computing power, has led to steeply decreasing costs in ICT making their applications (devices) increasingly accessible to consumers while constantly offering greater functionality. The ICT giant Intel estimates[14] that the **transistors** it now produces run 90,000 times more efficiently and are 60,000 times cheaper than the first one it produced in 1971.

Transistors

Transistors are the basic elements of standard integrated circuits (IC) with many transistors that are interconnected by circuitry forming a single electronic chip.

The transistor was invented by scientists at Bell Laboratories in 1947, rapidly replacing the vacuum tube as a regulator for electronic signals. It is a device that regulates current or voltage flow and acts as a switch (or gate) for electronic signals. Transistors typically consist of three layers of a semiconductor material, each capable of carrying a current. A small change in the current or voltage at the inner semiconductor layer (which acts as the control electrode) produces a large, rapid change in the current passing through the entire component. The component can thus act as a switch, opening and closing an electronic gate many times per second. It can also act as a current amplifier. Electrodes can be attached to each of the three layers of the semiconductors in order to better control the flow of electrons (or holes) through the transistor.

Field-effect transistors (FETs) use this three electrode system. In some FETs, the semiconductors layers are coated with metal oxides, forming MOSFETs (metal oxide semiconductor FETs). Metal oxide semiconductors are also present in *CMOS technologies*, complementary metal oxide semiconductor technologies. CMOS technology uses both N-type and P-type semiconductors in a complementary way for electrical control. Computers and many other ICT devices use circuitry based on CMOS technology. CMOS components use almost no power when not needed. However, the direction of the current can be very rapidly changed in CMOS transistors and they can become hot, limiting the speed at which circuits such as microprocessors can operate.

See: http://whatis.techtarget.com

The continuation of 'More Moore' relies on being able to reduce the size of electronics on an indefinite basis. While that may be possible for some future years[15], companies are also seeking to sustain and grow their sales by increasing performance through the stacking of components in forms known as 'system on a chip' (SoC) or 'system in a package' (SiP). Nanotechnology can contribute not only in the miniaturisation of ICT (More Moore) but also in this new direction (**More than Moore**). 'More than Moore' may indeed prove to be the better route for companies, in terms of cost competitiveness, as the fabrication facilities to make smaller and smaller components (More Moore) require very high levels of investment in infrastructure, an estimated USD 6 billion in 2015 for a new semiconductor fabrication plant (a so-called 'Fab'). New functionality and better performance in semiconductor-based applications is being targeted through the use of nanostructures such as nanowires and nanomaterials.

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[14] Reported in April 2015 in http://www.economist.com/blogs/economist-explains/2015/04/economist-explains-17

[15] Intel expects to be able to maintain the law to 2025 at least, slimming its transistors down to 5nm, about the thickness of a cell membrane (ibid).

The manufacture of silicon-based computer chips

Sand contains a high percentage of the semiconductor material silicon and is the starting material for computer chips. The silicon is melted and cooled into a solid monocrystalline lattice cylinder (ingot) with, for example, a diameter of 300 millimetres (mm) and a weight of about 100 kilogrammes (kg). Each ingot is cut into individual silicon discs (wafers) about one mm thick that are polished to a mirror-smooth surface.

Photolithography is used to imprint a pattern on the wafer. A light-sensitive, etch-resistant material (photoresist) is applied to the wafer surface. This can be done using a number of techniques including: physical vapour deposition (PVD), chemical vapour deposition (CVD), electrochemical deposition (ECD), molecular beam epitaxy (MBE) and atomic layer deposition (ALD). The photoresist is hardened and parts of it are exposed to ultraviolet light, making it soluble. The UV light passes through a mask (similar to a stencil), and then through a lens to shrink and print circuit patterns on each layer of every chip on the wafer. A chemical process is used to remove the soluble photoresist, leaving a patterned photoresist image.

Ions are embedded beneath the surface of the wafer in regions not covered by photoresist, changing the conductive properties of the silicon in the selected positions. A silicon dioxide layer is created over the wafer to insulate the transistor from other elements.

Multiple layers of high-k dielectric material can be applied to the wafer surface by atomic layer deposition. The high-k dielectric material improves performance and reduces leakage. This material is etched away in some areas, such as the silicon dioxide layer, as necessary.

Holes are etched into the insulation layer above the transistor and filled with copper or another material to form metal connections to other transistors.

The wafers are put into a copper sulphate solution. Copper ions are deposited onto the transistor using a process called electroplating. Excess material is polished off, revealing a specific pattern of copper. In a three-dimensional system, metal layers interconnect the transistors in a chip. The design of the chip determines how the connections are made. Although chips look flat, they can have more than 30 layers of complex circuitry.

After wafer processing is complete, each chip on a wafer is tested for its functionality. The wafer is cut into pieces (called die). Together, the substrate, the die and a heat spreader (a thermal interface that helps dissipate heat) form a completed processor. The substrate makes electrical and mechanical connections so that the processor can interact with the overall system.

Adapted from: https://www-ssl.intel.com/content/www/us/en/history/museum-transistors-to-transformations-brochure.html

Moving away from semiconductors, silicon photonics is being seen as a future means to enable the transmission of huge amounts of data at very high speeds with extremely low power over thin optical fibres. Combining these with semiconductor electronics, systems in a package may be able to integrate extremely fast III-V circuits with silicon-based circuits for transmission via optical fibres.

Future goals in ICT

- Semiconductor process, equipment, and materials: More Moore, More than Moore and System in Package (SiP) technology;
- Design technologies;
- Cyber-physical systems: embedded intelligent ICT systems that are interconnected, interdependent, collaborative, autonomous and provide computing and communication, monitoring/control of physical components/processes; and
- Smart system integration: 3D integration for sensing, data processing, actuating, networking, energy scavenging and managing, that combine nano-, micro-, and power-electronics with micro-electro-mechanical and other physical, electromagnetic, chemical and biological principles.

Adapted from http://www.ecsel-ju.eu/

Existing or soon-to-be-realised applications of nanotechnology in the field of ICT include: nanotechnology-enabled data storage technologies (e.g. hard disc media and computer memory); materials to make ICT (e.g. conductive inks for printed electronics); materials to enhance ICT (e.g. electro-conductive coatings); and nanotechnology-enabled components (e.g. multilayer ceramic capacitors and magnetic nanocomposites). Much more information on these (and the role of nanotechnology in them) is given in the section on *Products and Markets for ICT through Nanotechnology.* A large future market is anticipated in novel technology applications such as spin waves, spintronics, and quantum dot technologies, including quantum computing, novel sensors, graphene transistors and quantum cryptography.

2.1.2 Frontier ICT

Quantum computers are being developed by companies including D-Wave and IBM. They use qubits (quantum bits[16]) to represent a one or a zero (like a conventional computer) but they can also represent both a one and a zero at the same time, making quantum computers potentially much faster than conventional ones. In April 2015, IBM announced that they had overcome one of the barriers to quantum computing, the detection of quantum errors (for example, where one bit has flipped and taken a zero value instead of one)[17] while, in September 2015, D-Wave launched its D-Wave 2X system, a quantum computer of over one thousand qubits, that was subsequently installed at NASA's Ames Research Centre, in a collaboration between Google, NASA and the US Universities Space Research Association[18].

Quantum cryptography uses photons (light) to transfer encryption keys for secure systems via optical fibres. Nanotechnology coatings are being used to improve the quality of the fibres for transmission, in addition to nanoscale effects being at the core of quantum cryptography as a technology. Quantum key distribution is already in use in the global banking sector. Researchers are now working on twisting the light to increase the amount of information that can be transmitted by each photon, currently only one qubit. The technique uses the orbital angle momentum of the photon instead of its polarisation. [19]

Novel sensors: Energy harvesting uses autonomous and self-powered sensors, adsorbing energy from a renewable source that is continuously available in the ambient environment, without the need for battery replacement. For energy-harvesting to be adopted for a device, it must be able to match the need for energy in the device. Research is being done on reducing the gap between energy harvesting (supply) and device consumption (demand). Zero power switches would enable devices to operate without any energy being expended. More than Moore approaches are being researched to create nano-sized electronic switches. It has been shown that, theoretically, nano-magnetic zero-power switches that do not dissipate energy during operation are possible[20].

Graphene[21] *transistors* are being researched as a replacement for existing computer chip technologies because graphene, at a thickness of a single atom, can conduct electricity at room temperature. It is ultra-light, tough, 200 times stronger than steel and highly flexible. Its transparency and flexibility make it a candidate material for wearable electronics and bendable displays. Graphene transistors are being developed as photodetectors because of their ultra-high carrier mobility and light absorption in a broad range of wavelengths. Graphene field-effect transistors would perform well in high-frequency electronics[22].

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[16] A quantum bit is analogous to the binary digits (bits) of classical computing and relies on a two-state quantum-mechanical system (e.g. the polarisation of a photon, the two states being vertical and horizontal polarisation).

[17] http://www-03.ibm.com/press/us/en/pressrelease/46725.wss

[18] http://www.dwavesys.com/press-releases/d-wave-systems-announces-multi-year-agreement-provide-its-technology-google-nasa-and

[19] New Journal of Physics 17, 033033, http://m.iopscience.iop.org/article/10.1088/1367-2630/17/6/063008/pdf

[20] http://m.iopscience.iop.org/article/10.1088/0957-4484/26/22/222001/meta#nano512242fn3

[21] http://www.graphene.manchester.ac.uk/

[22] http://gr-sci.net/papers/10-02.PDF

2.1.3 Applications of ICT[23]

The applications of ICTs are manifold, from direct use as computers and phones to their being tools for signal processing and sensing applied to sectors including manufacturing, transport, health, energy and environment. Future applications may include *in vivo* health monitoring and drug delivery systems, smart home control systems and wearable computers. Sectoral examples are given below of a few of the current uses of ICT, particularly those in which nanotechnology is increasingly playing a role.

ICT in the transport sector

The transport industry is responsible for generating 7% of European GDP and 5% of employment. The mobility of people and the flow of goods to, from and within Europe must be cost-effective, safe and environmentally sustainable. Currently, the sector is responsible for the emission of 24% of greenhouse gases and 28% of CO_2, and is 97% dependent on fossil fuels.

The uses of ICT in the transport sector (now and in the future) include:

- Assisted driving systems (for fuel efficiency, safety, etc.);
  - Distance and speed regulation (as safety systems and for fuel efficiency);
  - Warning systems (e.g. obstacle avoidance systems);
  - Autonomous driving (driverless vehicles);
- Advanced positioning and communication systems; and
- Improved logistics management.

By 2017, the market for automated driving support systems alone (e.g. collision warning, drowsiness monitoring and night vision) is expected to reach USD 7.6 billion, representing a CAGR of 28.1% over the period 2012 to 2017. Also by 2017, sales of human machine interfaces (HMI) and navigation systems are expected to reach USD 5.2 billion (CAAGR of 9.8% over the same period).

ICT in the health sector

ICT, particularly as it becomes miniaturised with the help of nanotechnology, is increasingly seen as a key tool for personalised healthcare. Applications include personal diagnosis and monitoring, implants and enhanced levels of telemedicine across the community, all important to a growing and ageing population. In 2015, there are 901 million people aged 60 or over, 12% of the global population[24]. Within that, Europe has the highest percentage of its population aged 60 or over at double the average, 24%. The annual rate of growth of the global population aged 60 or above is 3.26% and the total is projected to be 1.4 billion by 2030 and 2.1 billion by 2050. With the aims of long life and healthy living, personalised medicine and home healthcare have a significant role to play.

Examples of the use of ICT in health include:

- Implantable pacemakers (since the late 1950s);
- Clip-on finger monitors of blood oxygen levels (pulse oximeters) (since the 1980s);
- Scanners such as MRI, CT and CAT scanners (since the 1970s and 1980s); and
- Glucose-sensing bio-implant insulin pumps for diabetes treatment (since the 2000s, e.g. 2003 in the UK [25]).

Advances that are being made using nanotechnology and ICT together, and already at the demonstration stage[26], include:

- Wearable E-skin that can measure heart rate and blood pressure[27]; and
- Paper diagnostic machines the size of a credit card that can give instant readings on blood and saliva samples[28].

[23] http://www.smart-systems-integration.org/public/about/objectives-mission (Strategic Research Agenda, accessed Nov. 2015)
[24] http://esa.un.org/unpd/wpp/
[25] http://www.nice.org.uk/guidance/ta151
[26] http://phys.org/news/2015-05-e-skin-pocket-sized-diagnostic-machines-patients.html#jCp
[27] http://www.sciencedaily.com/releases/2015/05/150512090729.htm
[28] http://www.ifm.liu.se/applphys/biosensors-and-bioelectro/research/biosensors/

Working at the level of nanotechnology but further away in terms of development are:

- Combining nano-carriers and MRI scanning for brain cancer therapy[29];
- Neural implants for severely disabled or injured people[30];
- 3-d scanning to help in the study of degenerative bone diseases such as osteoporosis[31];
- Ultrasensitive microRNA sensors for the diagnosis and treatment of pancreatic and other cancers[32]; and
- Tissue engineering with ICT controlling and optimising the bioreactor[33].

Much of the activity in ICT and nanotechnology for health is around biosensors. Healthcare companies report that the five technologies of greatest importance to their market are micro-electro-mechanical systems (MEMS), micro-optical electro-mechanical systems (MOEMS) and micro-fluidics; micro-sensors and micro-actuators; design and simulation technologies; semiconductor and More-than-Moore technologies; and micro-nano-bio-systems (MNBS). All of these use or, as scales are reduced in the search for new and better products and processes, they will use, or become, nanotechnology. Global sales of biosensors were USD 8.5 billion in 2012 and were expected to double to USD 16.8 billion by 2018, a large market for nanotechnology-related products across health, food, environment, etc. Remote patient monitoring (including support systems) has been estimated at a market value of USD 10.6 billion in 2012[34] while the total global health and personal well-being sector was estimated in 2011 to be over USD 300 billion[35]. The nanotechnology-based medical device market was estimated to be USD 5 billion in 2014, rising to USD 8.5 billion in 2019 (CAGR 11%)[36].

ICT in the manufacturing sector

ICT is ubiquitous in the modern manufacturing sector, as is nanotechnology. The main technologies used by companies in the sector are reported to be similar to those in healthcare: micro-sensors and micro-actuators; MEMS, MOEMS and micro-fluidics; design and simulation technologies; and semiconductor and More-than-Moore technologies. These are applied in

- Manufacturing and prototyping equipment;
- Process control systems linked to intelligent sensors;
- Robotics and factory automation; and
- Testing and inspection.

Nanotechnology and ICT work together in areas including: sensor systems for factory processes, robotics and testing; nano-coatings for heat reduction on electronic, electrical and mechanical components; testing and inspection at very small scales, in conjunction with signal processing systems; smart control of the work environment and monitoring of the workforce; and proto-typing using 3-D printing.

Within ICT, nanotechnology is present in components and materials. It may also play a significant role in the future in novel systems and new materials for ICT. Applications include data storage (Co, Ni, Fe nanowires); sensors (nanowires, graphene); transistors (graphene, nanowires); energy harvesters (nanowires); light-emitting diodes and lasers (nanowires); and electronic paper/ flexible electronics/ transparent screens (thin films and coatings). More information about nanotechnology in ICT follows below.

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[29] http://phys.org/news/2015-11-nanocarriers-brain-cancer-therapy.html
[30] http://actu.epfl.ch/news/neuroprosthetics-for-paralysis-an-new-implant-on-t/
[31] http://phys.org/news/2015-11-d-nanostructure-bone-visible.html
[32] http://phys.org/news/2015-11-nanotech-based-sensor-micrornas-blood-cancer.html
[33] A tissue engineering bioreactor can be defined as a device that uses mechanical means to influence biological processes. See http://epubs.rcsi.ie/cgi/viewcontent.cgi?article=1045&context=anatart
[34] http://www.kaloramainformation.com/about/release.asp?id=3159
[35] Medical Devices Industry and Market Prospects 2012-2022, Vision Gain 2012, www.visiongain.com
[36] MarketsandMarkets, http://www.marketsandmarkets.com/PressReleases/nanotechnology-medical-device.asp

2.2 Role of nanotechnology in ICT

The main goals of manufacturers of traditional ICT, such as chips for electronics, include:

- Reduced size (to make smaller devices);
- Greater computing capacity/speed while maintaining size requirements;
- Increased transmission capacity while maximising signal coherence; and
- Higher density data storage/memory (non-volatile).

Associated goals include:

- Minimising heat output; and
- Minimising the costs associated with materials.

While these are the goals of using nanotechnology in traditional ICT and electronics, in the future, nanotechnology may offer radical new solutions in ICT, including quantum and DNA computing. Some examples of the ways in which nanotechnology is being used or developed to improve ICT include:

- Silver nanowires, being highly conductive and flexible, are potential replacements for the indium tin oxide that is currently used to make transparent, conductive layers for tactile displays[37].
- Nanoscale quantum dots, in the form of a thin film in front of an LCD backlight, are being used in novel television screens[38]. Quantum dots (QDs) of different sizes each emit a different colour of light, improving the reproduction rate and brightness compared with conventional liquid-crystal or LED displays, making for a more saturated appearance of colour. The QD technology is also expected to be cheaper than organic LED screens.
- Nanoimprint lithography[39] is a technique to produce higher resolution patterns for integrated circuits than traditional photolithography. It has been used to fabricate field-effect transistors and single-electron memories. It is a simple, low-cost, and high-throughput process for replicating micro- and nanoscale patterns using mechanical deformation to create a pattern on a resist-coated substrate. The resist may be cured using heat or ultra-violet light. One mould may be used repeatedly to routinely make patterns at the scale of tens of nanometres.
- Nanotechnology-based imaging systems are being used to position components with great precision in three dimensions in the research, testing and manufacture of ICT and in combination with ICT systems.[40]
- Research is underway on carbon nanotubes (CNTs) as integrated light sources, modulators and detectors in silicon-based photonic devices. Single wall carbon nanotubes (SWNTs) are mono-dimensional materials, with specific electronic and optical properties relevant to electronics and opto-electronics devices, including light sources.
- Hard disc drives are magnetic memories that do not lose the information stored in them when the power is removed. They are however, relatively slow to access, much slower than random access memories (RAM). Many new solid-state technologies are being developed based on the magnetic spin of their materials. One such is spin-transfer-torque magnetic RAM (STT-MRAM) in which the information is stored in the spin of nano-magnets and accessed electrically[41]. This set of technologies is known as spintronics[42].
- Spin–torque nano–oscillators (STNOs) have outstanding advantages of a high degree of compactness, high–frequency tunability, and good compatibility with the standard complementary metal–oxide–semiconductor process, which offer prospects for future wireless communication.
- Plant-based photonic devices may in the future be used as sensor and communication networks. Photonic structures occur in plants and fruits as well as in butterflies, beetles, jellyfish and birds[43]. In plants, these structures affect the internal absorption and channelling of light. It may be possible to use this channelling effect in sensors and/or for energy harvesting. Plants may

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37 https://www.basf.com/us/en/company/news-and-media/news-releases/2015/03/P-US-14-37.html
38 http://www.ibtimes.com/quantum-dots-promise-cheaper-4k-tvs-are-they-really-better-oled-video-1782802
39 http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4079920/
40 Physics World Focus on Nanotechnology: reaping the benefits of nanomaterials, May 2015 www.physicsworld.com.
41 http://www.nature.com/nnano/journal/v10/n3/full/nnano.2015.50.html#close
42 http://www.nature.com/subjects/spintronics
43 http://rsif.royalsocietypublishing.org/content/10/87/20130394#sec-9

also be able to power a small circuit using the sugars they produce, or act as chemical sensors and communicate information by fluorescent signalling[44].

The purpose of nanotechnology in ICT products currently on the market is discussed in the later section on *Products and Markets*.

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

[44] Physics World Focus on Nanotechnology: reaping the benefits of nanomaterials, May 2015 www.physicsworld.com.

3 EU POLICIES AND PROGRAMMES FOR NANOTECHNOLOGY AND ICT

Support for public sector research and development (R&D) in the European Union is funded by Member States either directly through national programmes or indirectly via the programmes administered by the European Commission and its agencies. In addition, research and development are funded by companies (intra- and extra-mural R&D) and by philanthropic bodies and individuals. This report concentrates mainly on funding via the European Commission (EU funding), on Member State funding and on the outputs of industry funding of its own R&D.

EU funds for research and innovation are provided through dedicated programmes. In 2014-2020, these include the Framework Programmes (currently Horizon 2020), covering all research fields and fully dedicated to funding research and innovation activities; sectoral research programmes (nuclear energy, coal and steel, space); and the European Structural and Investment Funds. These programmes are complemented by five other EU programmes with links to research and innovation activities: The Third Health Programme[45], Life[46], Erasmus+[47], COSME[48] and the Connecting Europe Facility[49].

This section will first consider the EU Framework Programmes.

3.1 The EU Framework Programmes: supports for nanotechnology

The Framework Programmes (FPs) being the largest source of EU funds for R&D, they have the greatest role in EU funding of nanotechnology R&D. Support specifically named as being for nanosciences and nanotechnologies was first provided at a significant level in the Sixth Framework Programme (FP6, 2002-2006) [50]. Within FP6 funding, 56.6% of ICT nanotechnology projects were funded under Information Society while 25% were funded under NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices).

Nanotechnology funding in FP6 was followed up with targeted funding in the Seventh Framework Programme (FP7, 2007-2013). The largest part of funding for ICT and nanotechnology under the Co-operation Programme was under ICT (46.1%). Under that theme, for example, ICT Challenge 3 (Alternative Paths to Components and Systems) covers nano-electronics and photonics, the heterogeneous integration of these key enabling technologies with related components and systems, as well as advanced computing and control systems at a higher level. Other themes under Co-operation that supported ICT were NMP (Nanosciences, Nanotechnologies, Materials and new Production Technologies) with over 10% of funding and the Joint Technology Initiatives[51] (JTIs) with over 8%.

The ICT topics were also funded under FP7 in non-specific basic research and in People and Capacities:

- The European Research Council (ERC): total funding of over EUR 7.5 billion in FP7 (and EUR 13.1 billion in 2014-2020 under Horizon 2020[52]) for investigator-driven, bottom-up research ideas in science, engineering and interdisciplinary research, awarded through open competition, with 18.8% of nanotechnology ICT funding;

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[45] Preventing diseases, protecting EU citizens from cross-border health threats, contributing to innovative health systems, and facilitating better access to healthcare.
[46] For environment, biodiversity and climate change.
[47] Supporting relocation for education and training purposes.
[48] Supporting the creation and expansion of companies, especially by expanding their research and innovation activities.
[49] Improving trans-European infrastructure for transport, energy and telecommunications.
[50] FP6 NMP: Nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices: thematic priority 3 under the 'Focusing and integrating community research' of the 'Integrating and strengthening the European Research Area' specific programme, 2002-2006.
[51] Joint Technology Initiatives (JTIs) are long-term Public-Private Partnerships which are managed within dedicated structures based on Article 187 of the Treaty on the Functioning of the European Union (TFEU) (see more information later in this chapter)
[52] http://erc.europa.eu/

- The Marie Curie Actions[53]: total funding of up to EUR 4.7 billion FP7 in 2007-2013 (and EUR 6.16 billion Horizon 2020 funding in 2014-2020) for training, mobility and career development of researchers with 10% of nanotechnology ICT funding; and
- The Capacities Programme[54]: total budget of EUR 4.1 billion for research infrastructure; research for the benefit of SMEs; regions of knowledge and support for regional research-driven clusters; research potential of Convergence Regions; science in society; support to the coherent development of research policies; and international co-operation, with 2% of nanotechnology ICT funding.

Framework Programme funding is covered in much greater detail later in this chapter.

ICT, Nano and Health: the Micro- and Nano-Bio Systems cluster in FP6 and FP7[55]

One ICT activity of relevance to nanotechnology and health is the Micro- and Nano-Bio Systems cluster that looks at how systems can be integrated for applications that have, or interact with, biological components. Other areas of application include environmental monitoring, and food and beverage quality and safety.

MNBS projects to date have had targets of achieving substantial improvements via system integration (e.g. miniaturisation and reduced power consumption, integration of molecular and cell biology), improving system quality and/or reliability, and reducing the time-to-market. MNBS has sub-groups on biomedical applications; miniaturised and lab-on-chip systems for biological (*in vitro*), chemical and biochemical analysis; and systems for *in vivo* interaction with the human body, etc. These aim, *inter alia*, to accelerate the development of integrated diagnostic, monitoring and therapeutic devices.

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

The ERA-NET scheme began under FP6 to support collaboration between and co-ordination of national research programmes. For example, some activities of the ERA-NET *ERA-SPOT - Strengthen Photonics and Optical Technologies for Europe* (2005-2009, total funding EUR 880,000, started by funding agencies from Austria, France, Germany, Slovenia, and Sweden) are relevant to the ICT sector. ERA-SPOT aimed to consolidate activities in optical technology (OT) through the co-ordination of national research funding programmes, by developing and implementing joint strategies and actions.

The ERA-NET scheme continued under FP7 to develop and strengthen the co-ordination of national and regional research programmes through ERA-NET Plus actions, providing in a limited number of cases with high European added value, additional EU financial support to facilitate joint calls for proposals between national and/or regional programmes. For example, ERANET+ projects targeting ICT have been funded in OLAE+.

OLAE+[56] (2011-2016, funding EUR 6 million) is the Organic and Large Area Electronics European competition for collaborative R&D funding. Its goal is to consolidate funding activities throughout Europe and achieve the best possible exploitation of the resources and the innovative potential of European industry and science. OLAE+ uses joint calls focussing on organic and large area electronics technology, materials and systems. The topic and basic concept for this ERANET+ originated from the Mirror Group of the European Technology Platform Photonics21 that was made up of governmental representatives from the Member and Associated States involved with the promotion of photonics.

[53] http://ec.europa.eu/research/mariecurieactions/ Marie Curie Actions became Marie Skłodowska-Curie Actions under Horizon 2020.
[54] http://ec.europa.eu/research/fp7/index_en.cfm?pg=capacities
[55] http://cordis.europa.eu/fp7/ict/micro-nanosystems/home_en.html
[56] www.olaeplus.eu/

Under FP7, there are also the two examples of CHIST-ERA and ICT-AGRI:

- CHIST-ERA[57], the European Co-ordinated Research on Long-term Challenges in Information and Communication Sciences & Technologies, is carried out by national and regional research funding organisations with the contribution of the EU. The main purpose is to foster co-operation across countries, with the greater level of attention being on research that involves multiple disciplines. In the last few years, the topics on which the calls were issued were the Internet of Things, the terahertz band for next-generation mobile communication systems, and quantum information and technologies.
- Also partially related to nanotechnology and ICT is ICT-AGRI[58], which aims to support "the effectiveness and efficiency of national research programmes within information and communication technology (ICT) and robotics for a competitive, sustainable and environmentally-friendly agriculture".

Networks of Excellence (NoE) were introduced in the Sixth Framework Programme (FP6) with the objective of combatting fragmentation in the European Research Area (ERA) by integrating the critical mass of resources and expertise needed to enhance Europe's global competitiveness in key areas relevant to a knowledge-based economy. These bottom-up initiatives are led by consortia targeting specific research or technological challenges. They include NANOFUNCTION and ACROPOLIS:

- The NANOFUNCTION ICT Network of Excellence (Beyond CMOS nano-devices for adding functionalities to CMOS) received an EC research funding contribution of EUR 2.8 million (2010-2013). The consortium involves partners from industry and academia located in ten Member States, working on the integration of nanostructures with CMOS (complementary metal–oxide–semiconductor) chips in order to improve the range of functionality on a nano scale[59]. The partners concentrated on "ultra-sensitive nano-sensors capable of detecting signals in molecules; nano-structures for harvesting energy for the development of autonomous nano-systems; nano-devices for spot cooling of integrated circuits; and nano-devices for radio-frequency (RF) communication"[60].
- ACROPOLIS[61] (Advanced coexistence technologies for radio optimisation in licensed and unlicensed spectrum) was established in 2010 with mainly academia partners. Its objective is to "maximise the potential of wireless communications systems" and "to reduce the fragmentation of research in Europe on coexistence technologies such as spectrum sharing and cognitive radio". It has received an EU research funding contribution of EUR 3 million.[62]

European research is also being co-ordinated through collaboration on the development, establishing and running of large research infrastructures, so large that they cannot easily be funded by one agency or country alone. Under the auspices of the European Strategic Forum on Research Infrastructures (ESFRI)[63], Member States are coming together to fund infrastructures related to ICT, energy, health and other fields. EU grants support the preparatory phases of all selected projects and assist in implementation and operation of prioritised projects. There was EU funding of EUR 1.85 billion in FP7 and about EUR 2.5 billion in Horizon 2020. Research infrastructures relevant to ICT include the project Partnership for Advanced Computing in Europe (PRACE)[64] and the European Magnetic Field Laboratory (EMFL)[65], which form part of the infrastructure needed to enable ICT applications of nanotechnology.

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57 http://www.chistera.eu/
58 http://www.era-platform.eu/era-nets/ict-agri/
59 http://cordis.europa.eu/project/rcn/95145_en.html
60 http://cordis.europa.eu/programme/rcn/853_en.html
61 http://www.ict-acropolis.eu/.
62 http://cordis.europa.eu/project/rcn/95593_en.html
63 http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=home
64 http://www.prace-project.eu/
65 www.emfl.eu

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

- EUREKA's Eurostars;
- European Technology Platforms; and
- Joint Technology Initiatives (and Joint Undertakings).

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

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

3.2.1 Overview

Project-related data was extracted from the eCorda database for the EU Sixth Framework Programme (FP6) and the EU Seventh Framework Programme (FP7)[66]. The total number of projects was 35,265, of which 25,238 were FP7 projects and 10,027 were FP6 projects. There were 210,177 participations, of which 133,615 were in FP7 and 76,562 were in FP6.

From the initial set of 35,265 projects, 4,143 were found to be related to nanotechnology in that they contained, in the title or abstract of the project, the term "nano"[67] or another relevant term[68]. Thus, nanotechnology projects form over 10% of the total FP projects. The share of nanotechnology projects increased slightly between FP6 (10.4%) and FP7 (12.3%).

75% of the 4,143 projects were FP7 projects and 25% were FP6 projects. The relative shares of nanotechnology projects were similar to those found for FP projects in general (72% in FP7 and 28% in FP6).

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

		Total	FP7	FP6
FP total	Number of FP Projects	35,265	25,238	10,027
	Share of FP Projects (total)	100%	71.6%	28.4%
Nanotechnology	Number of FP Projects	4,143	3,096	1,047
	Share of FP Projects (NT)	100%	74.7%	25.3%
Share of nanotechnology of total FP (projects)		11.7%	12.3%	10.4%

Number and share of ICT nanotechnology projects

The number of projects (in FP6 and FP7 together) that were related to both ICT and nanotechnology was determined using a keyword search[69], to be 1,307, approximately 32% of the total number of projects related to nanotechnology. The percentages of ICT nanotechnology projects were very similar in FP7 (31.9%) and FP6 (30.5%).

Projects in FP7 comprised over 75% of all ICT nanotechnology with less than 25% of projects being in FP6. The proportion of FP7 projects is slightly higher than for either nanotechnology projects (74%) or FP projects (72%), that for FP6 ICT NT being lower.

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

[67] 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".

[68] Unlike the other sectors considered by the project (HT, EN, PH, MF), for ICT additional projects were identified by use of keywords such as graphene. These were judged to be too important in ICT to be omitted. This did, however, result in the total number of nanotechnology projects being different for ICT (4,143) and the other sectors (3,544).

[69] See Annex for details of keywords

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

	Numbers of projects		
	Total	FP7	FP6
Total FP projects, all topics	35,265	25,238	10,027
Nanotechnology FP projects	4,143	3,096	1,047
ICT nanotechnology FP projects	1,307	988	319
	Shares (number of projects)		
	Total	FP7	FP6
Total FP projects, all topics	100%	71.6%	28.4%
Nanotechnology (NT) FP projects	100%	74.4%	25.6%
ICT NT FP projects	100%	75.6%	24.4%
ICT NT projects as % of all NT projects	31.5%	31.9%	30.5%
ICT NT projects as % of all FP projects	3.7%	3.9%	3.2%

Funding of ICT nanotechnology projects

The 1,307 nanotechnology ICT projects received an EC contribution of EUR 2,655 million. The EC contribution for ICT projects was EUR 655 million (24.7%) in FP6 and EUR 2 billion (75.3%) in FP7. In FP6, the EC contribution for nanotechnology and ICT represented 33.4% of the total nanotechnology EC contribution, whereas in FP7 it was 35.3% indicating a relative small increase of ICT-related funding within nanotechnology funding, as shown in the figure below.

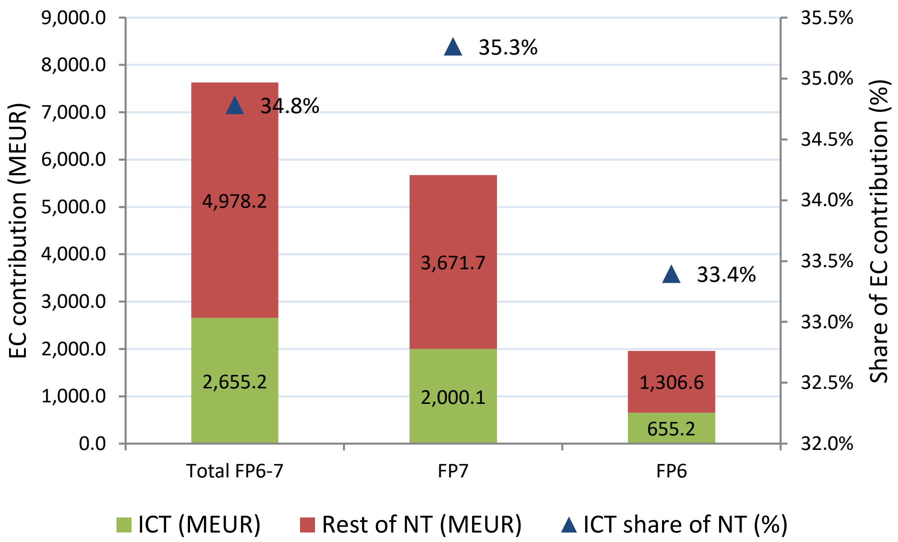

Figure 3-1: Funding of ICT nanotechnology for FP6 and FP7 together, for FP7 and for FP6

3.2.2 Activities by programme and sub-programme

3.2.2.1 FP6 ICT nanotechnology activities

There were 1,047 nanotechnology projects in FP6, approximately 10.4% of the total number of projects in FP6. Of those, 319 were ICT-related, 30.5% of FP6 nanotechnology projects and 3.2% of FP6 projects as a whole.

FP6 was structured in three main blocks of activities:

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

There was, in addition, the EURATOM activity.

In FP6, projects specific to nanotechnology and ICT made up approximately 33.4% of all nanotechnology activities as measured by EC funding allocation. They took place mainly under the priority of *Focusing and integrating the ERA*. In fact, 89.3% of all funding for ICT activities under FP6 came from this priority. The remaining 10.7% was funded under *Structuring the ERA*.

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

FP6 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP6	FP6 NT	FP6 ICT	FP6	FP6 NT	FP6 ICT	FP6	FP6 NT	FP6 ICT
I Focusing and Integrating ERA	**4,735**	**535**	**174**	**13,445.0**	**1,618.5**	**584.7**	**80.5%**	**82.5%**	**89.3%**
Thematic Priorities	3,374	461	163	12,027.5	1,543.4	574.7	72.1%	78.7%	87.7%
1. Life Sciences	602	21	1	2,336.5	64.1	10.0	14.0%	3.3%	1.5%
2. Information Society	1,089	135	97	3,798.9	525.3	370.9	22.8%	26.8%	56.6%
3. NMP	444	283	58	1,534.2	896.9	163.9	9.2%	45.7%	25.0%
4. Aeronautics and Space	241	8	4	1,066.1	23.1	13.6	6.4%	1.2%	2.1%
5. Food Quality and Safety	189	0	0	754.2	0.0	0.0	4.5%	0.0%	0.0%
6. Sustainable Development	666	11	3	2,300.9	31.7	16.3	13.8%	1.6%	2.5%
7. Citizens and Governance	143	3	0	236.6	2.4	0.0	1.4%	0.1%	0.0%
Specific Activities	1,361	74	11	1,417.5	75.1	10.0	8.5%	3.8%	1.5%
Policy Support	520	32	5	604.2	44.1	5.7	3.6%	2.2%	0.9%
Horizontal Research Involving SMEs	490	33	5	463.1	27.5	4.2	2.8%	1.4%	0.6%
International Co-operation	351	9	1	350.3	3.5	0.1	2.1%	0.2%	0.0%
II Structuring the European Research Area	**5,096**	**508**	**145**	**2,744.2**	**327.2**	**70.4**	**16.4%**	**16.7%**	**10.7%**
Research and Innovation	240	3	0	224.0	3.9	0.0	1.3%	0.2%	0.0%
Human Resources and Mobility	4,546	478	141	1,723.1	243.0	61.3	10.3%	12.4%	9.4%
Research Infrastructures	147	17	3	717.6	74.3	8.8	4.3%	3.8%	1.4%
Science and Society	163	10	1	79.5	6.0	0.2	0.5%	0.3%	0.0%
III Strengthening the ERA	118	3	0	317.3	8.0	0.0	1.9%	0.4%	0.0%
Co-ordination of Activities	99	3	0	303.8	8.0	0.0	1.8%	0.4%	0.0%
Research & Innovation Policies	19	0	0	13.5	0.0	0.0	0.1%	0.0%	0.0%
EURATOM	78	1	0	185.7	8.0	0.0	1.1%	0.4%	0.0%
TOTAL	10,027	1,047	319	16,692.3	1,961.7	655.2	100.0%	100.0%	100.0%

Within these Thematic Priorities:

- Information Society had 97 projects and EUR 370.9 million of EC funding (56.6% of the total), the largest amount of nanotechnology ICT funding;
- NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had 25% of the total (EUR 163.9 million) for 58 projects;
- Human Resources and Mobility had the highest number of projects (141), which amounted to 9.4% of all ICT funding, with EUR 61.3 million;
- Other programmes which gathered EC funding were Sustainable Development (2.5%), Aeronautics and space (2.1%), Life Sciences (1.5%), Research Infrastructures (1.4%), Policy Support (0.9%) and Horizontal Research Involving SMEs (0.6%).

3.2.2.2 FP7 ICT nanotechnology activities

ICT nanotechnology projects comprised 3.9% of the total number of projects in FP7[70] and, with 988 ICT nanotechnology projects, 31.9% of FP7 nanotechnology projects. Nanotechnology activities make up approximately 12% of the total EC FP7 funding to date, and ICT NT activities 35.3% of NT funding and 4.5% of total FP7 funding.

The broad objectives of FP7 group into four categories:

- Co-operation;
- Ideas;
- People; and
- Capacities.

The largest proportion of funding for ICT nanotechnology is seen under the Co-operation Specific Programme ICT (Information and Communications Technologies) with EUR 921.8 million (46.1% of total nano ICT funding in FP7) for 256 projects.

European Research Council, under the Ideas Specific Programme, has the next highest funding with EUR 376.2 million (18.8%) for 207 projects. NMP (10.2% of funding), Marie-Curie Actions (10%), and Joint Technology Initiatives (8.3%) followed in terms of EC funding allocated to ICT nanotechnology.

Health, Energy, Environment, Transport, Socio-Economic Sciences, Space, Security, Research Infrastructures, Research for the Benefit of SMEs, Regions of Knowledge, Research Potential and International Co-operation accounted for the remaining 6.6% of all EC funding in ICT nanotechnology.

[70] Data extraction January 2015

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

FP7 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP7	FP7 NT	FP7 ICT	FP7	FP7 NT	FP7 ICT	FP7	FP7 NT	FP7 ICT
COOPERATION	**7,834**	**976**	**388.0**	**28,336.3**	**3,565.9**	**1,383.1**	**63.1%**	**62.9%**	**69.2%**
Health	1,008	38	6	4,791.7	168.1	15.3	10.7%	3.0%	0.8%
Food, Agri and Bio	516	25	0	1,850.7	97.1	0.0	4.1%	1.7%	0.0%
ICT	2,328	330	256	7,877.0	1,169.3	921.8	17.5%	20.6%	46.1%
NMP	805	427	56	3,238.6	1,649.3	203.1	7.2%	29.1%	10.2%
Energy	368	32	11	1,707.4	106.9	33.9	3.8%	1.9%	1.7%
Environment	494	12	2	1,719.3	29.2	2.2	3.8%	0.5%	0.1%
Transport	719	21	9	2,284.2	78.8	17.3	5.1%	1.4%	0.9%
Socio-economic Sciences	253	2	2	579.6	2.4	2.4	1.3%	0.0%	0.1%
Space	267	22	11	713.3	44.2	17.9	1.6%	0.8%	0.9%
Security	314	6	1	1,295.5	16.4	2.3	2.9%	0.3%	0.1%
General Activities	26	0	0	312.7	0.0	0.0	0.7%	0.0%	0.0%
Joint Technology Initiatives	736	61	34	1,966.4	204.1	167.0	4.4%	3.6%	8.3%
IDEAS	**4,525**	**654**	**207**	**7,673.5**	**1,173.2**	**376.2**	**17.1%**	**20.7%**	**18.8%**
European Research Council	4,525	654	207	7,673.5	1,173.2	376.2	17.1%	20.7%	18.8%
PEOPLE	**10,716**	**1,305**	**371**	**4,777.5**	**657.7**	**201.0**	**10.6%**	**11.6%**	**10.0%**
Marie-Curie Actions	10,716	1,305	371	4,777.5	657.7	201.0	10.6%	11.6%	10.0%
CAPACITIES	**2,025**	**160**	**22**	**3,772.0**	**273.9**	**39.8**	**8.4%**	**4.8%**	**2.0%**
Research Infrastructures	341	20	3	1,528.4	79.7	8.4	3.4%	1.4%	0.4%
Research for the benefit of SMEs	1,028	78	10	1,249.1	99.9	15.7	2.8%	1.8%	0.8%
Regions of Knowledge	84	4	1	126.7	7.3	2.8	0.3%	0.1%	0.1%
Research Potential	206	28	5	377.7	57.8	11.4	0.8%	1.0%	0.6%
Science in Society	183	16	0	288.4	16.5	0.0	0.6%	0.3%	0.0%
Research Policies	26	0	0	28.3	0.0	0.0	0.1%	0.0%	0.0%
International Cooperation	157	14	3	173.4	12.7	1.5	0.4%	0.2%	0.1%
EURATOM	138	1	0	358.1	1.1	0.0	0.8%	0.0%	0.0%
Fusion	4	0	0	5.2	0.0	0.0	0.0%	0.0%	0.0%
Fission	134	1	0	352.8	1.1	0.0	0.8%	0.0%	0.0%
TOTAL	**25,238**	**3,096**	**988**	**44,917.3**	**5,671.8**	**2,000.1**	**100.0%**	**100.0%**	**100.0%**

3.2.3 Activities by participant type

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

Table 3-5: Participations in FP6 and FP7 including funding and share of funding[71]

	Total FP6 and FP7			NT in FP6 and FP7			ICT in NT in FP6 and FP7		
	Particip.	EC Funding	Share of Funding	Particip.	EC Funding	Share of Funding	Particip.	EC Funding	Share of Funding
HES	76,777	25,736.0	41.8%	9,145	3,552.5	46.6%	3,136	1,190.9	44.9%
REC	53,384	17,304.4	28.1%	5,564	2,175.2	28.5%	1,775	778.9	29.3%
PCO	25,067	7,021.3	11.4%	2,893	810.2	10.6%	1,196	418.6	15.8%
SME	29,428	6,882.6	11.2%	3,687	878.2	11.5%	820	199.3	7.5%
Other	24,961	4,626.8	7.5%	1,262	210.3	2.8%	351	67.5	2.5%
Total	209,617	61,571.1	100.0%	22,551	7,626.4	100.0%	7,278	2,655.3	100.0%

Higher education institutes (HES) received close to half (44.9%) of the EC contribution to nanotechnology and ICT, as shown in the table above and the figure below. They are followed by research organisations (REC, 29.3%), large companies (PCO, 15.8%), small and medium-sized companies (SME, 7.5%) and other organisations (OTH, 2.5%).

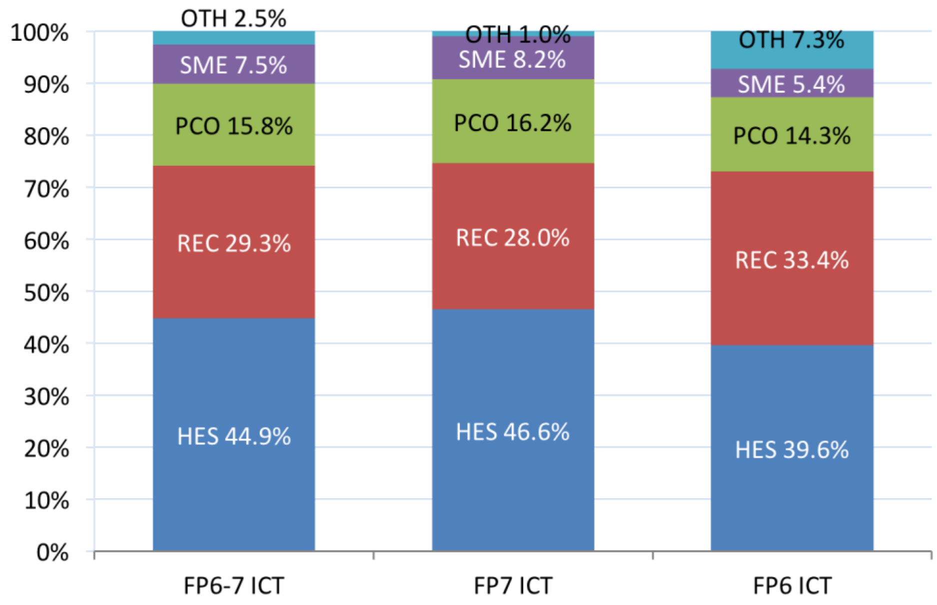

Figure 3-2: Shares of EC contribution by organisation type for nanotechnology and ICT

The proportion of funding going to organisations in the higher education sector (44.9%) is only slightly lower than that corresponding to their share of nanotechnology funding (46.6%), and higher

[71] The EC contribution in eCorda projects and the participant database differ by a small amount. The figures reported here for participants therefore do not exactly match those for projects in previous sections.

than their share for FP funding overall (41.8%). The relative importance of HES rose from 39.6% in FP6 to 46.6% of all ICT funding in FP7.

For research organisations, their share dropped from FP6 (33.4%) to FP7 (28%). The proportion going to companies rose from FP6 to FP7 (from 14.3% to 16.2% in the case of PCOs; and from 5.4% to 8.2% for SMEs).

Overall, the participant types are rather aligned with those of NT and FP. The only significant differences occur for large companies (where the percentage of EC funding is higher for ICT), and SMEs, where the opposite is true.

3.2.4 Activity by organisations receiving funding

The organisations receiving the largest amounts of funding for ICT nanotechnology activities were the CEA[72] (FR) (EUR 105.44 million for 156 projects); the CNRS[73] (FR) (EUR 100.4 million for 193 projects); IMEC[74] (BE) (EUR 72.63 million for 110 projects) and Fraunhofer[75] (DE) (EUR 71.7 million for 113 projects). See table below.

Out of the top 25 recipients, 10 were higher education institutions, 9 were research organisations, and 6 were companies. The top ten are from France (3), Belgium, Germany, Switzerland, the UK, the Netherlands, Sweden and Italy. The companies STMicroelectronics, Infineon Technologies, IBM Research GmbH and Philips all feature in the top 25 organisations receiving funding.

The second table below indicates the most active companies in FP ICT nanotechnology projects by funding. In this sector, none of the 25 most relevant companies were SMEs.

The French-Italian company group STMicroelectronics, which has its headquarters in Geneva, Switzerland, obtained over EUR 80 million in 100 projects through its different companies (STMicroelectronics Crolles 2 SAS, STMicroelectronics SRL, STMicroelectronics S.A. and STMicroelectronics Grenoble 2 SAS). There are also the groups of companies of Philips (NL and DE) Infineon (DE, AT) with over 40 projects and EUR 26 million each. IBM Research GmbH (DE) and Thales SA (FR) received between EUR 16 and 17 million. The rest of the companies in the top 25 received less than EUR 10 million.

[72] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[73] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr
[74] Interuniversitair Micro-Elektronica Centrum Vzw, www.imec.be
[75] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de

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

	ICT - Top participants	Country	No. of Projects	EC Funding (MEUR)	Share of ICT Funding
1	CEA[76]	FR	156	105.44	4.25%
2	CNRS[77]	FR	193	100.40	4.05%
3	IMEC[78]	BE	110	72.63	2.93%
4	Fraunhofer-Gesellschaft[79]	DE	113	71.70	2.89%
5	EPFL[80]	CH	86	50.45	2.04%
6	University of Cambridge	UK	83	44.48	1.79%
7	Technische Universiteit Delft	NL	63	41.13	1.66%
8	STMicroelectronics Crolles 2 SAS	FR	23	39.00	1.57%
9	Chalmers Tekniska Hoegskola AB[81]	SE	52	34.12	1.38%
10	CNR[82]	IT	97	32.15	1.30%
11	Max Planck Gesellschaft[83]	DE	55	28.18	1.14%
12	ETHZ[84]	CH	45	25.18	1.02%
13	VTT[85]	FI	43	21.50	0.87%
14	STMicroelectronics SRL	IT	48	20.31	0.82%
15	Infineon Technologies AG	DE	40	20.04	0.81%
16	STMicroelectronics S.A.	FR	24	19.67	0.79%
17	University of Manchester	UK	20	19.39	0.78%
18	Kungliga Tekniska Hoegskolan (KTH)[86]	SE	33	17.76	0.72%
19	Weizmann Institute of Science[87]	IL	24	17.71	0.71%
20	Forschungszentrum Juelich GmbH[88]	DE	25	17.64	0.71%
21	CSIC[89]	ES	50	17.51	0.71%
22	Brno University of Technology	CZ	5	17.29	0.70%
23	IBM Research GmbH	CH	33	16.72	0.67%
24	Phillips Electronics Nederland B.V.	NL	32	16.61	0.67%
25	Imperial College	UK	38	16.49	0.67%

[76] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[77] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr
[78] Interuniversitair Micro-Elektronica Centrum Vzw, www.imec.be
[79] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[80] École Polytechnique Fédérale de Lausanne, the Swiss Federal Institute of Technology in Lausanne www.epfl.ch
[81] http://www.chalmers.se/en/About-Chalmers/Pages/default.aspx
[82] Consiglio Nazionale Delle Ricerche, the Italian National Research Council www.cnr.it
[83] Max-Planck-Gesellschaft, the Max Planck Society www.mpg.de
[84] Eidgenössische Technische Hochschule Zürich, Swiss Federal Institute of Technology in Zurich www.ethz.ch
[85] Teknologian Tutkimuskeskus, Technical Research Centre of Finland www.vtt.fi
[86] https://www.kth.se/en
[87] http://www.weizmann.ac.il/pages/
[88] http://www.fz-juelich.de/portal/DE/Home/home_node.html
[89] Consejo Superior de Investigaciones Cientificas, the Spanish National Research Council www.csic.es

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

	ICT - Top Company Participants	Country	NUTS2	SME	No. of Projects FP6-7	EC Funding (MEUR)
1	STMicroelectonics Crolles 2 SAS	FR	FR714		23	39.00
2	STMicroelectronics SRL	IT	ITC45		48	20.31
3	Infineon Technologies AG	DE	DE21H		40	20.04
4	STMicroelectronics S.A.	FR	FR105		24	19.67
5	IBM Research GmbH	CH	CH040		33	16.72
6	Phillips Electronics Nederland B.V.	NL	NL414		32	16.61
7	Thales SA	FR	FR105		40	16.31
8	Phillips Technologie GmbH	DE	DE600		14	9.34
9	NXP Semiconductor Nederlands BV	NL	NL414		24	8.23
10	Siemens Aktiengesellschaft	DE	DE212		15	6.75
11	AMS AG	AT	AT221		12	6.10
12	Infineon Technologies Austria AG	AT	AT211		15	6.03
13	S.O.I.Tec Silicon on Insulator Technologies SA	FR	FR714		6	5.75
14	Robert Bosch GmbH	DE	DE115		12	4.83
15	Aixtron SE	DE	DEA25		11	4.12
16	ON Semiconductor Belgium BVBA	BE	BE235		9	4.05
17	Airbus Defense and Space GmbH	DE	DE21H		13	4.01
18	NXP Semiconductors Belgium NV	BE	BE242		13	3.95
19	Telefonica Investigacion y Desarrollo SA	ES	ES300		5	3.92
20	Mapper Lithography B.V.	NL	NL333		3	3.65
21	Stmicroelectronics Grenoble 2 SAS	FR	FR714		5	3.46
22	Micron Semiconductor Italia SRL	IT	ITC45		13	3.46
23	ARM Limited	UK	UKH12		4	3.39
24	Nokia OYJ	FI	FI181		9	3.38
25	OSRAM Opto Semiconductors GmbH	DE	DE232		5	3.34

3.2.5 Participation by country

In total, 65 countries took part in ICT nanotechnology projects funded under FP6 and FP7. The top fifteen are shown in the table below, with funding and shares of funding for each country.

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

Rank	Country	ICT NT funding (MEUR)	% of funding
1	DE	504.5	19.0%
2	FR	435.0	16.4%
3	UK	311.3	11.7%
4	IT	202.3	7.6%
5	NL	176.6	6.7%
6	CH	163.0	6.1%
7	BE	139.9	5.3%
8	ES	133.7	5.0%
9	SE	104.7	3.9%
10	AT	88.3	3.3%
11	FI	57.7	2.2%
12	IL	52.7	2.0%
13	EL	50.2	1.9%
14	DK	46.1	1.7%
15	IE	34.3	1.3%
	TOTAL	**2,500.4**	**94.2%**

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

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

	FP Total			Nanotechnology			ICT and Nanotechnology		
	MEUR	Rank	Share of FP	MEUR	Rank	Share of NT	MEUR	Rank	Share of ICT
DE	10,164.1	1	16.5%	1,395.5	1	18.3%	504.5	1	19.0%
FR	7,319.3	3	11.9%	936.4	3	12.3%	435.0	2	16.4%
UK	9,295.2	2	15.1%	989.3	2	13.0%	311.3	3	11.7%
IT	5,046.5	4	8.2%	615.4	4	8.1%	202.3	4	7.6%
NL	4,438.4	5	7.2%	511.5	6	6.7%	176.6	5	6.7%
CH	2,503.2	8	4.1%	423.9	7	5.6%	163.0	6	6.1%
BE	2,518.0	7	4.1%	327.3	8	4.3%	139.9	7	5.3%
ES	4,200.6	6	6.8%	544.2	5	7.1%	133.7	8	5.0%
SE	2,386.7	9	3.9%	321.3	9	4.2%	104.7	9	3.9%
AT	1,612.2	10	2.6%	204.6	10	2.7%	88.3	10	3.3%
Total	**49,484.1**		**80.4%**	**6,269.3**		**82.2%**	**2,259.4**		**85.1%**

The top three countries accounted for almost half of the total EC funding for ICT nanotechnology projects. The same three countries, in almost the same order, head the ranking for nanotechnology projects and for FP projects overall, as seen in the table below. The list is topped by Germany with a share of 19%, followed by France (16.4%) and the UK (11.7%). Other countries, like Italy, the Netherlands and Switzerland, follow at a distance.

The figure below shows the ranking of countries participating in ICT nanotechnology projects. In most cases, the share of funding for ICT nanotechnology projects is lower than the shares for both nanotechnology projects and FP projects as a whole. There are some exceptions to this rule, with France, in particular, and then Belgium, Germany, Switzerland and Austria having higher percentages of funding for ICT nanotechnology. It is worth mentioning the case of France with a share of funding of ICT nanotechnology projects that is 4.1% higher than its share of funding of nanotechnology projects. It can be concluded that these countries show a higher specialisation in the field of ICT nanotechnology.

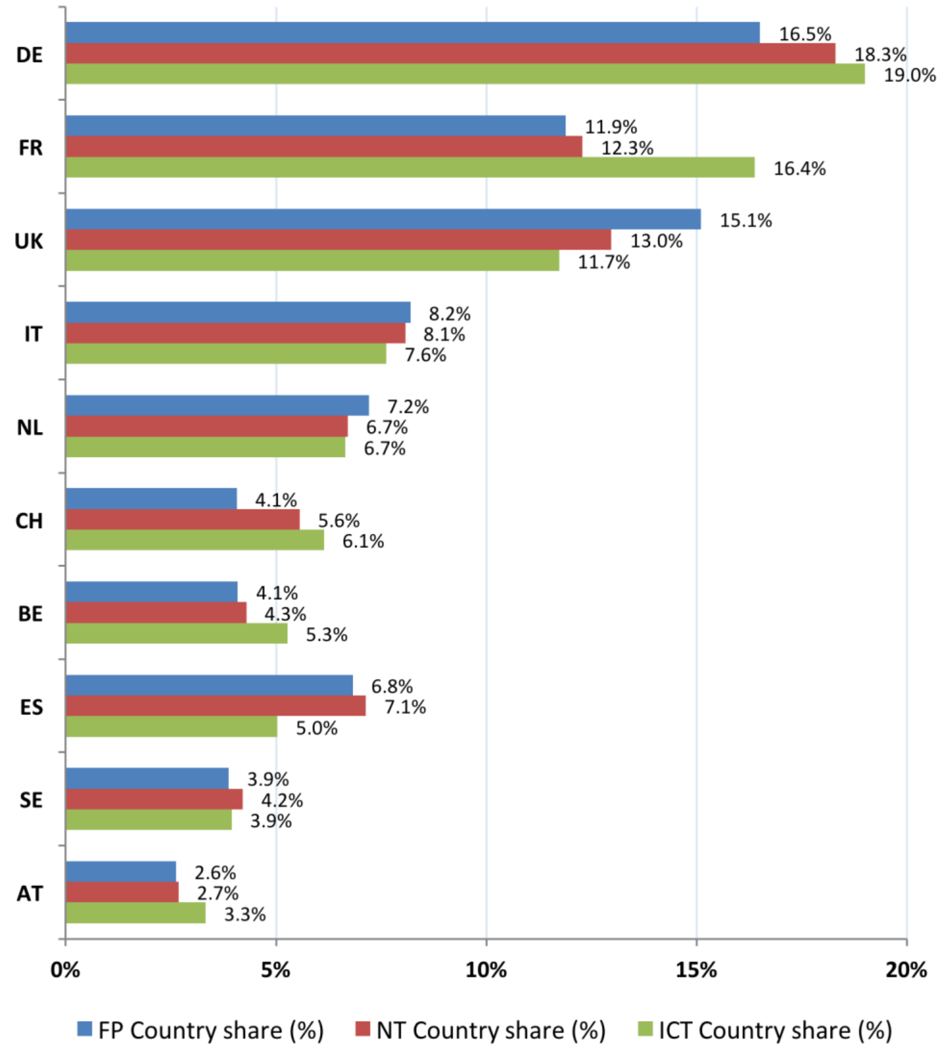

Figure 3-3: Percentage shares of FP funding by country in FP, NT and ICT nanotechnology

In the figure below (the EC funding for ICT nanotechnology projects in FP6 and FP7 (bars) and the country shares (points or diamonds), five countries have increased their share of funding for ICT nanotechnology projects from FP6 to FP7 (The Netherlands, Switzerland, Spain, Sweden and Austria). The Netherlands and Switzerland are the most significant cases, as they increased their shares of funding from 4.6% to 7.3% and from to 4.7% to 6.6%, respectively. Belgium, on the other hand, reduced its share of funding from 7.2% in FP6 to 4.6% in FP7.

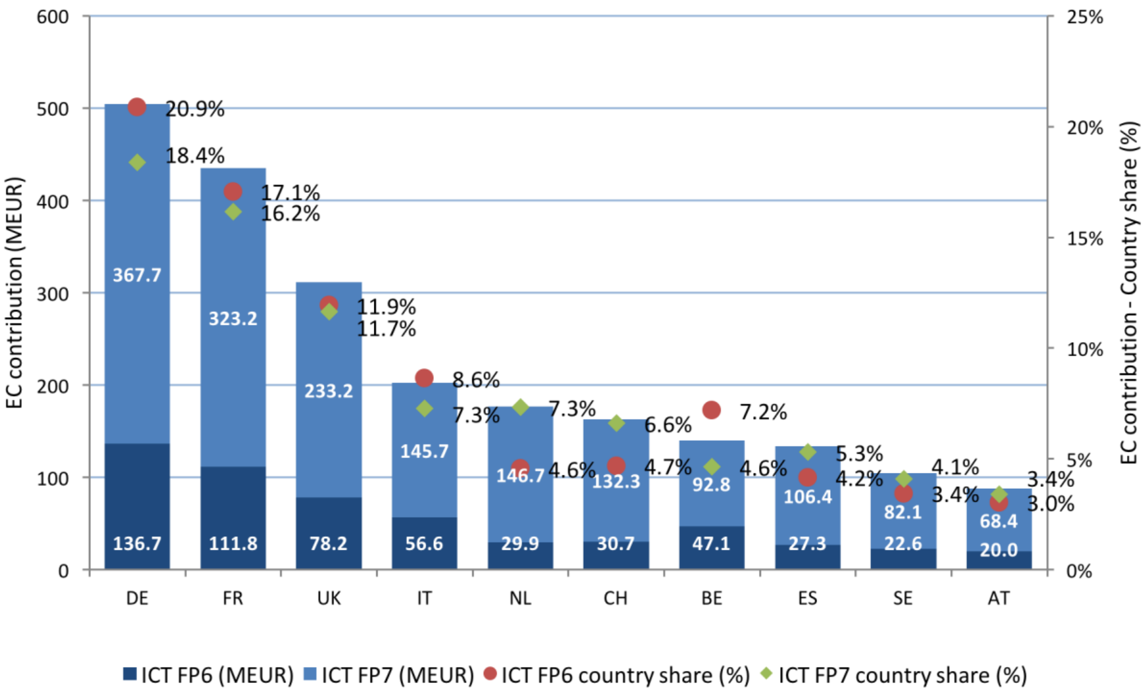

Figure 3-4: EC funding for ICT NT activities in FP6 and FP7 in MEUR and country shares

3.2.6 Snapshot of outputs from FP7

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

In the review of the 106 SESAM reports, it was found that:

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

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

- 171 publications, an average of 17 publications per project, the same as for nanotechnology overall; and
- 6 patent applications, an average of 0.6 per project, slightly less than for nanotechnology overall.

Thus, of the projects under review, ICT nanotechnology projects under FP7 produce the average number of publications and less than the average patents for nanotechnology FP7 overall, as captured in the SESAM reports to date.

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

3.3 Other EU policies and programmes

3.3.1 EU policies and programmes: Industry

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

Under FP7, the objective of ICT research funding is to strengthen the science and technology base to the level of global leadership, to stimulate innovation and creativity in products, processes and services, and to enhance the use of ICT for public benefit in society and the economy. EUR 921 million have been allocated to the ICT theme under FP7, making this the largest in budgetary terms under the Co-operation Programme.

The *Competitiveness and Innovation Framework Programme* (CIP)[90] (running from 2007 to 2013 with a budget of EUR 3.6 billion) aimed to provide better access to finance and business support to SMEs. With particular reference to ICT, it supported the take-up and use of ICT. One of the three sub-programmes dealt with the Information Communication Technologies Policy Support Programme (ICT-PSP)[91]. The priority areas include ICT for health, ageing and inclusion, Digital Libraries, ICT for improved public services, ICT for energy efficiency and smart mobility, Multi-lingual web and Internet evolution.

A more recent policy is the *European Strategy for KETs*, particularly relevant for ICT. Key Enabling Technologies (KETs) are a priority for European industrial policy. The European Strategy for KETs, which includes micro- and nano-electronics, nanotechnology, photonics (as well as industrial biotechnology, advanced materials, and advanced manufacturing technologies), aims to increase the exploitation of KETs in the EU and to reverse the decline in manufacturing to stimulate growth and jobs. In 2012, the European Commission tabled its strategy to boost the industrial production of KETs-based products, e.g. innovative products and applications of the future. The strategy seeks for the EU to keep pace with its main international competitors in industrial capabilities and capacities, restoring growth in Europe and creating jobs in industry, at the same time addressing current key societal challenges. The European Commission also identified KETs as a key priority within its Europe 2020 strategy, and they are seen as essential to *Flagship Initiatives* such as *The Innovation Union* and *The Digital Agenda for Europe* (see the section on *European policies and programmes: ICT for more on the Digital Agenda*).

In accordance with the strategy for KETs, "A European Strategy for micro- and nano-electronic components and systems"[92] has been developed. Its aim is to maintain the EU in a leading position in designing and manufacturing micro and nano electronics, as well as to create jobs, through: (i) a European industrial roadmap, involving the whole value chain; (ii) a Joint Technology Initiative (see below ECSEL); and (iii) measures to improve competitiveness. More concretely, the strategy focuses on areas including the promotion of capital investment, smart specialisation, access to design and dialogue among stakeholders.

Research by companies in the EU is also supported through the EUREKA Eurostars[93] initiative established under Article 185 of the Treaty on the Functioning of the European Union (TFEU), in partnership between the European Commission, the Member States and the countries associated with the Framework Programmes. Eurostars supports European R&D-performing SMEs to commercialise their research. It helps them to accelerate the time to market of products, processes and services. It also encourages them to develop and internationalise their business. Funding of up to EUR 100 million was made available through EUREKA for the period 2008-2013, the EU contribution comprising a maximum of one third of the funding provided by the participating countries. Funding for Eurostars has continued with a total public budget of EUR 1.14 billion in 2014-2020, EUR 861 million of national funding and EUR 287 million of EU funding from Horizon 2020. In the 39 success stories identified for Eurostars, two relate to nanotechnology, one to IT and telematics technologies and four to information processing and information systems.

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[90] http://ec.europa.eu/cip/
[91] http://ec.europa.eu/cip/ict-psp/index_en.htm
[92] http://ec.europa.eu/digital-agenda/en/news/communication-european-strategy-micro-and-nanoelectronic-components-and-systems
[93] https://www.eurostars-eureka.eu/

Another type of mechanism is the European Technology Platform (ETP)[94]. ETPs are bottom-up, industry-led stakeholder fora, the aim of which is to increase interaction between research actors and to facilitate the development of medium to long-term research and technological goals and associated roadmaps. They do not fund research projects but are a co-ordination mechanism. ETPs contribute to design, and update and provide recommendations on the Strategic Research Agenda on the specific sector with which they are dealing. ETPs now exist across the themes of ICT, energy, environment, production and processes, transport and the bio-based economy.

Under the ICT themes, the ETPs ARTEMIS, ENIAC, EPoSS, ETP4HPC, euRobotics, NEM, NESSI, Networld 2020 and Photonics21 are listed. The most relevant for this report include NEM, ETP4HPC and EPoSS (as well as former ETPs ENIAC and ARTEMIS described below).

- NEM (initially Network and Electronic Media Initiative, now New European Media) [95] was launched under FP7 to help "the convergence between consumer electronics, broadcasting and telecoms". It includes the major stakeholders that together developed a Strategic Research and Innovation Agenda (SRIA). NEM focuses on digital content; distributed media applications; future media delivery networks and network services; and new user devices and terminals.
- ETP4HPC (the European Technology Platform for High Performance Computing (HPC)) [96], a contractual Public Private Partnership under H2020[97], focuses on: new technologies (HPC stack elements); system characteristics (extreme scale requirements); and new HPC deployments and HPC usage expansion.
- EPoSS (the European Technology Platform on Smart Systems Integration)[98] provides a common approach on Innovative Smart Systems Integration and integrated Micro- and Nano-systems from research to production; defines common future priorities and road maps; mobilises resources. EPoSS represents the Smart Systems community in the Joint Technology Initiative for Electronic Components and Systems for European Leadership (JTI ECSEL). The platform aims to provide a common European approach on innovative and smart systems integration from research to production, with an agreed roadmap for action and a strategic R&D agenda and to provide the resources to deliver the roadmap from public and private sources. EPoSS has members in over 20 Member States including large companies, SMEs, universities and other public organisations undertaking research and development.
- Net!works (now called Networld 2020)[99], the European Technology Platform for communications networks and services, supports the development of mobile and wireless, fixed and satellite communications.
- Photonics21 (a contractual Private Partnership under H2020) focuses on seven priority areas (e.g. working groups): information and communication; industrial manufacturing and quality; life sciences and health; emerging lighting, electronics and displays; security, metrology and sensors; design and manufacturing of components and systems; photonics research, education and training.

Joint Technology Initiatives (JTIs) are long-term Public-Private Partnerships managed within dedicated structures based on Article 187 of the Treaty on the Functioning of the European Union (TFEU). JTIs support large-scale multinational research activities in areas of major interest to European industrial competitiveness as well as issues of high societal relevance. They are established in cases where the scale and scope of the initiative make the loose co-ordination through ETPs and support by the regular instruments of the Framework Programme for Research and Development insufficient[100]. Under FP7, six areas were identified for the development of a JTI: Nano-electronics (ENIAC)[101]; Embedded Computing Systems (ARTEMIS); Innovative Medicines; Fuel Cells and Hydrogen; Aeronautics; and GMES (global monitoring for environment and security).

[94] http://ec.europa.eu/research/innovation-union/index_en.cfm?pg=etp
[95] http://nem-initiative.org/what-is-nem/
[96] http://www.etp4hpc.eu
[97] In 2013, under Horizon 2020, the European Commission launched the contractual Public Private Partnerships (cPPPs) to leverage more than EUR 6 billion of investments through H2020 calls.
[98] http://www.smart-systems-integration.org/public
[99] http://networld2020.eu/vision-mission/
[100] http://era.gv.at/directory/142
[101] Since 2014, ENIAC and ARTEMIS has been replaced by ECSEL (https://ec.europa.eu/digital-agenda/en/time-ecsel)

- ENIAC[102], the JTI in nano-electronics. The ENIAC Joint Undertaking was established in February 2008 to co-ordinate European nano-electronics research activities through competitive calls for proposals. It describes itself as a public-private partnership in nano-electronics strengthening European competitiveness and sustainability, bringing together the ENIAC Member States, the European Commission and AENEAS, the association of R&D actors in the field.
- ARTEMIS (Advanced Research & Technology for EMbedded Intelligence and Systems)[103] involves disciplines such as mechanics, electronics, control and software engineering and aims to make Europe the leader in embedded and cyber-physical systems. ARTEMIS merged into another JTI, ECSEL, in 2014. The ARTEMIS Industry Association has remained, representing actors in embedded and cyber-physical systems within Europe. The association represents industry and the public sector (large companies, SMEs, universities and research institutes) in the ECSEL JU.
- ECSEL is the Joint Technology Initiative for Electronic Components and Systems for European Leadership[104] and is the public-private partnership in electronic components and systems, under H2020 (covering the topics addressed in FP7 within the ARTEMIS and the ENIAC JTIs and in the ETP EPoSS). Its consortia are collaborating on projects to develop smart systems; systems and components for smart energy; smart cities; smart governance; and smart living, including photonics. The current members of ECSEL are the European Union (through the Commission); Member States and Associated Countries to Horizon 2020; and three associations (EPoSS[105], AENEAS and the ARTEMIS Industry Association) representing the actors from the areas of micro- and nano-electronics, smart integrated systems and embedded/cyber-physical systems.

3.3.2 EU policies and programmes: ICT

Launched in 2010, the Digital Agenda for Europe[106] aims to better exploit the potential of ICT to foster innovation, growth and progress and contains several initiatives and actions to:

- Strengthen the ICT ecosystem (e.g. finance, procurement, standardisation);
- Develop ICT-based infrastructures (e.g. high-capacity and high-performance communication network, distributed computing infrastructures, data infrastructures, high-performance computing (HPC) infrastructures);
- Support emerging technologies research (through incubators – e.g. Future and Emerging Technologies (FET)[107]-, Future Networks[108], Future Internet Research and Experimentation Initiative (FIRE)[109]; and
- Maintain the leadership in components and system (electronics, organic and large era electronics, photonics, cyber physical system, advanced computing and smart manufacturing).

In 2013, in the context of the Digital Agenda for Europe[110], the European Commission launched the I4MS[111] initiative (ICT Innovation for Manufacturing SMEs) as part of the public private partnership *Factories of the Future* (PPP FoF)[112]. I4MS was given a funding contribution of EUR 77 million, taken from the FoF total budget (EUR 660 million). Involving twelve EU Member States and five Associated Countries (FYROM[113], Israel, Norway, Switzerland and Turkey), this initiative aims to support SMEs and mid-caps[114] (40% of the funds) in the manufacturing sector to provide them access to competences for the digital transformation, to innovation network and to funding through, for example, European competence centres/innovation hubs. This is a way to position SMEs and mid-caps to exploit ICT to modernise Europe's manufacturing capabilities by profiting from the latest

[102] http://www.eniac.eu/web/index.php
[103] https://artemis-ia.eu/about_artemis.html
[104] http://www.ecsel-ju.eu/web/index.php
[105] http://www.smart-systems-integration.org/public
[106] https://ec.europa.eu/digital-agenda/en/digital-europe
[107] https://ec.europa.eu/digital-agenda/en/future-emerging-technologies-fet
[108] https://ec.europa.eu/digital-agenda/future-internet
[109] http://www.ict-fire.eu/home.html
[110] https://ec.europa.eu/digital-agenda/en/innovation-ict-manufacturing-smes
[111] http://i4ms.eu/projects/projects.php
[112] Public Private Partnership Factories of the Future (PPP FoF), established in 2008 and continued also under H2020, targets in particular SMEs and supports them in tackling global competitiveness by improving the technological base of manufacturing across a broad range of sectors.
[113] Former Yugoslav Republic of Macedonia
[114] A company with a market capitalisation between USD 2 and USD 10 billion, calculated by multiplying the number of shares by its stock price.

advances in ICT. Some FP7 projects in the field of HPC cloud-based simulation services and intelligent sensor-based equipment are associated with this initiative (e.g. INTEFIX, FORTISSIMO, CloudFlow and CloudSME).

3.3.3 EU policies and programmes: Structural and Investment Funds

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

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

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

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

The first two ESI Funds above are the ones most relevant to ICT and nanotechnology, albeit that the topic is likely to capture only a small part of their budget, particularly in comparison with the funding available under the Framework Programmes, and the ICT theme in particular.

3.3.4 EU policies and programmes: Cohesion funds

SMART SPECIALISATION AND REGIONAL RDI POLICY

The European Commission's Cohesion Policy aims to reduce differences between regions in Europe and to ensure growth across the continent. Structural Funds are among the main tools to implement the policy, and it is within this framework that smart specialisation was introduced. The Smart Specialisation Strategies (RIS3) [115] aim to focus regional innovation policies on regional priorities based on existing areas of strength; competitive advantage; and potential for excellence in each region.

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

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

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

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

4 POLICIES AND PROGRAMMES IN MEMBER STATES FOR NANOTECHNOLOGY AND ICT

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

For ICT and nanotechnology, specific initiatives at Member State level, past or present, include:

Austria: The Austrian NanoInitiative[116] (2004-2011, total funding EUR 70 million, administered by the Austrian Research Promotion Agency (FFG)). The initiative works on a collaborative basis across Austria and trans-nationally with consortia of research institutes, universities and firms working on problem-driven basic research questions with a medium-term perspective (5-7 years). The focus of the programme, matching the remit of its funding agency FFG, has been to invest in projects with considerable market potential and relevant to Austrian companies. The type of activities begun under the programme are now continuing under the thematic areas FFG's research funding programmes. For example, since 2012, nanotechnology is supported, *inter alia*, via FFG's thematic research funding for *Production of the Future*.

Belgium: In 1984, the Government of Flanders granted EUR 62 million (as an initial investment) to create the first associated laboratory of IMEC[117] in Leuven/ Louvain (Belgium). IMEC is a research institute that provides laboratories, facilities and technical support rooms to partners including industry. For the period 2002-2006, the Government of Flanders contributed EUR 34 million (24% of IMEC's total revenue), while IMEC's revenues from contract research were more than EUR 100 million). In 2007, the Government of Flanders granted around EUR 48 million. IMEC focuses on R&D in microelectronics, nanotechnology, design methods and technologies for ICT systems.

Denmark: Under the Danish Council for Strategic Research, the Programme Commission on Strategic Growth Technologies[118] has had annual calls of total annual value approximately EUR 10 million for research projects on ICT, nanotechnology and biotechnology. The programme is now managed by the Innovation Fund Denmark. Between 2005 and 2010, EUR 116 million was allocated to strategic research centres, research alliances and research projects, EUR 62 million being for nanotechnology, biotechnology and ICT.

Finland: FinNano, the Finnish nanoscience and nanotechnology programme, was established in 2005 and co-ordinated jointly by Tekes and the Academy of Finland. Over EUR 120 million were invested by the programme between 2005 and 2010, with the aim of providing support across the whole innovation chain for nanotechnology from basic research to commercial products. Its goals for 2006–2009 were to draft "common guidelines for the development of nanotechnology and its commercial applications" with the joint efforts of business and academia. Work groups were created for application areas, including for example, ICT and electronics.[119] Tekes collaborates also with China in the China-Finland ICT Alliance through joint calls in the area of ICT, nanotechnology and 'cleantech'.[120]

France: The French Agence National de la Recherche (ANR) channels public funding into priority areas including Nanotechnologies and Manufacturing. Since 2006, the P2N programme[121] aims to strengthen national excellence in the areas of micro and nano-engineering (ranging from core technologies to systems), and speed up technology transfer to French firms in order to exploit the potential of the nanotechnologies. Miniaturisation, new technologies and new devices for electronics and nano-photonics are among the thematic priorities that have been targeted in annual calls. The

[116] https://www.ffg.at/nano-das-programm
[117] http://www2.imec.be/be_en/about-imec/imec-strategy/mission-and-vision.html
[118] http://en.innovationsfonden.dk/strategic-research/
[119] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf
[120] http://www.tekes.fi/en/programmes-and-services/grow-and-go-global/china/
[121] http://www.agence-nationale-recherche.fr/en/projects-and-results/calls-for-proposals-2013/aap-en/nanotechnologies-and-nanosystems-p2n-2013/

EUR 35 billion economic stimulus package Investissements d'Avenir (Investments for the Future) was launched at the end of 2009.

Germany: Germany was the first country in Europe to recognise a need for a specific funding measure for nano-electronics and -photonics, introducing the lead innovation programme "Nanofab" and "NanoLux" as early as 2001. Even earlier - in 1999 - the German Federal Ministry of Education and Research (BMBF) launched the *Framework Concept for the Production of Tomorrow*. The Nanofab programme ran until 2014 with an overall budget of EUR 403 Million. The main rationale was to foster the manufacturing industries of Germany in an ever more dynamic and competitive environment with enhanced mobility of goods, capital and information. The Framework Concept comprised four thematic fields of action amongst which was the area of production processes and production equipment (including primary shaping and recasting, chipping, surfaces and layers, heat treatment, assembling, and measurement engineering). Furthermore, the programme Optical Technologies (2002-2012, total funding of EUR 275.5 million administered by VDI Technologiezentrum) supported co-operative R&D projects in the realm of nano-electronics, information and communication (as well as healthcare systems and biotechnology, environment, traffic and mobility). Its successor, the Photonics Research programme was launched in 2012 with a funding of EUR 100 million per annum. It is sub-divided into three fields of action: optical systems, especially next generation optical systems; innovative applications of light for humans, production and the environment; and promotion of start-ups and creation of favourable general conditions.

In addition, in Germany at regional level, the Research Strategy of Thuringia (2008) covered research areas such as photonics; optical technologies, micro- and nano-technologies, micro-electronics; and information and communication technologies. The main fields of activity of regional research policy are (i) to support competitiveness; (ii) to strengthen networks; (iii) to support young researchers; and (iv) to invest in infrastructure.

Italy: The Italian National Research Programme 2004-2006 stressed the importance of nanotechnology and, among its focus areas, mentioned nano-fabrication and electronics. In September 2014, MISE (the Ministry for Economic Development) within its FCS (Fondo per la crescita sostenibile, fund for sustainable growth) allocated EUR 300 million low interest loans (of which 60% earmarked for SMEs), covering areas including nanotechnology, ICTs, advanced manufacturing, etc. (only technologies associated with H2020)[122].

Lithuania: Since 2012, the Agency for Science, Innovation and Technology (MITA) has actively promoted innovative start-ups. The High Technology Development Programme (2012) aims to encourage scientists, researchers and students to establish start-ups or spin-off companies. Thirteen new companies have obtained public funding (a maximum of EUR 20,000) across high-tech areas including information technology; nanotechnology; mechatronics; laser technology; and biotechnology[123].

The Netherlands: NanoNed (2004 – 2010, total funding of EUR 235 Million administered by the Dutch Ministry for Economic Affairs), the Nanotechnology R&D initiative in the Netherlands, has clustered the Dutch expertise on nanotechnology and enabling technology into a national network. The NanoNed programme was organised into eleven independent programmes, or flagships, amongst which were Bottom-up Nano-Electronics and Nano-Fabrication. In 2011, NanoNed was followed by NanoNextNL[124], a consortium of more than a hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities. Stakeholders collaborate on fundamental as well as applied research through research projects. NanoNextNL is expected to grow into an open-innovation ecosystem, with new partners joining the consortium. Industry has committed to continue its support for NanoNextNL after 2015.

In addition, innovation in the Netherlands is organised under the *Top Sector Policy*[125] announced in 2010. Businesses, researchers and government work closely together in *Top consortiums for Knowledge and Innovation* (TKIs). The only policy objective that has been set specifically for the top sector policy is that public and private parties should participate in the TKIs for an amount of at least €500 million by 2015, 40% of which should be financed by trade and industry. The formal objective

[122] https://rio.jrc.ec.europa.eu/en/country-analysis/Italy/country-report
[123] https://rio.jrc.ec.europa.eu/en/country-analysis/Lithuania/country-report
[124] http://www.nanonextnl.nl/
[125] http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/smart-industry

set for the top sector policy is that it should contribute to "a stronger innovative capacity in the Dutch economy." i.e. that the Netherlands will be ranked among the top five knowledge economies worldwide by 2020 and will spend 2.5% of GDP on R&D by 2020.

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

Portugal: The International Iberian Nanotechnology Laboratory[126] (INL) was established as the result of a joint decision of the Governments of Portugal and Spain, in November, 2005. With a total investment of EUR 46.5 million (of which EUR 30 million came from the European Regional Development Fund, "Spain – Portugal" Operational Programme, 2007-2013). INL is an international research organisation in the field of nanoscience and nanotechnology. Established as an Intergovernmental Organisation (IGRO), the INL is developing itself into a state-of the art research environment (including nanofabrication facilities) for materials science at nanoscale, nano-electronics, nano-biotechnology and nanomedicine. In addition to being a facility for researchers in Portugal and Spain, it hosts those from non-EU countries such as Brazil. Among the key research activities at INL is nano-electronics (including spintronics, MEMS and nano-devices).

Slovakia: The Ministry of Education, Science, Research and Sports (MESRS)[127] published the Action Plan for the Innovation Strategy for Smart Specialisation, 2014-2020[128]. The Action Plan focused on measures to encourage R&D expenditure of companies and applied research. The Action Plan identified also seven priority areas that include material research and nanotechnologies (about EUR 42 million) and information and communication technologies (about EUR 10 million).[129]

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

The United Kingdom (UK): In 2002, the UK Government, after issuing the Taylor Report which recognised the increase of investment in nanotechnology worldwide, allocated GBP 90 million (EUR 131.4 million)[130] of funding for the Micro- and Nano-Technology Manufacturing Initiative. This funding was committed between 2003 and 2007. Approximately one third of this investment went to Collaborative R&D MNT Projects, and two thirds to capital infrastructure. Generally built on existing university or business expertise, the twenty-four facilities are targeted at addressing a broad range of key application areas where micro/nano scale activity is considered key to future UK industry capability and where the UK has some strength[131].

More generally, the main player in UK policy measures related to nanotechnology as a key enabling technology (KET) is the Department for Business, Innovation and Skills (BIS) and its agency, the Technology Strategy Board, now called Innovate UK[132]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[133] and identified future potential growth sectors and

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126 http://inl.int/
127 https://www.minedu.sk/about-the-ministry/
128 http://s3platform.jrc.ec.europa.eu/regions/SK
129 http://s3platform.jrc.ec.europa.eu/documents/10157/511834/PPT_Slovakia_Dublin%20FINAL%2026%206%202014.pdf.
130 Average yearly conversion rate, 2003-2007 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-gbp.en.html)
131 However, following to an evaluation in 2010, the initiative was judged quite unsuccessful (*source*: http://www.cientifica.com/why-has-the-uk-given-up-on-nanotechnology/)
132 https://www.gov.uk/government/organisations/innovate-uk
133 https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative

commercialisation opportunities. Much of the activity around environment, health and safety in the UK is under the remit of DEFRA.

The UK Enabling Technologies Strategy 2012-2015[134] also addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.

[134] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015

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

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
AT	Austrian NANO Initiative[135] (NANO)	2004-2011	Directly Targeting NT	Multiannual, funding collaborative R&D, co-ordinating NANO-related policy measures at national and regional levels. Since 2012, NT is supported via FFG's thematic research funding e.g. Production of the Future	IND SME HEI PRO	FFG	70 over 8 years
AT	------	From 2012	Thematic, not NT Specific	Since 2012, NT R&D is being supported via FFG's thematic research funding e.g. Production of the Future	All	FFG	450 for all disciplines (over the preceding 4 years when funding was managed by BMVIT)
BE	IMEC	From 1984	Thematic, not NT Specific	Since 1984 the Government of Flanders is supporting IMEC research institute	All	Government of Flanders	Initial investment: 62 For every period the contribution increased until reaching around 48 in 2011.
DK	Strategic Research in Growth Technologies[136]	From 2005	Directly Targeting NT	Programme to strengthen research at the bio-nano-ICT interface for socio-economic benefit	IND SME HEI PRO	Innovation Fund Denmark	c. 10 per annum
FI	FinNano[137]	2005-2009	Directly Targeting NT	Multiannual funding for nano S&T to study, exploit and commercialise nano.	IND SME HEI PRO	Tekes	70 over 5 years
FR	Nanomaterials Mandatory Reporting Scheme[138]	From 2013	Directly Targeting NT	Mandatory reporting scheme for nanomaterials of 100g and above	All	ANSES	n/a
FR	PNANO P2N	2002-5 2006 -13	Directly Targeting NT	R&D on • Nanotechnologies, Nanodevices, Micro-Nanosystems • Simulation and Modelling of Nanosystems • Nanotechnologies for Biology, Health and Agro-food • Nanotechnologies for Energy and Environment • Integrative Research Projects for Nanosystems	IND SME HEI PRO and Individuals	ANR[139]	139.8 for P2N over 8 years
FR	Investissements d'avenir	From 2011	Generic	Excellence initiatives including nanobiotechnology and bioinformatics	IND SME PRO	ANR	12 per annum
DE	Nanotechnology	2004-	Directly	Five leading-edge innovation programmes including	All	BMBF	24 over 3 years

[135] https://www.ffg.at/nano-aktuell ; https://www.ffg.at/11-ausschreibung-produktion-der-zukunft
[136] http://innovationsfonden.dk/en/about-ifd
[137] www.tekes.fi
[138] https://www.anses.fr/fr/lexique/nanotechnologies
[139] http://www.agence-nationale-recherche.fr/

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

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
				Knowledge and Innovation (TKIs).			500 million by 2015, 40% of which from trade and industry.
ES	Strategic Action of Nano Science, Nano technologies, new materials and new industrial processes	2008-2011	Directly Targeting NT	To enhance the competitiveness of industry by generating new knowledge and applications based on the convergence of new technologies, where nanotechnology plays a central role.	IND SME HEI PRO	Ministry	33 over 4 years
PT	International Iberian Nanotechnology Laboratory	2005 to date	Directly Targeting NT	International research organisation in the field of nanoscience and nanotechnology, the result of a joint decision of the Governments of Portugal and Spain. Becoming a state-of the art research environment (including nanofabrication facilities) for nano-biotechnology, nano-electronics, nanomedicine and materials science at nanoscale. INL hosts researchers from the EU and non-EU countries including Brazil.	IND SME HEI	Governments of Portugal and Spain	46.5 (of which 30 from ERDF Spain – Portugal" Operational Programme) over 7 years
SK	Action Plan for the Innovation Strategy for Smart Specialisation (RIS3) 2014-2020	2014-2020	Targeting NT, but not only	The Action Plan focused on measures to encourage R&D expenditure of companies and applied research. The Action Plan identified also seven priority areas that include material research and nanotechnologies and information and communication technologies.	Industry	MESRS	Around 42 for nanotechnology Around 10 for ICT
UK	Micro and Nanotechnology Manufacturing Initiative[140]	2003-2007	Directly Targeting NT	Support for collaborative R&D and capital infrastructure, co-financed by industry	Industry	DTI	329 over 4 years, over 100 from public funds
UK	UK Nanotechnologies Strategy	2009-2012	Directly Targeting NT	Targets the ways by which nanotechnologies can address major challenges facing society such as environmental change, ageing and growing populations, and global means of communication and information sharing.	IND SME HEI PRO	TSB, EPSRC, BBSRC and MRC	
UK	Key Enabling Technologies Strategy	2012-2015	NT as Underpinning Technology	Addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having	Business mainly	Innovate UK	GBP 20m a year in higher-risk, early-stage innovation across advanced materials; biosciences; electronics, sensors and photonics;

140 http://www.innovateuk.org/

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

5 POLICIES AND PROGRAMMES IN OTHER COUNTRIES[141]

5.1 Europe

5.1.1 Non-EU Member States

5.1.1.1 Norway

From 2002 to 2011, Norway addressed nanotechnology for ICT through its Programme on Nanotechnology and New Materials (NANOMAT)[142] with 'ICT inclusive microsystems' being one of its thematic investment areas. It covered, for example, nanomaterials and nanocomponents for electronics, data storage, optics, sensors, actuators and radio frequency components; integration of nanomaterials into sensors and actuators; nano-structuring; and nano-fluidics[143].

In 2012, a follow-on programme to run until 2021 was initiated, the Nanotechnology and Advanced Materials Programme (NANO2021)[144]. Managed by the Research Council of Norway[145], this large-scale programme covers research on nanoscience, nanotechnology, micro-technology and advanced materials. The programme is designed to further raise the level internationally of the Norwegian knowledge base in nanotechnology and advanced materials. NANO2021 receives funding from the Ministry of Education and Research and the Ministry of Trade and Industry. The annual budget in the period 2013-2021 has been set at NOK 92.1 million (EUR 10 million[146])[147].

5.1.1.2 The Russian Federation

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

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

RUSNANO now combines an open joint-stock company and a Fund for Infrastructure and Educational Programmes (FIEP). It had capital funding in 2008-2009 of over USD 4 billion (EUR 2.8 billion[148]) but this dropped to USD 2.6 billion (EUR 1.9 billion[149]) by the end of 2010, falling further thereafter. A gradual privatisation of RUSNANO began in 2011. The mission of RUSNANO is to grow the national nanotechnology industry through the commercialisation of nanotechnology and the co-ordination of nanotechnology-related innovation. It acts as a co-investor in nanotechnology projects having substantial economic or social potential.

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[141] The UN method of classifying countries by macro geographical (continental) regions and geographical sub-regions was followed (http://unstats.un.org/unsd/methods/m49/m49regin.htm)

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

[143] http://www.forskningsradet.no/prognett-nanomat/Programme_description/1226993562834

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

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

[146] At the current exchange rate, October 2015

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

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

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

RUSNANO has a very wide range of activities spanning from research to foresight to infrastructure, education, standards and certification. Its research projects fall under six clusters, some of them relevant to ICT, such as the optoelectronics and nano-electronics cluster. As of October 2010, fifteen out of 83 industrial investment projects had been on nano-photonics, as well as seven on nano-electronics[150].

5.1.1.3 Switzerland

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

CTI funds the Swiss MNT network (micro and nanotechnology) as one of the core innovative themes of national and international importance[151]. The Swiss MNT Network is an R&D consortium of the major public R&D institutions in micro and nanotechnology whose goal is to simplify access to industries looking for competences and expertise for their projects[152]. Members include ETH Zürich, Hightech Zentrum Aargau, Centre of Micronanotechnology (EPFL), Adolphe Merkle Institute and companies such as IBM, BASF and Novartis. There are also some regional networks that include nanotechnology as priority: i-net innovation networks Switzerland – i-net Nano[153], and Nano-Cluster Bodensee[154]. Most activities are strongly focused on R&D to support industry.

5.2 The Americas

5.2.1 North America

5.2.1.1 Canada

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

Alberta

The National Institute for Nanotechnology (NINT) is a research institution located in Edmonton on the main campus of the University of Alberta. Its primary purpose is nanotechnology research. The Institute was established in 2001 as a partnership between the National Research Council of Canada (NRC), the University of Alberta and the Government of Alberta. As an institute of the NRC, its core funding comes from the Government of Canada and additional funding and research support from the university, the Government of Alberta and various federal and provincial funding agencies.

Following the announcement in 2007 of the Government of Alberta's Nanotechnology Strategy, nanoAlberta was created as an implementation organisation for that Strategy. NanoAlberta provides leadership to and co-ordination of the Province's wide range of capabilities, organisations and individuals with the aim of gaining a return of CND 20 billion (EUR 13.4 billion[155]) in market share for nano-enabled commerce by 2020.

Quebec

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

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

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

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

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

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

[155] Current conversion rates, October 2015

merger with the Consortium Innovation Polymères, NanoQuébec has formed part of Prima Québec, Quebec's advanced materials research and innovation hub.

Quebec's Nano Action Plan 2013-2018[156] specifically targets four priority sectors: microsystems, health, industrial materials and forestry. It covers infrastructure, financing of innovation, knowledge transfer and technology transfer, and national and international outreach horizontally across the four priority areas.

Via a central point (QNI or Quebec Nanotechnology Infrastructure), it co-ordinates and provides infrastructure for 300 experts using a fund of CND 300 million (EUR 200 million[157]). QNI has particular strengths in micro-nanofabrication, characterisation, synthesis and modelling. Other infrastructure can be accessed but is not funded via QNI.

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

NanoQuébec collaborates with Prompt, a non-profit corporation whose mission is to encourage university and industry collaboration in R&D with a particular focus on ICT industry as ICT-related innovation is considered important for the economy of Quebec (which has 5,000 related companies with about 140,000 employees).[158]

Ontario

An ICT-related initiative, but with its main focus on photonics, took place also in Ontario. The Canadian Photonics Fabrication Centre (CPFC)[159] opened in 2005 as a partnership between the National Research Council and Carleton University. Its aim is to support the growth of the photonics sector in Canada. The Canadian government and the province of Ontario contributed CDN 30 million (EUR 45 million)[160] and CDN 13 million (EUR 19.5 million) respectively to the capital cost of the building and equipment. The CPFC is located at the NRC laboratories and the NRC covered the operating costs of the facility.

5.2.1.2 The United States of America (US)

The National Nanotechnology Initiative[161] was launched in 2000 across a group of eight Federal agencies with some responsibility for nanotechnology research, application and/or regulatory activity, and has grown to include 25 Federal agencies. It aims to create collaborations and bring together expertise to work on shared goals, priorities, and strategies thereby leveraging the resources of the participating agencies. The goals of the NNI Goals are to advance world-class nanotechnology research and development; foster the transfer of new technologies into products for commercial and public benefit; develop and sustain educational resources, a skilled workforce and the supporting infrastructure and tools to advance nanotechnology; and support the responsible development of nanotechnology.

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

The NSET Subcommittee is composed of representatives from agencies participating in the NNI and

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[156] http://www.nanoquebec.ca/media/plan-action_en1.pdf
[157] Current conversion rates, October 2015.
[158] http://www.promptinc.org/en/about-us/prompt-at-a-glance/
[159] http://www.nrc-cnrc.gc.ca/eng/solutions/facilities/prototyping_index.html
[160] Average rate 2005, CDN 1.5 to EUR 1.00 (www.x-rates.com)
[161] http://www.nano.gov/

NSET has Working Groups on Global Issues in Nanotechnology; Nanotechnology Environmental & Health Implications; Nano-manufacturing, Industry Liaison, & Innovation; and Nanotechnology Public Engagement and Communications.

In February 2014, the National Nanotechnology Initiative released a Strategic Plan[162] outlining updated goals and five "programme component areas" (PCAs). The goals focus on extending the boundaries of research; fostering the transfer of technology into products; developing and sustaining skilled people (with the right infrastructure and toolset) for nanotechnology; and supporting responsible development of nanotechnology. The five PCAs include a set of five Nanotechnology Signature Initiatives (NSIs) as well as PCAs for foundational research; nanotechnology-enabled applications, devices, and systems; research infrastructure and instrumentation; and environment, health, and safety. The five Nanotechnology Signature Initiatives (NSIs) are also relevant to ICT (for example, nano-electronics, nanotechnology for sensors and sensors for nanotechnology.

The 2014 NNI Strategic plan also identifies the different priorities and interests of departments/agencies, for example, nanotechnology and ICT are relevant to:

- Intelligence Community (IC)/Office of the Director of National Intelligence (ODNI) with reference to ultralow-power non-volatile memory for saving power in data centres and satellites; and
- Department of Defence (DoD) (quantum information science, communications and information processing systems needed for persistent surveillance).

The NNI's budget supplement proposed by the Obama administration for Fiscal Year 2015 provided for USD 1.5 billion (EUR 1.2 billion[163]) of funding. Cumulative NNI investment since fiscal year 2001, including the 2015 request, totals almost USD 21 billion (EUR 17 billion[164]). Cumulative investments in nanotechnology-related environmental, health, and safety research since 2005 is nearly USD 900 million (EUR 680 million[165]). The Federal agencies with the largest investments are the National Institutes of Health (NIH), the National Science Foundation (NSF), the Department of Energy, the Department of Defence, and the National Institute of Standards and Technology (NIST).

Some of the above-mentioned institutions (like NIST, with its main focus on measurement sciences and standards development) have areas dedicated to nanoscience and nanotechnology (for NIST including nano-electronics and nanoscale electronics and nano-magnetics) as well as to information technology and electronics and telecommunications[166]. The latter includes optoelectronics, quantum information, semiconductors, sensors and microelectronics. Information Technology Manufacturing at NIST[167] encompasses subject areas including nano-manufacturing, green manufacturing, robotics, systems integration, etc. NIST also provides facilities to support production, through the Centre for Nanoscale Science and Technology (CNST)[168], established in 2007. The CNST facilitates access to commercial state-of-the-art nanoscale measurement and fabrication tools through its NanoFab. One focus area is Future Electronics.

Another important actor active in nanotechnology is the NSF. This federal agency, with an annual budget of USD 7.3 billion (EUR 6.8 billion[169]) (FY 2015), funds approximately 24% of all federally-supported basic research (except for medical sciences) conducted by America's colleges and universities[170]. With reference to the ICT sector, the Directorate for Computer & Information Science &Engineering (CISE) is particularly relevant, dealing with advanced cyber-infrastructure, computing and communications foundations, computer and networks systems, and information and intelligent systems. CISE is also leader of the National Strategic Computing Initiative (NSCI)[171] in collaboration with academia and industry, aiming at maximising "benefits of high-performance computing (HPC) research, development, and deployment". Also the Directorate of Engineering (ENG), Division Electrical, Communications and Cyber Systems Division (ECCS) is active in the field of ICT, in

[162] http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf
[163] Average yearly conversion rate, 2015 (*source*: www.wolframalpha.com)
[164] Average yearly conversion rate, 2001-2015 (*source*: www.wolframalpha.com)
[165] Average yearly conversion rate, 2005-2015 (*source*: www.wolframalpha.com)
[166] http://www.nist.gov/electronics-and-telecommunications-portal.cfm
[167] http://www.nist.gov/manufacturing-portal.cfm
[168] http://www.nist.gov/cnst/index.cfm
[169] Current conversion rate, November 2015 (*source*: www.wolframalpha.com)
[170] http://www.nsf.gov/about/
[171] https://www.whitehouse.gov/the-press-office/2015/07/29/executive-order-creating-national-strategic-computing-initiative

particular with the programmes on electronics, photonics and magnetic devices (EPMD) and communications, circuits, and sensing-systems (CCSS).

In additional to these Federal initiatives, there exist several policy initiatives at State level[172]. Programmes for the promotion of nanotechnologies currently exist in 23 states. Notable examples are the Texas Emerging Technology Fund[173], the Oklahoma Nanotechnology Initiative[174], the Illinois Nanotechnology "Collaboratory"[175], and the Oregon Nanoscience and Micro-Technologies Institute (ONAMI)[176]. The State-level organisations typically undertake some or all of the following activities: fostering collaboration on nanotechnology topics and challenges between researchers and research centres; higher education/industry joint projects; education and outreach; access to technology experts and infrastructure; early-stage funding and investment opportunities; technology transfer and commercialisation; and awareness raising in the community.

Finally, an international industry-led initiative relevant for ICT is sponsored by the United States Semiconductor Industry Association (SIA)[177] together with the European Semiconductor Industry Association (ESIA), the Japan Electronics and Information Technology Industries Association (JEITA), the Korean Semiconductor Industry Association (KSIA) and the Taiwan Semiconductor Industry Association (TSIA). They drafted the International Technology Roadmap for Semiconductors[178] "to ensure cost-effective advancements in the performance of the integrated circuit and the advanced products and applications that employ such devices". [179] The Roadmap focuses on devices (including 3D power scaling, edgeless wrapped materials and CMOS), system integration (e.g. spinwave devices) and manufacturing (related to nano integrated circuits and big data).

5.2.2 South America

5.2.2.1 Argentina

A first initiative to foster nanotechnology in Argentina was established in 2003 when the national Science and Technology Secretariat started to organise research networks in the field. In 2004, the Secretariat, looked to address gaps in what being done under the National Agency for Scientific and Technological Promotion (ANPCYT, Agencia Nacional de Promoción Científica y Tecnológica[180]) as a result of which four nanoscience and nanotechnology networks were approved in 2005, bringing together around 250 scientists. In the same year, the Argentinian-Brazilian Nanoscience and Nanotechnology Centre (CABN, Centro Argentino-Brasileno de Nanociencia y Nanotecnología) was created as a binational co-ordination body integrating research groups, networks of nanoscience and nanotechnology, and companies in Argentina and Brazil, in order to support scientific and technological research in the area and to improve the human and scientific resources of both countries.

The Argentinian Foundation for Nanotechnology (FAN)[181] was initiated in 2005 by the Economy and Production Ministry, with the aim of stimulating training and developing technical infrastructure to promote advances in nanotechnology and the adoption of nanotechnology by industry. It also aimed to encourage the participation of researchers, institutions and companies from Argentina in international networks.

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

In 2011, the Ministry of Science, Technology and Productive Innovation published the Argentina

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[172] http://www.nano.gov/initiatives/commercial/state-local
[173] http://gov.texas.gov/. As of October 2010, the Texas Emerging Technology Fund has given a total of UDS 173 million to 120 companies as well as UDS 161 million to educational institutions.
[174] http://www.oknano.com /
[175] http://nano.illinois.edu/collaboration/index.html
[176] http://onami.us/
[177] http://www.semiconductors.org/
[178] http://www.semiconductors.org/news/2014/04/01/press_releases_2013/international_technology_roadmap_for_semiconductors_explores_next_15_years_of_chip_technology/
[179] http://www.itrs.net/about.html
[180] http://www.agencia.mincyt.gob.ar/frontend/agencia/fondo/agencia
[181] http://www.fan.org.ar/en/

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

5.2.2.2 Brazil

Systematic policy support for nanotechnology started in 2001, when the Brazilian Ministry of Science and Technology (MCT) through the Brazilian National Research Funding Agency (Conselho Nacional de Desenvolvimento Científico e Tecnológico or "CNPq") earmarked BRL 3 million (USD 1 million) (EUR 1.12 million[182]) over four years to form Co-operative Networks of Basic and Applied Research on Nanosciences and Nanotechnologies. Four national research networks were established: semiconductors and nano-structured materials; nano-devices; molecular nanotechnologies and interfaces; and nano-biotechnology. In late 2004, a network on Nanotechnology, Society and Environment was created that was independent of the formal funding mechanisms.

Since 1999, Brazil's national plan has comprised an annual budget and a four-year strategic plan (the Plano Plurianual or PPA). In 2003, the Ministry created a special division for the general co-ordination of nanotechnology policies and programmes whose work resulted in a proposal for specific nanotechnology-related funding. That proposal was taken up in the PPA in 2004-2007, which provided for BRL 78 million (c. USD 28 million) (EUR 22 million[183]) over 4 years for the Programme for the Development of Nanoscience and Nanotechnology. The aim of the programme was "to develop new products and processes in nanotechnology with a view to increasing the competitiveness of Brazilian industry", which it implemented by supporting networks, research laboratories and projects.

A review of the funding in the light of the 2004 policy on Industrial, Technological and Foreign Trade, the government reconsidered the original budget and increased Federal investment for 2005 and 2006 from the original USD 19 million (EUR 15 million[184]) to c. USD 30 million (EUR 24 million[185]) for those two years. Ten new research networks were set up to continue previous research activities but linking more closely to broader industry, technology, and trade policies. Industrial policy helped to reinforce the strategic status attributed at national level to nanotechnology and its role in enhancing Brazil's competitiveness. Of particular important in the programmes were the development of qualified human resources, the modernisation of infrastructure and the promotion of university-industry co-operation.

In 2012, the Brazilian Ministry for Science, Technology and Innovation (MCTI) launched the SisNANO[186] initiative, enabling scientists throughout Brazil to conduct experiments at 26 "open" laboratories offering the very best equipment for research in nanotechnology. University students and staff can use the facilities free of charge – provided that they submit a good research proposal – while scientists working in industry are able to access specialist equipment and expertise at highly subsidised rates. The laboratories offer facilities fundamental for improving for example, electron-spinning. A laboratory quite related to ICT sector is the Centre for Semiconductor Components, CCS, focused on "nano-electronics, nano-photonics and micro-electronics".[187]

In 2013, MCTI launched the Brazilian Nanotechnology Initiative (IBN) with funding estimated to be BRL 440 million (EUR 148 million[188]) for the 2013-2014 period. The implementation of IBN was an effort to further strengthen nanotechnology in Brazil by strengthening academic and industry linkages thereby to promote the scientific and technological development of the nanotechnology sector.

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[182] Average yearly conversion rate, 2001(*source*: www.wolframalpha.com)
[183] Average yearly conversion rate, 2004-2007 (*source*: www.wolframalpha.com)
[184] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[185] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[186] Sistema Nacional de Laboratórios em Nanotecnologias ftp://ftp.mct.gov.br/Biblioteca/39717-SisNANO.pdf
[187] http://www.ccs.unicamp.br/novosite/en/
[188] Average yearly conversion rate, 2013-2014(*source*: www.wolframalpha.com)

5.3 Asia

5.3.1 Eastern Asia

5.3.1.1 China

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

The National High Technology Research and Development Programme (the 863[189] programme announced in 1986) focuses on key high-technology fields of relevance to China's national development, supporting research and development, strengthening technological expertise and laying the foundations for the development and growth of high technology industries. Its goals are 'promoting the development of key novel materials and advanced manufacturing technologies for raising industry competitiveness' including nanomaterials. The programme is supervised by the National Steering Group of S&T and Education, and is managed by the Ministry of Science and Technology.

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

The 1997 "National Plan on Key Basic Research and Development" together with the "National Programme on Key Basic Research Project (973 Programme)" sought to strengthen basic research in line with national strategic targets[190]. The 973 Programme complements the 863 programme, funding basic research on nanomaterials and nanostructures (i.e. carbon nanotubes). The National Steering Committee for Nanoscience and Nanotechnology (NSCNN) was established in 2000 to coordinate and streamline all national research activities including overseeing the 863 and 973 programmes. The NSCNN consists of the Ministry of Science and Technology (MOST), the Chinese Academy of Sciences (CAS), the National Natural Science Foundation (NSFC), the National Development and Reform Commission (NDRC), the Ministry of Education (MOE) and the Chinese Academy of Engineering (CAE).

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

Nanotechnology is given priority status under the MLP, being seen as one of the Chinese 'megaprojects' in science. ICT is among the priority topics under "Information Industry and Modern Service Industry" area. It includes sensor networks and intelligent information processing. The MLP, in identifying the frontier technologies, stresses the key role of *ad hoc* network technology (mobile networks, computing networks, storage networks, sensor networks, low-cost real-time information processing systems, multi-sensor information integration, etc.). As the MLP is implemented in the context of the Five-Year Plan for S&T Development (2011-2015), it is relevant that it also emphasises key technologies for strategic and emerging industries (including nanotechnology with ICT, photonics, manufacturing and agriculture).

[189] The programme is named for its date, the 86 for 1986 and the 3 for the third month, hence 86/3 or 863. Likewise for the 973 programme launched in March 1997.

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

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

5.3.1.2 Japan

Strategic prioritisation of nanotechnology started in Japan under the Second Science and Technology Basic Plan (STBP) 2001-2005. Among the eight priority R&D topics of national importance were ICT and nanotechnology, as well as manufacturing technology and materials, energy, environmental sciences and life sciences, and the cross-cutting areas of infrastructure and frontier research. Nanotechnology was seen as being relevant to a broad range of fields and it was expected to help Japan to maintain its technological edge. Total governmental funding of this field grew in these years from JPY 85 billion (EUR 782 million)[191] in 2001 to JPY 97 billion (EUR 709 million[192]) in 2005.

In the subsequent STBP[193], which ran from 2006 to 2010, Japan established nanotechnology and materials as one of its four priority research fields, the others being information and communications, environmental sciences; and life sciences. Together with manufacturing, energy, environment, and frontiers, these formed eight Promotion Areas. The total budget over the five years was JPY 250 trillion (EUR 200 billion)[194]. There were five sub-areas under nanotechnology and materials – nano-electronics; fundamentals for nanotechnology and materials; materials; nanotechnology and materials science; and nano-biotechnology and biomedical materials.

In 2010, a 'New Growth Strategy' was introduced to combat the lengthy stagnation of the Japanese economy. The strategy sought to create jobs by tackling the issues faced by the economy and society. This took the form of a reorientation of priorities towards green innovation (reducing emissions and addressing climate issues); life innovation (healthy and long living); the Asian economy (issues of specific Asian concern including falling birth rates and ageing societies); and tourism and the regions. Growth-related strategies for ('making Japan a superpower in') science, technology and ICT, for employment and human resources, and for the financial sector were also identified as essential in supporting growth. The strategy also addressed the issues arising from the earthquake, tsunami and nuclear crisis of 2011.

The same priorities were incorporated in 2011 into the Fourth Science and Technology Basic Plan (2011-2015) with a budget of EUR 250 billion (JPY 25 trillion). As with the New Growth Strategy, and in contrast to the previous Basic Plan for Science and Technology, the Fourth Basic Plan shifted away from emphasising technologies towards "demand driven and solution-oriented topics" as well as to "problem solving and issue-driven policies" and the "deepening the relationship between society and science and technology." Two broad based areas are prioritised: Life Innovation and Green Innovation and an emphasis has been placed on technologies to reduce global warming, provision and storage of energy supply, renewable energies, and diffusion of such technologies. As there is no specific emphasis on individual technologies, nanotechnology is incorporated across research and development without being specifically targeted.

5.3.1.3 Korea (South)

Long a topic of relevance in Korea, support for nanoscience and nanotechnology reached a new level in December 2000 with the announcement by the National Science and Technology Council (NSTC)[195] of the Korean National Nanotechnology Initiative (KNNI). Nanotechnology was also identified as one of six priority fields in the National Science and Technology Basic Plan (2002–2006). The NT

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

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

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

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

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

Development Plan was approved by the NSTC on in July 2001 and the NT Development Promotion Act passed in November 2002 by the National Assembly. The initiative is now in its 3rd phase (2011-2020), with focus on 'clean nanotech'. Investment in phase 1 (2001-2005) was 105.2 billion Won (EUR 83 million[196]); phase 2, 277.2 billion Won (EUR 1,541.8 million[197]).

Under its KNNI, Korea has focused on establishing specific support mechanisms (programmes, systems and societies) and centres of excellence across the country. The launching of the National Programme for Tera-Level Nano-devices (2000) was followed by the founding of the Nanotechnology Industrialisation Support Centre (2001) and the Korean Advanced Nanofabrication Centre[198] (KANC) (2003). In more recent times, building on former centres, Korea established two NST centres at the Institute for Basic Science: the Centre for Nanoparticle Research and the Centre for Nanomaterials and Chemical Reactions (2012)[199]. In total, 24 nanotechnology-related centres now exist in Korea.

The Korean Institute of Science and Technology (KIST)[200] has a Material and Life Science Division, covering nanotechnology, ICT and biotechnology. Also related to ICT and nanotechnology at KIST, the Post-silicon Semiconductor Institute has a specialised Centre for Spintronics as well as a Centre for Electronic materials, a Centre for Opto-Electronic Materials and Devices, and a Centre for Quantum Computing[201]. In addition, by 2010, over forty universities had nanotechnology departments.

Under the Nanotechnology Development Promotion Act 2002, Korea also established in 2004 the Korean Nano Technology Research Society (KoNTRS)[202] as a mechanism for co-operation between researchers working on nanotechnology throughout the country, to develop collaborative research programmes between institutions (public and private) and to support the government in establishing appropriate national NST policies.

Korea has since continued to invest in nanotechnology, with the review by NSTC in 2006 of the first five years of its NNI leading to support continuing for an additional ten years. In this third phase of the NT Development Plan (2011-2020), there is greater focus on clean nanotechnology and overall the policy has evolved, moving away from funding fundamental research towards more application-driven actions.[203]

Korea has also sought to develop its nanotechnology policy and policy system, with the production of the Korean Nanotechnology Roadmap in 2008 and the establishment of the National Nanotechnology Policy Centre (NNPC) in 2010. The NNPC announces on its web site[204] the national vision for Korea to be "the world's number one nanotechnology power" and the four goals:

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

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

- The Fundamental Nanotechnology Mid-term Strategy [NT 7-4-3 Initiative] through which the Ministry of Education, Science and Technology (MEST) supported 35 green nanotechnologies in seven areas as well as funding four infrastructure projects;

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196 Average yearly conversion rate, 2001-2005 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
197 Average yearly conversion rate, 2006-2010 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
198 http://www.kanc.re.kr/kancEnglish/center/center_overview.jsp
199 https://www.ibs.re.kr/eng/sub02_04_03.do
200 KIST is a science and technology institute. It was the first S&T research institute founded in Korea following the joint statement by the Presidents of Korea and the US on the "Establishment of a Korean Industrial and Applied Science R&D Institute" (1966) http://eng.kist.re.kr/kist_eng/?sub_num=728
201 http://eng.kist.re.kr/kist_eng/?sub_num=1596
202 http://kontrs.or.kr/english/index.asp
203 http://www.nanotechmag.com/nanotechnology-in-south-korea/
204 http://www.nnpc.re.kr/htmlpage/15/view

- The Nano Fusion Industry Development Strategy by MEST and the then Ministry of the Knowledge Economy (MKE), which sought to support nanotechnology all across the value chain, from the research laboratory to the marketplace;
- The National Nano Infrastructure Revitalisation Plan, also by MEST and MKE, to link nanotechnology infrastructures together, thereby giving them new impetus; and
- The Nano Safety Management Master Plan 2012-2016 to define methods and processes for the identification and manage any safety risks that emerge with the development, commercialisation and manufacture of nanotechnology products.

2012 saw the creation of the Nano-Convergence Foundation (NCF)[205] whose remit is to increase the commercialisation of national NST research outcomes. It operates under the joint support of the Ministry of Science, ICT & Future Planning (MSIP) and the Ministry of Trade, Industry & Energy (MOTIE). Korea plans to invest 930 billion Korean Won (ca. USD 815 million, EUR 740 million[206]) by 2020 in the NST, with projects in the Nano Convergence 2020 programme eligible to receive up to 2 billion Korean Won (EUR 1.5 million[207]) each.

5.3.1.4 Taiwan (Chinese Taipei)[208]

The National Nanoscience and Nanotechnology Programme[209] was approved for a period of six years by the National Science Council (NSC) in 2002. With a budget envelope of USD 700 million (EUR 740 million[210]) and actual expenditure estimated to be USD 625 million (EUR 486 million[211]) over 2003-2008, the aim of the programme was to foster nanotechnology research and development in research institutes, universities and private companies, achieving academic excellence and supporting commercialisation. The Academic Excellence part of the programme includes physical, chemical and biological properties of nano-sensors, nano-structures, nano-devices and nano-biotechnology. Industrial applications are the remit of the Industrial Technology Research Institute (ITRI). ITRI has 13 research laboratories and centres in areas including optoelectronics, electronics, mechanical and systems, applied materials, biomedicine, chemistry and mechanics. The Information and Communications Research Laboratories[212] and the Electronic and Optoelectronic System Research Laboratories are relevant for the ICT sector.[213] The latter, in particular, conducts research in new semiconductor architectures, including advanced memories, 3D-IC and ultra-fine line, and embedded-interposer-carrier substrates.

The National Nanoscience and Nanotechnology Programme also co-ordinates the nanotechnology research efforts of government agencies mainly through the establishment of common core facilities and education programmes, by promoting technology transfer and commercialisation into industrial applications and establishing internationally competitive nanotechnology platforms. Among the thematic priorities of the programme overall have been the design and fabrication of interconnects, interfaces and system of functional nano-devices, and the development of MEMS/NEMS technology.

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

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

[205] http://www.nanotech2020.org/download/english_brochure.pdf
[206] Current exchange rate, November 2015 (*source*: www.wolframalpha.com)
[207] Current exchange rate (November 2015) (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[208] http://www.twnpnt.org/
[209] http://www.twnpnt.org/english/g01_int.asp
[210] Average yearly conversion rate, 2002 (*source*: www.wolframalpha.com)
[211] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2768287/
[212] https://www.itri.org.tw/eng/Content/Messagess/contents.aspx?SiteID=1&MmmID=617766557770066341
[213] https://www.itri.org.tw/eng/Content/Messagess/contents.aspx?SiteID=1&MmmID=617751557022321307

nano-biotechnology and applied nanotechnology in traditional industries.

5.3.2 Southern Asia

5.3.2.1 India[214]

The Nanomaterials Science and Technology Initiative (NSTI) was launched by the Ministry of Science and Technology's (MST) Department of Science and Technology (DST) in October 2001 to support priority areas of research in nanoscience and nanotechnology; strengthen national characterisation and infrastructural facilities; enhance nanotechnology education in order to generate trained manpower in the area; and create an applications-related interface between educational institutions and industry. The Indian government committed to investing USD 16 million (EUR 14 million[215]) in nanomaterials research and commercial development over the five-year duration of the initiative, 2002-2006. The funding was used for projects, centres of excellence, conferences, advanced courses (schools) and post-doctoral fellowships. Within its basic and application-oriented research programmes, it supported work on nanomaterials for pharmaceuticals and drug delivery, gene targeting and DNA chips.

A capacity-building programme for nanoscience and nanotechnology (called Nano Mission)[216] was announced in 2007. It was implemented by DST with a budget of EUR 155 million over 5 years. In that time, India raised its publication output in nano-science and –technology generating about 5000 research papers and about 900 PhDs directly from Nano Mission funding. Under the programme, scientists were given access global state-of-the-art facilities in countries including Japan and Germany. The programme is also seen as having resulted in products including nano hydrogel-based eye drops, pesticide removal technology for drinking water, water filters for arsenic and fluoride removal and nano silver based antimicrobial textile coatings. Finally, it facilitated discussions on standards for nanotechnology at national level.

The continuation of the Nano Mission was approved by the Government in February of 2014 and EUR 91 million (INR 650 crore) were sanctioned for the time period 2012 to 2017[217]. The programme will continue to support nanoscience and technology by promoting basic research, human resource development, research infrastructure development, international collaborations, national dialogues, and nano-applications and technology development. In the area of development of products and processes, the programme has focused, and will continue to focus, on areas of national relevance including sensor development, safe drinking water, materials development and drug delivery.

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

- The Council of Scientific and Industrial Research (CSIR)[218] has a network of 38 laboratories and other partners involving about 4600 scientists in research and development across a wide range of disciplines, including nanotechnology, and for application areas including electronics and instrumentation.
- In 2003, the CSIR launched the New Millennium Indian Technology Leadership Initiative (NMITLI) to foster public-private partnerships via grant-in-aid funding to public partners and soft loans to their industrial partners. The initiative specifically targeted nanosciences and nanotechnologies; biotechnology; energy and materials.[219]
- The CSIR's International Science and Technology Directorate (ISAD) facilitates nanotechnology workshops and projects in collaboration with partners from South Africa, France, South Korea, China and Japan[220].
- The MST's Science and Engineering Research Council (SERC)[221] supports frontier and

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[214] http://www.oecd.org/science/nanosafety/37277620.pdf; http://nanomission.gov.in/; http://www.ris.org.in/images/RIS_images/pdf/DP%20193%20Amit%20Kumar.pdf, http://erawatch.jrc.ec.europa.eu/erawatch/opencms/information/country_pages/in/country?section=ResearchPolicy&subsection=ResPolFocus
[215] Average yearly conversion rate, 2002-2006 (*source*: www.wolframalpha.com)
[216] http://nanomission.gov.in/;
[217] http://timesofindia.indiatimes.com/home/science/Govt-approves-Rs-650-crore-for-Nano-mission/articleshow/30722422.cms
[218] www.csir.res.in/
[219] http://www.csir.res.in/external/heads/collaborations/NM.pdf
[220] http://www.teriin.org/div/ST_BriefingPap.pdf
[221] www.dst.gov.in/about_us/ar05-06/serc.htm

interdisciplinary research. Support for nanotechnology projects has been provided through its R&D schemes for basic science and engineering science.

5.3.2.2 Iran[222]

The Islamic Republic of Iran ranked 23rd in the world in nanotechnology in 2007, second to Korea in citations in Asia[223], but, by 2012, it had moved to 10th place[224, 225]. In 2013, Iran ranked 20th in science production in the world (Thomson Reuters) and 18th in science production for medicine. According to the Ministry, its share of global science production rose from 1.39% in 2013 to 1.69% percent in 2014, as measured by indicators including the number of scientific papers, the quality and quantity of documents, patenting inventions, industrial plans, partnership with foreign universities, and the use of technology in domestic organisations.

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

Iran began its nanotechnology activities with a Study Committee for Nanotechnology in 2001. Its work led to the development of the Iran Nanotechnology Initiative Council (INIC)[226], established in 2003 to develop policies to foster nanotechnology in Iran and monitors their implementation. The Council also funds researchers, having supported over 1400 researchers for nanotechnology activity between 2004 and 2010, at a cost of USD 12 million[227] (EUR 9 million[228]).

INIC has also funded the development of research and training facilities for nanotechnology research, such as the Institute for Nanoscience and Nanotechnology (INT) at the Sharif University of Technology. The INT, established in 2004, was the first institute to offer a PhD in nanotechnology in Iran[229]. INIC undertakes education and awareness-raising activities including a students' Nano Club, seminars, workshops, publications and a multi-lingual (Arabic, Persian, Russian and English) website[230].

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

INIC operates through working groups on areas including Human Resource Development; Technology Development and Production; and Education and Awareness. It also addresses standards and regulations through the Iran Nanotechnology Standardisation Committee (INSC)[231], a body established in 2006 as a collaboration between the INIC and the Institute of Standard and Industrial Research of Iran (ISIRI)[232].

Continuing to support nanotechnology and the work of INIC, a "Future Strategy" was adopted in 2005 by the Cabinet, a 10-year nanotechnology development (2005 - 2014). Its mission was to place Iran among the top fifteen advanced countries in nanotechnology in the world. The focus was placed on building and using infrastructure and human resources; improving communication and networking both within Iran and internationally; and generating economic added value from nanotechnology as a means of achieving economic development[233].

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[222] See also http://www.sciencedev.net/Docs/Iran_Nano.pdf (2010)
[223] http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file11959.pdf
[224] http://statnano.com/report/s29
[225] http://www.nanotech-now.com/news.cgi?story_id=45237
[226] http://nano.ir/index.php?lang=2
[227] http://www.nanotech-now.com/news.cgi?story_id=36557
[228] Average yearly conversion rate, 2004-2010 (*source*: www.wolframalpha.com)
[229] http://blogs.scientificamerican.com/guest-blog/science-and-sanctions-nanotechnology-in-iran/
[230] http://nano.ir/index.php?ctrl=static_page&lang=2&id=397&section_id=22
[231] http://nanostandard.ir/index.php?lang=2
[232] http://www.isiri.com/
[233] http://statnano.com/strategicplans/1

5.3.3 South-Eastern Asia

5.3.3.1 Malaysia

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

The Malaysian National Nanotechnology Initiative (NNI) was established in 2006 to advance nanotechnology and related sciences by clustering local resources and knowledge of Malaysian researchers, industry and the government. The NNI paved way for the establishment in 2010 of the National Nanotechnology Directorate under the Ministry of Science, Technology and Innovation (MOSTI). The National Nanotechnology Directorate (NND)[234] facilitates nanotechnology development in Malaysia by acting as a central co-ordination agency.

To further support activity on these priority areas, the National Innovation Council of Malaysia in 2011 identified the need for a national organisation for nanotechnology commercialisation. NanoMalaysia[235] was created in 2011 as a company under the Ministry of Science, Technology and Innovation (MOSTI). It is responsible for commercialisation of nanotechnology research and development; industrialisation of nanotechnology; facilitation of investments in nanotechnology; and human capital development in nanotechnology.

In 2011, the Top down Nanotechnology Research Grant (NanoFund) was introduced and NanoMalaysia Centres of Excellence created. Among these are the Institute of Nano-Electronics and Engineering (INEE)[236] (with research groups on memory devices, photonics and novel silico devices) and the Institute of Micro Engineering and Nano-electronics (IMEN), at UKM[237], specialised in MEMS/NEMS and nano-electronics and micro- and nano-electronics system.

5.3.3.2 The Philippines[238]

Nanotechnology was first identified as a priority area in the Philippines in 2009 when the Department of Science and Technology (DOST) formed a multidisciplinary group to create a roadmap for the development of nanotechnology in the country. The Nanotechnology Roadmap for the Philippines identified five key sectors for the application of nanotechnology that also coincided with the priority areas of DOST for R&D support. These areas were: information and communications technology and semiconductors; health; environment; food and agriculture; and energy.

Both the MAPUA Institute of Technology and the University of Philippines Diliman are active in nanotechnology R&D for ICT and semiconductor applications.[239]

5.3.3.3 Singapore

With the aim of transitioning to a knowledge-based economy, Singapore has relied, since the early 1990s, on its five-year basic plans for science and technology (S&T). Foresight and technology scanning were key components of the process by which the 2010 plan[240] was developed. Thirteen technology scanning panels were established, including one on 'Exploiting Nanotechnologies'. There were also foresight panels on semiconductors, broadband, information storage, manufacturing, materials and infrastructure, intelligent systems, the grid, information management, energy, environmental technologies, engineering science in medicine, and frontiers in chemicals.

In the 2010 strategy document, the connection is made between the S&T Plan and the Manufacturing 2018 Plan Intelligent National Plans of Singapore's Economic Development Board[241], and the Roadmap (ITR5) of the Infocomm Development Authority[242]. It links nanotechnology research and

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[234] http://www.mosti.gov.my/en/about-us/divisions-departments/national-nanotechnology-directorate-division-nnd/
[235] http://www.nanomalaysia.com.my/index.php?p=aboutus&c=whoweare
[236] http://inee.unimap.edu.my/
[237] www.ukm.my/
[238] http://www.techmonitor.net/tm/images/d/d1/10jan_feb_sf3.pdf
[239] http://nanotech.apctt.org/countryreports/Philippines%20Country%20Report.pdf
[240] https://www.mti.gov.sg/ResearchRoom/Pages/Science-and-Technology-Plan-2010.aspx
[241] www.edb.gov.sg
[242] www.ida.gov.sg

development to industrial development and supports collaboration between industry, research institutes and universities. The aim is for an enhancement of applied research in nanotechnology to enable industrial clusters including ICT, electronics, precision machinery, transportation machinery, engineering, chemicals, food, and environmental. The Plan also indicates nanotechnology is fundamental and horizontal to these clusters.

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

The main funding agency for nanoscience and nanotechnology (NST) in Singapore is the Agency for Science, Technology & Research (A*STAR)[243]. A*STAR's Nanotechnology Initiative started in 2001 with the target of building on existing capabilities to develop specific areas of NST research always with applications and potential use by industry as a goal. A*STAR research institutes involved in NST include the Data Storage Institute[244] (that includes the Data Centre Technologies and the Non-Volatile Memories), the Institute of High Performance Computing[245], the Institute for Infocomm Research, and the Institute of Microelectronics[246] (with a MEMS and nano-electronics programme).

In 2010, A*Star's SIMTech launched the Nanotechnology in Manufacturing Initiative (NiMI) to foster collaborative efforts between research and industry, developing industrial capability and enhancing competitiveness. NiMI concentrates "on the application of nanotechnology in the processes of forming, joining and coating", particularly for the electronics industry, nanocomposite physical vapour deposition (PVD) coatings and others. Characterisation is also a relevant part of the initiative.[247]

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

5.3.3.4 Thailand

Thailand has been active in nanotechnology since at least 2003 when it established NANOTEC[248] as the leading national agency for nanotechnology development. It operates under the jurisdiction of the National Science and Technology Development Agency (NSTDA) and the Ministry of Science and Technology (MOST), one of four such agencies. The guiding aims of NANOTEC are to contribute to society; increase Thailand's competitiveness; and improve the quality of life and the environment of the people of Thailand through research and development in nanoscience and nanotechnology. NANOTEC undertakes and supports research, development, design and engineering in nanotechnology, and the transfer of the resulting technology to industry and the marketplace. In 2013, the Central Laboratory of NANOTEC consisted of twelve units located at the Thailand Science Park. These covered areas including nano-characterisation; engineering and manufacturing characterisation; integrated nano-systems, nanomaterials for energy and catalysis, hybrid nanostructures and nanocomposites; nanoscale simulation; and functional nanomaterials and interfaces.

In 2012, the National Nanotechnology Policy Framework (2012-2021)[249] and the Nanosafety and Ethics Strategic Plan (2012-2016)[250] were approved by government for implementation by the Ministry of Science and Technology, and relevant agencies. The Framework has three primary goals:

- Utilising nanotechnology to develop materials, products, and equipment in order to enhance the quality of life, wellness, and environment;
- Improving agricultural technology and manufacturing industry that meet the demand of the market through nanotechnology; and

[243] www.a-star.edu.sg/
[244] http://www.a-star.edu.sg/dsi/Home.aspx
[245] http://www.a-star.edu.sg/ihpc/Research/Overview.aspx
[246] https://www.a-star.edu.sg/ime/
[247]http://www.a-star.edu.sg/Media/News/Press-Releases/ID/1363/ASTAR-SIMTech-Nanotechnology-in-Manufacturing-Initiative-NiMI-to-Overcome-Challenges-to-Tap-Market-Potential.aspx
[248] http://www.nanotec.or.th/th/wp-content/uploads/2013/05/NANOTEC-brochure11.pdf
[249]http://www.nanotec.or.th/en/wp-content/uploads/2012/02/The-National-Nanotechnology-Policy-framework-exe-sum.pdf
[250] http://www.nanotec.or.th/en/

- Becoming ASEAN's leader in nanotechnology research and education.

The overall strategic direction of the Framework encompasses four target clusters, including manufacturing industry and electronics, and defines seven flagship products including nano-electronics. It aims to achieve its goals through actions in human resources, research and development, infrastructure development, management (of quality, safety and standards) and technology transfer.

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

5.3.4 Western Asia

5.3.4.1 Israel

The first nanotechnology policy initiative in Israel was the establishment of the Israel Nanotechnology Initiative (INNI)[251] in 2002 as a shared action of the Forum for National Infrastructures for Research & Development (TELEM)[252] and the ministry for the economy (now called the Ministry for Industry, Trade and Labour)[253]. INNI's mission is "to make nanotechnology the next wave of successful industry in Israel by creating an engine for global leadership". To achieve this, actions have been taken on scientific research in nanoscience and nanotechnology (NST); on increasing public-private collaboration on NST; on speeding up commercialisation of NST; and on leveraging funding from both public and private sources to support NST in Israel. INNI is closely linked to the national system with its Director appointed by the Chief Scientist at the Ministry, and its Board operating out of the MAGNET Programme[254] at the Office of the Chief Scientist.

Since the identification of nanoscience and nanotechnology (NST) as a national priority area in 2007, the areas that have been targeted have included research infrastructure; training Israeli scientists in NST; attracting foreign researchers to work in Israeli institutions; increasing collaboration in NST and publication output of the highest international standard; fostering public-private partnerships; and knowledge transfer and commercialisation of NST. Investment has been c. USD 20 million (EUR 15.5 million[255]) per annum for basic NST equipment plus another almost USD 10 million (EUR 8 million[256]) per annum for new infrastructure and facilities.[257] The aim has been to create a sustainable basis for NST within the universities via training, recruitment and the provision of facilities on the basis that, without a strong research base, direct investment in technology will not be able to generate the required returns in terms of technology development and deployment.

In addition, the Triangle Donation Matching (TDM) programme[258] was launched under the INNI in 2006, a five-year national programme to support NST research infrastructure in six universities in Israel. A total of USD 250 million (EUR 198 million[259]) has been invested by Israeli Universities, private donors and the Israeli government to recruit leading nano-scientists and acquire equipment, facilities and laboratories for six nano-centres at the universities. The first impact was seen at Technion, Israel's Institute of Technology[260, 261], in 2005 (before the official launch of the programme), the other five research universities receiving support in 2006. One of them is the Hebrew University Centre for Nanoscience and Nanotechnology whose focus areas includes nano-optronics for sensing and communication applications and nanomaterials for industrial applications

[251] http://www.nanoisrael.org/
[252] http://www.trdf.co.il/eng/fundinfo.php?id=2846
[253] http://www.economy.gov.il/English/Pages/default.aspx
[254] http://www.moital.gov.il/NR/exeres/111E3D45-56E4-4752-BD27-F544B171B19A.htm
The Magnet programme supports companies and academics to form consortia to research precompetitive generic technologies. Direct funding is up to 66% of the cost of the project with no obligation to repay royalties.
[255] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[256] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[257] Figures for funding under the programme to 2012.
[258] http://www.nanoisrael.org/category.aspx?id=1278
[259] Average yearly conversion rate, 2006 (*source*: www.wolframalpha.com)
[260] The Technion centre was co-funded by the Russel Berrie Foundation via a donation of USD 26 million which, together with funding from Technion itself, the Office of the Chief Scientist and the Ministry of Finance, made up to USD 78 million for the Russell Berrie Institute for Research in Nanotechnology.
[261] Israel Institute of Technology http://www.technion.ac.il/en/

and also has a specialisation in sol-gel-based nanomaterials. Work is also taking place at the Institute of Nanotechnology and Advanced Materials at Bar-Ilan University in several areas, including computers.[262] Furthermore, photonics and electronics is among the research activities of the Ilse Katz Institute for Nanoscale Science & Technology, at Ben-Gurion University, with a specialisation in design, simulation and fabrication of nano-photonic chips and devices.[263]

To help academics and industry to access the facilities of the six Israeli nano centres, the INNI has made available a national nano infrastructure catalogue[264]. The catalogue of equipment includes pricing for the use of the equipment and contact information. Industry users are supported by the university nano-centres to enable them to be effective in using their R&D equipment.

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

5.3.4.2 Saudi Arabia[265]

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

During the implementation of the NNP, nanotechnology centres began to be established, such as the Centre of Excellence in Nanotechnology (CENT) established 2005 at the KFUPM[266]; and the CNT established in 2006 at the KAU[267] that covers the fields of electromechanical (MEMS/NEMS) devices, semiconductors nanomaterials and computational nanotechnology. These centres operated in the context of the multidisciplinary programme of Strategic Priorities for Nanotechnology 2008-2012, put in place by the Saudi Arabian Ministry of Economy and Planning in 2008.

Additional nanoscience and nanotechnology centres followed. The Centre of Excellence of Nano-manufacturing Applications (CENA) was established in 2009 at KACST (active in the area of fabrication of sensors) and the King Abdullah Institute for Nanotechnology (KAIN)[268] established in 2010 at the KSU in the Riyadh Techno Valley. The KAIN covers areas including telecommunications, manufacturing of nanomaterials, energy, medicine and pharmaceuticals, food and environment, and water treatment and desalination. Companies also collaborate on nanotechnology research with the nanotechnology centres.

5.3.4.3 Turkey

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

[262] http://nano.biu.ac.il/research-centers/nano-materials
[263] http://in.bgu.ac.il/en/iki/Pages/Research-Activity1.aspx
[264] http://www.nanoisrael.org/category.aspx?id=13671
[265] A review of nanotechnology development in the Arab World, Bassam Alfeeli et al., Nanotechnology Review, 2013 (05/2013; 2(3):359-377)
[266] King Fahd University of Petroleum and Minerals, Riyadh
[267] King Abdul Aziz University, Jeddah
[268] http://nano.ksu.edu.sa/en

Organisation (SPO) for the period 2007-2013.

Projects in nanotechnology are supported by the Scientific and Technological Research Council of Turkey (TUBITAK) and the Ministry of Development (MoD) and, between 2007 and 2014, it is estimated[269] that nanotechnology received State support of about one billion Turkish Lira, or c. USD 500 million (EUR 367 million[270]). Over 20 nanotechnology research centres, departments and graduate schools have been established including NanoTam[271] (with a research programme on gallium nitride devices) and Unam[272] at Bilkent University (focused on optics and fibre lasers, and nanophotonics); Sabanci University Nanotechnology Research and Application Center (SUNUM)[273]; and the Micro and Nanotechnology Department at the Middle East Technical University[274].

5.4 Oceania

5.4.1.1 Australia

The National Nanotechnology Strategy (NNS) was put in place in 2007 by the Australian Department of Innovation, Industry, Science and Research as a dedicated strategy for nanotechnology, 2007 to 2009. The Australian Office of Nanotechnology was established to co-ordinate the strategy and ensure a whole-of-government approach to nanotechnology issues. A Public Awareness and Engagement Programme formed part of the NNS.

In 2009-2010, the NNS was replaced with a National Enabling Technology Strategy (NETS), a comprehensive national framework for the safe and responsible development of novel technologies (including nanotechnology and biotechnology). With funding over four years of AUS 38.2 million (EUR 28.3 million[275]), the strategy aimed to ensure good management and regulation of enabling technologies in order to maximise community confidence and community benefits from the commercialisation and use of new technology. Public engagement has remained an important topic in Australia for nanotechnology and other novel technologies.

In 2012, the National Nanotechnology Research Strategy[276] was prepared by the Australian Academy of Science, using funding received from the National Enabling Technologies Policy Section in the Department of Industry, Innovation, Science, Research and Tertiary Education. The Research Strategy highlighted the importance of developing the nanofabrication capabilities necessary to have a major impact on all areas of information and communication technology (ICT), for example, through the fabrication of quantum/nanoscale photonic, electronic and electromechanical structures. In addition, it identified Australia as being a world leader in optical fibres (through its Institute for Photonics and Advanced Sensing[277], Institute of Photonics and Optical Science[278] and Australian National Fabrication Facility (ANFF)[279]). The Strategy also identifies Australian strengths in the fabrication of nanomaterials relevant to ICT: structures on silicon (SoS) for nano-electronics and quantum computing applications; fabrication of III-V quantum dots, nanowires, metamaterials, plasmonic structures and photonic crystals for applications in electronics and photonics, including novel sensors; nanostructured glasses for novel optical fibres used for sensors and ICT applications; novel MEMS and nanostructures in II-VI semiconductors and germanium for applications in sensors, nano-photonics and nano-electronics.

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

[269] http://www.issi2015.org/files/downloads/all-papers/0720.pdf
[270] Average yearly conversion rate, 2007-2014 (*source*: www.wolframalpha.com)
[271] http://www.nanotam.bilkent.edu.tr/eng/main.html
[272] http://unam.bilkent.edu.tr/?page_id=576
[273] http://sunum.sabanciuniv.edu/
[274] http://mnt.metu.edu.tr/
[275] Average yearly conversion rate, 2010-2013 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-aud.en.html)
[276] https://www.science.org.au/publications/national-nanotechnology-research-strategy
[277] http://www.adelaide.edu.au/ipas/about/role/
[278] http://sydney.edu.au/ipos/
[279] http://www.anff.org.au/

and the growth of SMEs.

Australia also operates a network to link research facilities across the country, the Australian Nanotechnology Network[280]. The Network was established by bringing together four seed funding networks. It comprises about 1,000 active researchers from universities, institutes and government research organisations, half of whom are students. Its aims are to promote collaboration, increase multidisciplinary awareness and collaboration, foster forums for postgraduate and early career researchers, increase and improve awareness of nanotechnology infrastructure, and promote international links.

5.4.1.2 New Zealand

Nanotechnology strategies in New Zealand began by taking a networking approach and were led by the MacDiarmid Institute for Advanced Materials and Nanotechnology[281]. The Institute, formed in 2002, is a partnership between five Universities and two Crown Research Institutes in Auckland, Palmerston North, Wellington, Christchurch and Dunedin. It was awarded USD 23.2 million (EUR 19 million[282]) funding for 2003-2006 from the Ministry of Education and, in early 2006, developed a "Nanotechnology Initiative for New Zealand"[283] identifying where capability in nanotechnology could be developed in the country. The Initiative identified six programmes for nanoscience and nanotechnology research: nano-photonics, nano-electronics and nano-devices; nanotechnology for energy; nanomaterials for industry; nano- and micro-fluidics; bio-nanotechnologies; and social impacts of nanotechnology.

Also in 2006, the New Zealand government released a Nanoscience and Nanotechnologies Roadmap (2006-2015)[284]. Highlighting international and national research, the Roadmap placed nanotechnology amongst government's strategic priorities, setting high-level directions for nanotechnology-related research and policy in New Zealand. Among the key sectors, some potential areas and type of applications were identified. ICT and electronics and components (including photonic crystals and optical computing) are considered to be key sectors. Three priority areas for public funding were identified: the creation of new materials; diagnostic devices; and tools and techniques. The Roadmap noted the crucial importance of the programme on nano-photonics, nano-electronics and nano-devices, included in the Nanotechnology Initiative for New Zealand. The Ministry of Science and Innovation was put in charge of policy actions to implement the Roadmap.

The Ministry of Science and Innovation *Statement of Intent 2011-14* highlighted two high-level priorities – growing the economy and building a healthier environment and society. In addition to the traditional resource sectors of New Zealand, it sought to capability in knowledge-intensive activities, such as high-technology manufacturing and the services sector. Six priority areas were identified including high-value manufacturing and services, energy and minerals, health and society, as well as biological sciences, hazards and infrastructure, and the environment[285].

5.5 Africa

5.5.1.1 South Africa

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

- In 2002, the formation of the South African Nanotechnology Initiative (SANi)[286] with membership comprising academics, researchers, engineers, private sector companies, and research councils;
- In 2003, the launch of South Africa's Advanced Manufacturing Technology Strategy (AMTS)[287] by the Department of Science and Technology (DST);
- In 2005, the publication of the National Strategy on Nanotechnology (NSN)[288] by the DST. The strategy focuses on four areas:

280 http://www.ausnano.net/index.php?page=home
281 http://www.macdiarmid.ac.nz/
282 Average yearly conversion rate, 2003-2006 (*source*: www.wolframalpha.com)
283 http://www.macdiarmid.ac.nz/a-nanotechnology-initiative-for-new-zealand/
284 http://statnano.com/strategicplans/13
285 http://www.mbie.govt.nz/
286 http://www.sani.org.za/
287 http://www.esastap.org.za/download/natstrat_advmanu_mar2005.pdf
288 http://chrtem.nmmu.ac.za/file/35e56e36b6ab3a98fac6fc0c31ee7008/dstnanotech18012006.pdf

- establishing characterisation centres (national multi-user facilities);
- creating research and innovation networks (to enhance collaboration: inter-disciplinary, national and internationally);
- building human capacity (development of skilled personnel); and
- setting up flagship projects (to demonstrate the benefits of nanotechnology towards enhancing the quality of life, and spurring economic growth).

South Africa launched its first nanotechnology innovation centres in 2007 at the CSIR[289] and MINTEK[290]. Each centre has developed collaborative research programmes, often with other national institutions. These include programmes in designing and modelling of novel nano-structured materials, at the CSIR-National Centre for Nano-structured Materials (NCNSM)[291], and work on the application of nanotechnologies in the fields of water, health, mining and minerals at MINTEK.

In addition to engaging with European researchers through Framework Programmes, South Africa has established international collaboration mechanisms with other developing countries, e.g. the India–Brazil-South Africa (IBSA) partnership[292] enables joint projects and mobility[293] between S&T departments in those countries.

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

[289] http://www.csir.co.za/
[290] http://www.nic.ac.za/
[291] http://ls-ncnsm.csir.co.za/
[292] http://www.ibsa-trilateral.org/
[293] http://www.ibsa-trilateral.org/about-ibsa/areas-of-cooperation/people-to-people

6 PUBLICATIONS IN ICT NANOTECHNOLOGY

6.1 Overview

Around 1.8 million publications were identified[294] from the Web of Science as being related to nanoscience and technology (NST)[295] between 2000 and 2014. Of those, approximately 130,000 were identified as relating to nanotechnology and ICT. This volume of publications is equivalent to over 7% of all of the output for nanoscience and nanotechnology (NST).

The table below shows the publication output between 2000 and 2014. Over 38,000 publications on ICT were produced in EU 28 plus EFTA countries (EU28&EFTA, includes Switzerland and Norway), almost 30% of the total World ICT publications in the time-period 2000-2014. The share of EU28&EFTA has gradually decreased over time from almost 40% to less than 25%.

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

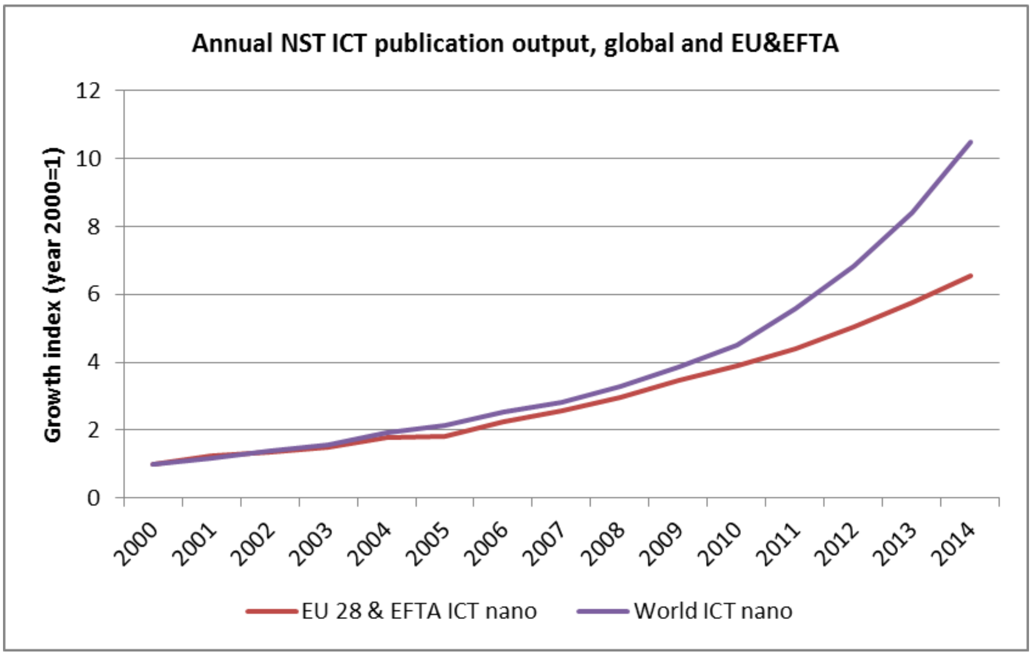
Year	World	EU 28 & EFTA	
	npub	npub	%
2000	2,259	826	36.6%
2001	2,668	1,034	38.8%
2002	3,135	1,122	35.8%
2003	3,562	1,249	35.1%
2004	4,336	1,473	34.0%
2005	4,829	1,489	30.8%
2006	5,716	1,860	32.5%
2007	6,357	2,115	33.3%
2008	7,467	2,456	32.9%
2009	8,697	2,871	33.0%
2010	10,153	3,215	31.7%
2011	12,616	3,625	28.7%
2012	15,463	4,157	26.9%
2013	19,017	4,759	25.0%
2014	23,704	5,411	22.8%
TOTAL	**129,979**	**37,662**	**29.0%**

Source: Derived from Web of Science

There has been a high level of growth in ICT publications as indexed to the year 2000. For the World, there has been almost a ten-fold growth while for the EU28&EFTA, it is around a six-fold growth.

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

[295] Search included all those publications having been produced with "nano" as a core term. The term "nanosecond" has been omitted as not being relevant to the study.



Source: Derived from Web of Science

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

Looking at the EU28&EFTA proportion of world output on ICT, it is seen to have decreased over time, as shown below. This is mainly caused by a sharp increase in the output from China.

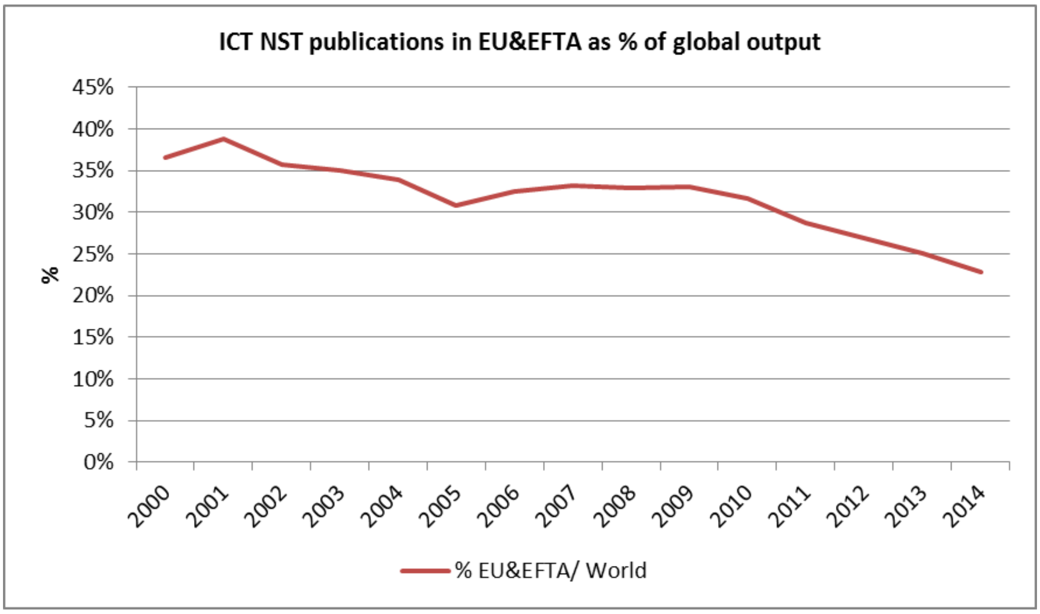


Figure 6-2: NST ICT publications as a percentage of NST World total, 2000-2014

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

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

Rank	Journal	npub
1	Applied Physics Letters	8,185
2	Physical Review B	7,976
3	Journal of Applied Physics	5,144
4	IEEE Transactions on Electron Devices	2,403
5	NANO Letters	2,349
6	Journal of Physical Chemistry C	2,129
7	Physical Review Letters	1,993
8	ACS NANO	1,762
9	Nanotechnology	1,712
10	IEEE Electron Device Letters	1,670

6.2 Activity by region and country

The most prolific region for NST ICT publications in 2014 (the most recent year for data collection) (calculated from the table of the top 25 publishing countries) was Asia, followed at a distance by EU28&EFTA and North America.

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

Region	npub
Asia	14,303
EU28&EFTA	5,411
North America	5,001
Middle East	693
Oceania	645

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

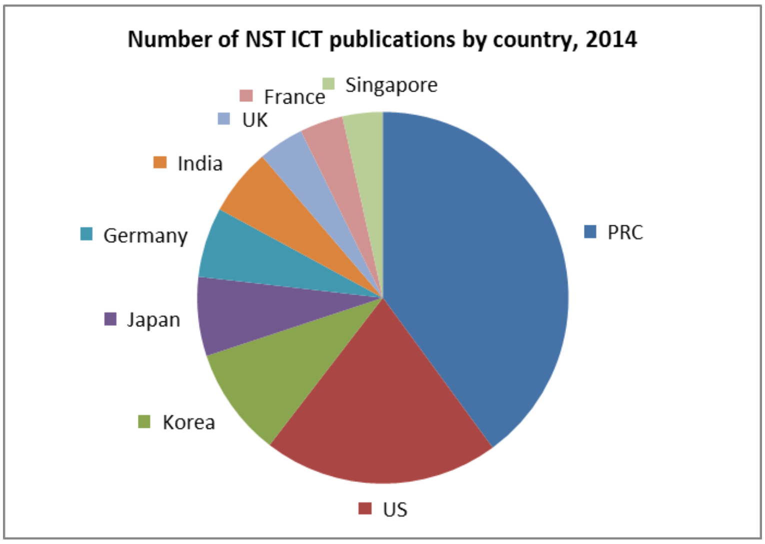


Figure 6-3: Number of NST ICT publications by country (top 9), 2014

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

Country	Region	npub
China (PRC)	Asia	8,997
USA	North America	4,624
South Korea	Asia	2,138
Japan	Asia	1,551
Germany	EU28&EFTA	1,371
India	Asia	1,316
United Kingdom	EU28&EFTA	898
France	EU28&EFTA	850
Singapore	Asia	790
Italy	EU28&EFTA	645
Spain	EU28&EFTA	619
Australia	Oceania	617
Canada	North America	468
Switzerland	EU28&EFTA	326
Sweden	EU28&EFTA	311
Belgium	EU28&EFTA	310
Saudi Arabia	Middle East	298
Netherlands	EU28&EFTA	274
Brazil	South & Central America	268

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

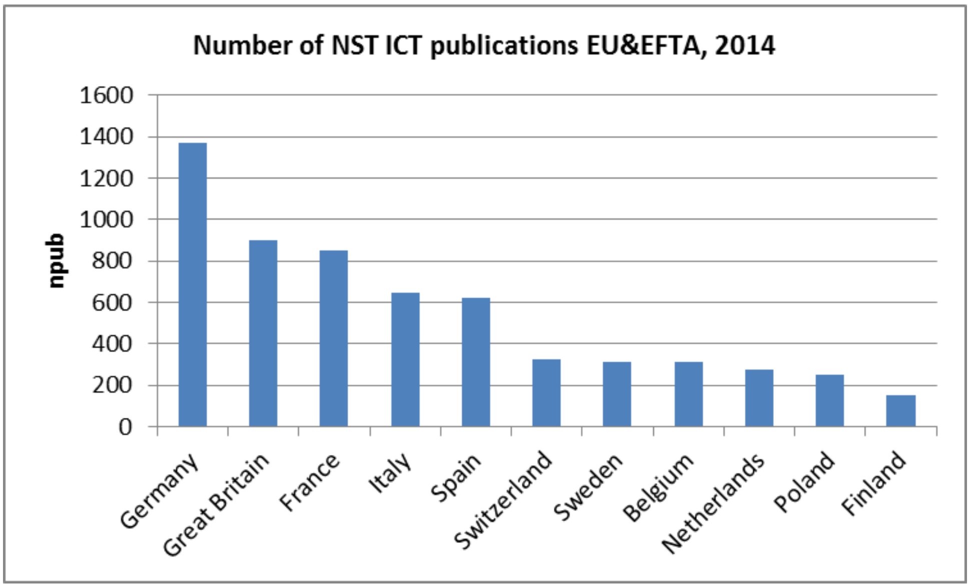


Figure 6-4: Number of NST ICT publications by EU&EFTA countries, 2014
Data for the top NST ICT publishing countries only

6.3 Activity by organisation type

The 25 most active organisations for NST ICT publications (npub) in 2014 are shown in the table below. The higher education organisations with the most nanotechnology ICT publications globally in 2014 were predominantly Asian universities, over half of the 25 organisations being from the People's Republic of China (PRC). The highest performing non-Asian universities were the University of California Berkeley (11th), MIT (15th), the University of Texas Austin (17th) and Stanford University (23rd) (all in the US).

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

	Country	University/ Research Institute	npub
1	PRC	Chinese Academy of Sciences	1,139
2	Singapore	Nanyang Technology University	388
3	PRC	Tsinghua University	375
4	PRC	Peking University	327
5	PRC	University of Science and Technology of China	309
6	PRC	Nanjing University	306
7	Singapore	National University of Singapore	297
8	Korea	Korea Advanced Institute of Science and Technology	273
9	PRC	Zhejiang University	258
10	Korea	Seoul National University	230
11	USA	University of California Berkeley	216
12	PRC	Jilin University	216
13	Korea	Sungkyunkwan University	206
14	Japan	University of Tokyo	200
15	USA	MIT	196
16	PRC	Shanghai Jiao Tong University	192
17	USA	University of Texas Austin	188
18	PRC	Wuhan University	188
19	PRC	Fudan University	186
20	PRC	Huazhong University of Science and Technology	178
21	PRC	Lanzhou University	175
22	Korea	Korea University	174
23	USA	Stanford University	173
24	PRC	Hunan University	172
25	Japan	Tohoku University	170

The higher education organisations (EU28&EFTA) with the most ICT publications in 2014 were the University of Cambridge, EPFL[296], University of Paris XI Sud, IMEC[297] and the Technical University of Dresden, as shown in the table below of the top ten NST publishing organisations for ICT publications.

[296] École Polytechnique Fédérale de Lausanne
[297] Interuniversitair Micro-Elekctronica Centrum Vzw

Table 6-6: Number of ICT publications by EU&EFTA organisation (top ten), 2014

Organisation	Country	npub
University of Cambridge	UK	132
EPFL[298]	CH	121
University Paris XI Sud	FR	105
IMEC[299]	BE	101
Technical University (TU) Dresden	DE	97
University of Manchester	UK	84
Imperial College London	UK	78
Aalto University	FI	77
University of Oxford	UK	76
Polish Academy of Sciences	PL	76

The companies with the most ICT publications globally in 2014 were IBM, Samsung Electronics Co. Ltd., and Nippon Telegraph (NTT) shown in the table of the top ten publishing companies below.

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

Company	npub
IBM Corporation	91
Samsung Electronics Co. Ltd.	45
Nippon Telegraph (NTT)	37
Intel Corporation	31
STMicroelectronics SA	29
Samsung Advanced Institute of Technology	29
Polyera Corporation	18
Diamond Light Source Ltd	16
Hewlett Packard Corporation	14

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

[298] École Polytechnique Fédérale de Lausanne
[299] Interuniversitair Micro-Elekctronica Centrum Vzw

7 PATENTING IN ICT NANOTECHNOLOGY

7.1 Overview

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

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector (and sub-sector, as appropriate)) and IPC (International Patent Classification) numbers. The IPC numbers used were both those for nanotechnology (i.e. B82, or B82Y for manufactured nanomaterials) and those related to the sector under consideration (ICT, health, energy, etc.)[300]. 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[301] applications registered at WIPO are protected under the Patent Cooperation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[302] that are members of the treaty.

7.2 Number and evolution over time of ICT nanotechnology patent families

Using the above methodology, 45,127 (simple) nanotechnology patent families[303, 304] of granted patents and patent applications were found in the period 1993-2011[305]. All were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[306].

In the same period, the number of ICT-related patent families identified among the nanotechnology patents is 5,536, 12.3% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EP and US do not sum to 100%. The highest percentage of applications relating to ICT and nanotechnology is in the US (91.8%) and the lowest at the EPO (35.4%), the difference being almost a factor of three.

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

Nanotechnology and ICT Applications (1993-2011)	Absolute Number	Percentage
Total Patent Families	5,536	100%
PCT Applications	2,521	45.5%
EP Applications	1,960	35.4%
US Applications	5,084	91.8%

[300] 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.
[301] http://www.wipo.int/pct/en/
[302] 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
[303] The definition of simple family is used, in which all documents having exactly the same priority or combination of priorities belong to one patent family (http://www.epo.org/searching/essentials/patent-families/definitions.html). The patent families include at least one PCT, EPO or USPTO patent application.
[304] 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/
[305] This year refers to the oldest year of the priority patents.
[306] While patents can be filed in individual patent offices, many inventors choose to file applications under the Patent Classification Treaty (PCT). All WIPO applications are PCT applications.

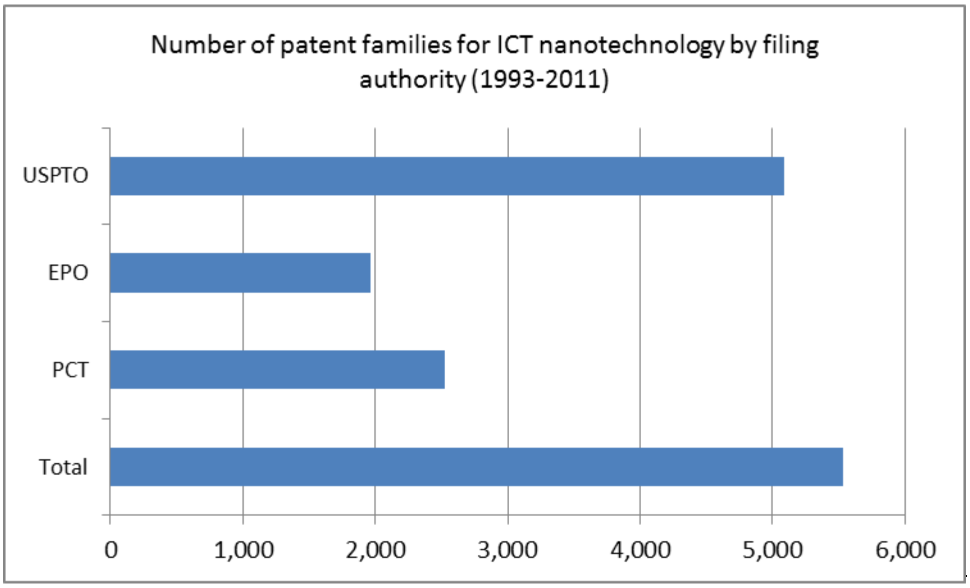


Figure 7-1: Number of patent families by filing authority (PCT, EPO, and USPTO)

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

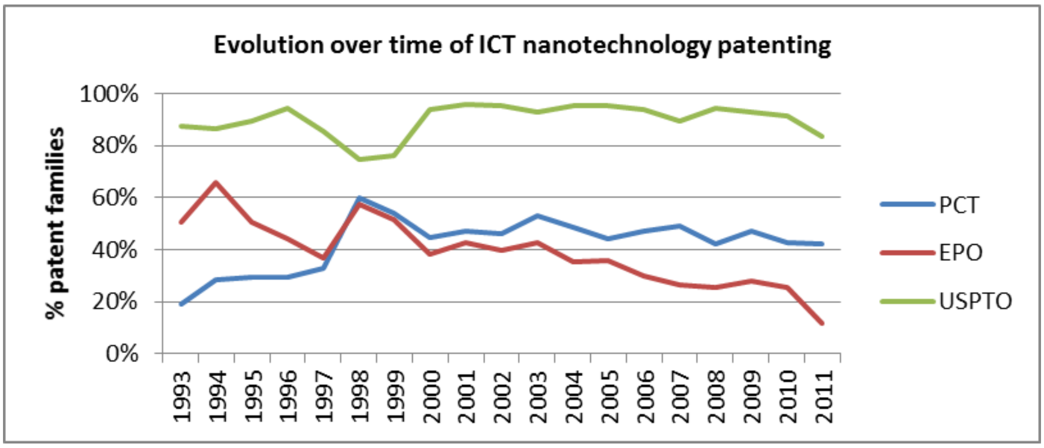


Figure 7-2: Evolution over time of WIPO (PCT), EPO and USPTO ICT nanotechnology patenting

The percentage of ICT nanotechnology patent applications in the EPO has dropped significantly over time, while the percentage has been more stable for USPTO and PCT filings[307]. This trend may indicate that patent filing in the US has remained important while the importance of filing in Europe has decreased.

7.3 Activity by filing country and region

By looking at PCT applications, it is possible to obtain an indication of the relative patenting activity of countries and regions. The top ten patent authorities through which PCT applications were filed are shown in the table, the US being by far the most prolific, followed by Japan, Europe (EPO) and the UK. The sum of the figures for the European patent offices in this top ten table and the EPO is just 427, considerably less than in the US. Even if all the remaining EU countries are allocated the

[307] It should be noted that the cost of applying for a US patent for an extended market is low compared with an EPO patent. There is less scrutiny of a US patent and there is evidence that a higher proportion of US patents are granted for inventions that are not novel, resulting in litigation later.

figure of the lowest European country in the table (France, 59), the total for the EU28 plus the EPO is less than the US.

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

Receiving Authority	No. of Patent Families (1993-2011)
United States	1161
Japan	511
European Patent Office (EPO)	194
United Kingdom	98
International Bureau (WIPO)	97
Germany	76
Korea	68
France	59
Canada	45
Australia	30

7.4 Activity by country of applicant

PATENT APPLICATIONS

Within the group of 5,536 ICT-related nanotechnology patent families, there is one or more EU28 or EFTA applicant in only 20% of them while there is participation from the rest of the world in over 80% of cases.

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

	EU28 & EFTA	Rest of World
Number of ICT nanotechnology patent families	1,020	4,691
Percentage of ICT nanotechnology patent families	18.4%	84.7%

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

By far the highest number of patent families is found where the country of the applicant is the US, followed by two Asiatic countries (Japan and, at considerable distance, Korea). Following these countries, there are European countries with a relatively high number of patent families: Germany (330), and then the Netherlands, the United Kingdom and France with between 175 and 200 patent families each.

Among the countries in the table with lower number of patent families, there are also several European countries, such as Austria (10) and Ireland (8).

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

	Country of applicant	No. of Patent Families	PCT	US	EP
1	United States	2196	58.9%	98.6%	39.2%
2	Japan	1787	30.0%	89.9%	25.4%
3	Korea	422	19.2%	92.7%	19.7%
4	**Germany**	**330**	**67.3%**	**78.5%**	**63.9%**
5	**Netherlands**	**197**	**52.8%**	**88.3%**	**63.5%**
6	**United Kingdom**	**181**	**85.1%**	**79.0%**	**60.2%**
7	**France**	**175**	**60.6%**	**84.0%**	**80.0%**
8	Taiwan (Chinese Taipei)	122	6.6%	100.0%	6.6%
9	Canada	100	67.0%	100.0%	41.0%
10	China	86	36.0%	89.5%	15.1%
11	Australia	56	64.3%	91.1%	48.2%
12	**Belgium**	**47**	**31.9%**	**89.4%**	**85.1%**
13	**Switzerland**	**46**	**76.1%**	**82.6%**	**73.9%**
14	**Sweden**	**42**	**92.9%**	**78.6%**	**64.3%**
15	Israel	42	81.0%	97.6%	45.2%
16	**Italy**	**40**	**60.0%**	**75.0%**	**65.0%**
17	Singapore	39	64.1%	87.2%	35.9%
18	Russian Federation	29	93.1%	65.5%	51.7%
19	**Spain**	**28**	**85.7%**	**67.9%**	**42.9%**
20	**Finland**	**26**	**92.3%**	**80.8%**	**50.0%**
21	India	14	85.7%	78.6%	50.0%
22	**Denmark**	**11**	**100.0%**	**81.8%**	**54.5%**
23	**Austria**	**10**	**50.0%**	**70.0%**	**60.0%**
24	**Ireland**	**8**	**62.5%**	**87.5%**	**37.5%**
25	Hong Kong	7	14.3%	100.0%	0.0%

More than 98% of patents by US applicants are filed with the USPTO while roughly 60% are filed as PCTs. Only 39% are filed by US applicants at the EPO.

There is not a clear preference among the European applicants file more to the EPO, as applicants in some countries seem to file more through other patent authorities (e.g. most of the patent families from Germany or the Netherlands have a US patent application, while other countries like the United Kingdom seem to prefer the PCT route). One explanation for this is that filing as a PCT provides applicants with more time to evaluate their invention and develop their patent before applying for a patent to be granted[308]. For example, 85% of patents have been filed as PCT by UK applicants in the 1993-2011 period for ICT nanotechnology inventions. This compares with UK applicants filing 79% at the USPTO and 60% at the EPO.

[308] In most cases, there are 30 months from the filing date of the initial patent application before an applicant has to begin national phase procedures with individual patent offices. http://www.wipo.int/pct/en/faqs/faqs.html

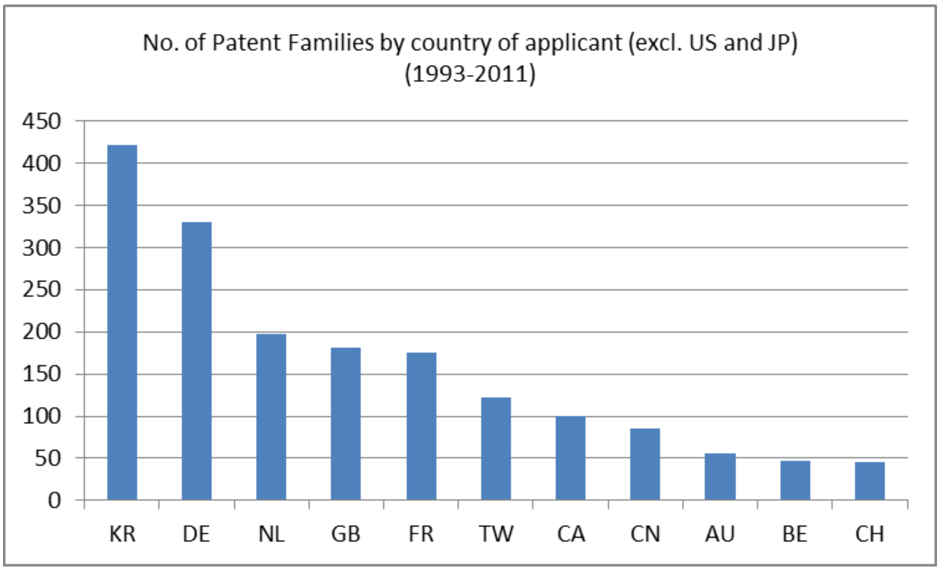


Figure 7-3: Number of patent families by country of applicant (excluding the US and Japan)

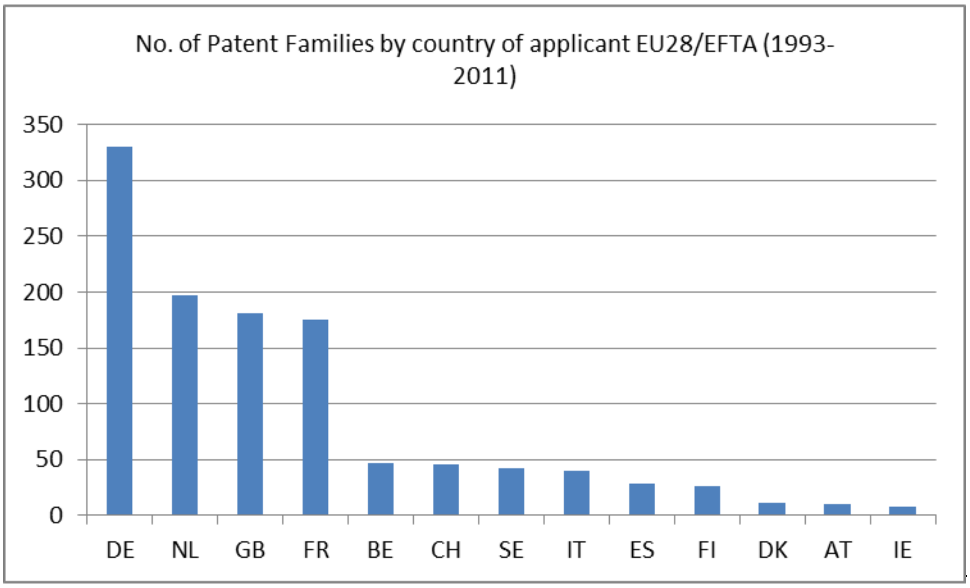


Figure 7-4: Number of patent families by country of applicant EU28/EFTA

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

World ranking	Country of applicant	No. of Patent Families	PCT	US	EP
2	Germany	330	67.3%	78.5%	63.9%
3	Netherlands	197	52.8%	88.3%	63.5%
5	United Kingdom	181	85.1%	79.0%	60.2%
8	France	175	60.6%	84.0%	80.0%
9	Belgium	47	31.9%	89.4%	85.1%
13	Switzerland	46	76.1%	82.6%	73.9%
14	Sweden	42	92.9%	78.6%	64.3%
16	Italy	40	60.0%	75.0%	65.0%
17	Spain	28	85.7%	67.9%	42.9%
19	Finland	26	92.3%	80.8%	50.0%
20	Denmark	11	100.0%	81.8%	54.5%
24	Austria	10	50.0%	70.0%	60.0%

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

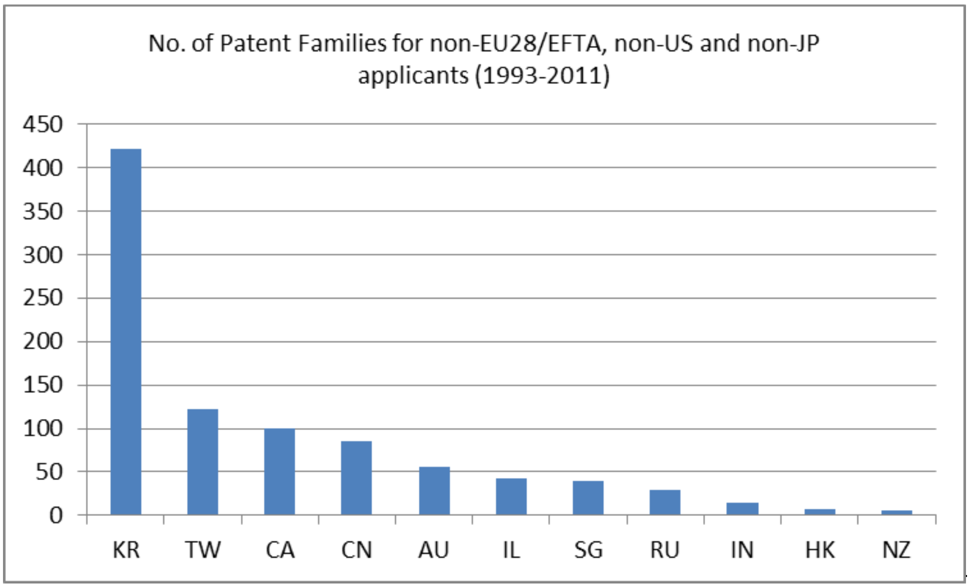


Figure 7-5: Number of patent families by country of applicant for non-EU28/EFTA (excluding the US and Japan)

GRANTED PATENTS

Applicants from the same EU and EFTA countries perform strongly in patents granted, namely those from Germany, France, the Netherlands and the United Kingdom.

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

	Country of applicant	No. of Patents Granted (1993-2011)	
		EPO	USPTO
1	Germany	74	142
2	France	51	90
3	Netherlands	37	108
4	United Kingdom	23	46
5	Italy	8	19
6	Belgium	6	23
7	Switzerland	4	13
8	Sweden	3	13
9	Austria	2	4
10	Norway	2	3
11	Spain	1	7
12	Denmark	1	2
13	Portugal	1	2
14	Finland	0	10
15	Ireland	0	4

These four main countries in terms of granted patents have more patents granted by the USPTO than by the EPO (see red bars in figure below). In some cases, like in Germany, the Netherlands or the UK the number of granted patents by the USPTO is twice as large as the number of patents granted by the EPO.

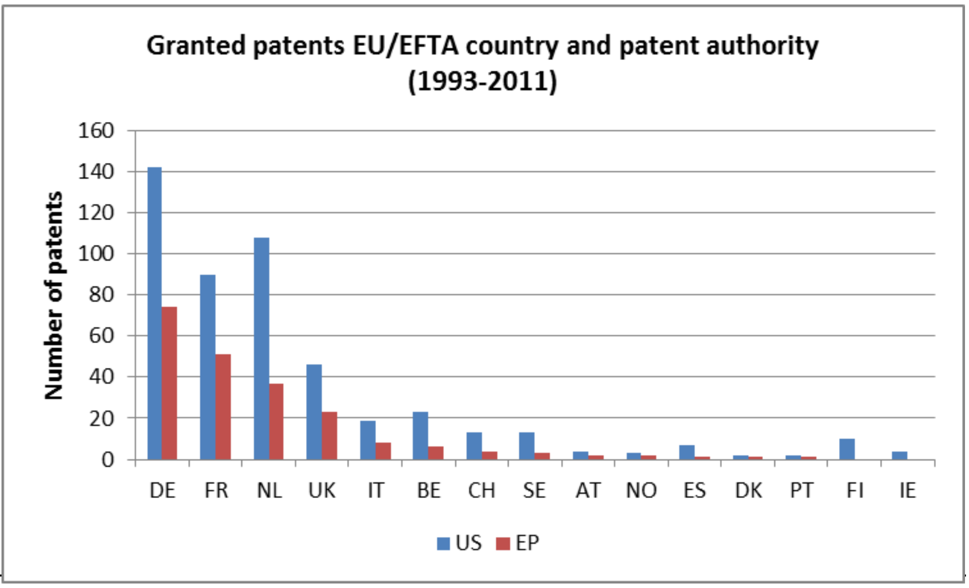


Figure 7-6: Granted patents by country of applicant for EU28/EFTA

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

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

	Country of applicant	No. of Patent Families
1	DE	330
2	NL	197
3	UK	181
4	FR	175
5	BE	47
6	CH	46
7	SE	42
8	IT	40
9	ES	28
10	FI	26

	Country of applicant	No. of Patents Granted
1	DE	216
2	NL	145
3	FR	141
4	UK	69
5	BE	29
6	IT	27
7	CH	17
8	SE	16
9	FI	10
10	ES	8

A very approximate estimate can be made of relative success in patenting between countries of applicants by comparing the number of patent families and the number of patents granted[309]. This shows a high success rate for France and the Netherlands (followed by Italy, Germany and Belgium and Austria with 60% or more).

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

	Country of applicant	Granted/ Applied %
1	France	80.6
2	Netherlands	73.6
3	Italy	67.5
4	Germany	65.5
5	Belgium	61.7
6	Austria	60.0
7	Finland	38.5
8	United Kingdom	38.1
9	Sweden	38.1
10	Switzerland	37.0

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.

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

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

INVT	CA	CH	CN	DE	ES	FR	JP	NL	KR	RU	TW	UK	US
APPL													
CA	92			9	9							5	26
CN		1	81			1	4						19
DE				293		15		11				15	60
FR		6		8		168						5	21
JP			5	6			1752					19	54
NL				14		9	25	91				12	76
KR			8				5		415	6			25
TW			15			1					98		19
UK				8		6	5					139	56
US	35			51			82					32	2068

7.5 Patenting activity by organisation type

7.5.1 Universities and public research organisations

PATENT APPLICATIONS

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

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

Rank	Country	Organisation	No. of patent families	PCT	US	EP
1	**FR**	CEA[310]	110	46.4%	59.1%	36.4%
2	US	University of California	69	66.7%	75.4%	24.6%
3	JP	Japanese S&T Agency	67	80.6%	52.2%	32.8%
4	US	California Institute of Technology	37	51.4%	97.3%	16.2%
5	KR	ETRI[311]	36	8.3%	80.6%	8.3%
6	**FR**	CNRS[312]	35	68.6%	45.7%	71.4%
7	US	MIT[313]	29	82.8%	79.3%	24.1%
8	**BE**	IMEC[314]	28	10.7%	57.1%	64.3%
9	TW	Industrial Technology Research Institute (ITRI)	20	0.0%	100.0%	0.0%
10	US	Rice University	18	72.2%	83.3%	22.2%

[310] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission, FR www.cea.fr
[311] Electronics and Telecommunications Research Institute, Korea
[312] Centre National de la Recherche Scientifique, FR
[313] Massachusetts Institute for Technology, US
[314] Interuniversitair Microelectronica Centrum, BE

Looking at the top 25 performing universities and PROs for patent families, 15 out of 25 are from outside the US, 6 being from the EU28 or EFTA (from France, Belgium, Germany, Spain and the United Kingdom). The tables show the top ten universities and PROs by number of patent families, followed by the top non-US universities and PROs (based on top 25 universities and PROs).

The table below shows the top 18 performing universities and PROs for patent families in EU28/EFTA countries. French organisations perform strongly (the two top organisations), as do organisations in Germany and the UK.

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

Rank	Country	Organisation	No. of Patent families	PCT	US	EP
1	FR	CEA[315]	110	46.4%	59.1%	36.4%
2	FR	CNRS[316]	35	68.6%	45.7%	71.4%
3	BE	IMEC[317]	28	10.7%	57.1%	64.3%
4	DE	Fraunhofer-Gesellschaft	11	36.4%	27.3%	18.2%
5	ES	CSIC[318]	11	81.8%	0.0%	18.2%
6	UK	Cambridge University	9	100.0%	22.2%	22.2%
8	FI	VTT[319]	9	44.4%	44.4%	44.4%
7	BE	KU Leuven	8	25.0%	50.0%	50.0%
9	UK	University of Glasgow	5	60.0%	40.0%	60.0%
10	UK	University of Oxford (ISIS Innovation)	4	75.0%	50.0%	50.0%

GRANTED PATENTS

Of the top 15 universities and research organisations, four are from the EU28/EFTA countries (as shown in the first of the two tables below which is ranked by the highest number of EPO patents granted between 1993 and 2011). Seven of the organisations are from the US.

Ranking by the number of USPTO patents granted between 1993 and 2011, six of the top 15 universities and research organisations are in the US with just three in the EU28/EFTA (CEA, IMEC and CNRS). See second table below.

[315] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[316] Centre National de la Recherche Scientifique
[317] Interuniversitair Microelectronica Centrum
[318] Consejo Superior de Investigaciones Cientificas, the Spanish National Research Council www.csic.es
[319] Teknologian Tutkimuskeskus, Technical Research Centre of Finland www.vtt.fi

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

Rank	Country	Organisation	EP	US
1	**FR**	CEA	16	43
2	**FR**	CNRS[320]	12	13
3	**BE**	IMEC	7	19
4	JP	Japanese S&T Agency	5	30
5	US	Rice University	3	12
6	US	California Institute of Technology	2	34
7	US	Stanford University	2	11
8	US	Northwestern University	2	9
9	US	Wisconsin Alumni Research Foundation	2	4
10	**DE**	Fraunhofer-Gesellschaft	2	2
11	KR	Korea University	2	2
12	JP	Kyoto University	2	1
13	US	University of California	1	31
14	KR	Electronics and Telecommunications Research Institute	1	24
15	US	MIT	1	21

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

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

[320] Centre National de la Recherche Scientifique

7.5.2 Activity of companies

PATENT APPLICATIONS

Of the top ten companies with the highest number of patent families (with percentages for PCT, US and EP applications), five are in Japan and three the United States. Germany is the only EU28 country that features in the table, marked in bold. It should be noted that some may be holding companies rather than research companies or manufacturers.

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

	Country	Company	No. of Patent families	PCT	US	EP
1	JP	Toshiba	239	5%	98%	7%
2	KR	Samsung	194	5%	80%	21%
3	US	IBM Corp	169	43%	94%	25%
4	JP	TDK Corp	159	13%	96%	16%
5	US	Hewlett Packard Co	133	44%	64%	52%
6	JP	Sony Corp	129	26%	87%	30%
7	JP	Fujitsu Ltd	122	23%	87%	0%
8	JP	Hitachi	121	17%	83%	14%
9	US	Seagate	87	29%	87%	2%
10	**DE**	Infineon Technologies	85	48%	74%	39%

Table 7-15: Number of patent families for top ten non-US companies (1993-2011)

World rank	Country	Company	No. of Patent families	PCT	US	EP
1	JP	Toshiba	239	5%	98%	7%
2	KR	Samsung	194	5%	80%	21%
4	JP	TDK Corp	159	13%	96%	16%
6	JP	Sony Corp	129	26%	87%	30%
7	JP	Fujitsu Ltd	122	23%	87%	0%
8	JP	Hitachi	121	17%	83%	14%
10	DE	Infineon Technologies	85	48%	74%	39%
11	NL	Hitachi Global Storage Technologies BV	83	0%	84%	25%
12	JP	Matsushita Elect Co Ltd	71	62%	66%	34%
13	JP	Fujifilm Corp	66	11%	79%	42%
14	NL	Philips	65	91%	51%	0%
15	JP	NEC Corp	63	60%	73%	17%

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[321]. 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.

[321] 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.

Companies from the US and South Korea are among the organisations with highest number of patents granted by the EPO. Infineon Technologies (Germany) and Philips (the Netherlands) are the fourth and fifth companies. Another Dutch company (NXP) is also in the table, with a significant number of EPO patents granted.

Table 7-16: Number of patent families for top ten non-US companies (1993-2011)

Country	Company	EP	US
US	IBM	23	139
US	Hewlett Packard Co	20	84
KR	Samsung	18	106
DE	Infineon Technologies	17	57
NL	Philips	15	9
US	EI Du Pont de Nemours & Co	12	27
JP	Fujitsu Ltd	11	72
NL	NXP BV	10	9
JP	Seiko Instruments	9	7
JP	Toshiba	8	194

Table 7-17: USPTO and EPO granted patents by company (sorted by US patents)

Country	Company	US	EP
JP	Toshiba	194	8
US	IBM	139	23
JP	TDK Corp	126	8
KR	Samsung	106	18
JP	Hitachi	97	8
JP	Sony	94	7
US	Hewlett Packard	84	20
JP	Fujitsu	72	11
NL	Hitachi Global Storage Technologies BV	68	8
US	Seagate	66	2

Interestingly, five of the top 10 the companies with the highest number of patents granted by the USPTO are Japanese while three are from the US. The Netherlands is the only EU28 country represented in the table (Hitachi Global Storage Technologies BV).

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

8 INDUSTRY AND NANOTECHNOLOGY FOR ICT

As a proxy for the nanotechnology ICT industry, this section initially presents secondary data on the sectors of manufacturing industry for ICT in which nanotechnology is most commonly found. While not specific to nanotechnology, it indicates the value of the sector, one in which nanotechnology is commonly used, in terms of the number of enterprises, turnover[322], production value[323] and value added[324], and employment numbers, as well as expenditure on research and development (R&D).

Later in the section, information is presented about (micro- and) nano-electronics industry.

8.1 Overview of the ICT industry

Following the OECD definition[325], the ICT sector includes both manufacturing, trade and services sub-sectors. For this report, only the ICT manufacturing sub-sectors are taken into account and within this sub-set only the following sub-sectors, given the scope of nanotechnology in ICT:

- Manufacture of electronic components and (loaded) boards (NACE Rev.2. 26.1);
- Manufacture of computers and peripheral equipment (NACE Rev.2. 26.2); and
- Manufacture of magnetic and optical media (NACE Rev. 2.26.9).

8.1.1 Number of EU ICT manufacturing enterprises

In 2012, a total of 16,640 firms were active in the above manufacturing sectors, of which most (60%) were active in the manufacture of electronic components and boards. The table below shows the number of enterprises for the above three types of ICT manufacturers[326]. The manufacture of electronic components and boards is the biggest sector, in terms of numbers of enterprises, value added and employment. The manufacture of magnetic and optical media is rather small (454 firms in 2012).

Table 8-1: Number of manufacturing enterprises involved in ICT manufacturing

Manufacturing	2005	2006	2007	2008	2009	2010	2011	2012
Electronic components and boards	:	:	:	10,500	10,000	10,333	10,272	9,986
Computers and peripheral equipment	:	:	:	6,970	:	7,000	6,045	6,200
Magnetic and optical media	:	:	:	426	418	473	410	454
Total	:	:	:	17,896	:	16,788	16,727	16,640

Note: 2005 – 2011: EU-27; 2012-2014: EU-28
Source: Eurostat, Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)

8.1.2 Turnover, production and value-added in EU ICT manufacturing

The ICT industry consists of many SMEs and a relatively small number of large enterprises, only 1.45% of the enterprise having more than 250 people employed.

Although many numbers are missing in the period 2005 – 2012, the table below confirms the general

[322] Turnover is defined in these statistics as market sales of goods or services supplied to third parties (Source: Eurostat).
[323] Production value measures the amount actually produced by the unit, based on sales, including changes in stocks and the resale of goods and services (Source: Eurostat).
[324] Value added is the gross income from operating activities after adjusting for operating subsidies and indirect taxes. Value adjustments (such as depreciation) are not subtracted (Source: Eurostat).
[325] OECD Information Economy–Sector definitions based on the International Standard Industry Classification (ISIC 4) available at http://www.oecd.org/science/scienceandtechnologypolicy/38217340.pdf), Annex 1, pg. 15.
[326] EUROSTAT (2015) Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)

assessment of the European ICT sector by the Joint Research Centre - Institute for Prospective Technological Studies (JCR-IPTS) in the PREDICT 2015 report[327].

Overall, the whole ICT sector value-added amounted to EUR 516.5 billion in 2012, representing a share of 3.99% of EU GDP. ICT services contributed by far the largest share of ICT sector value added (92.27% in 2012), accounting for 3.68% of EU GDP, but the ICT manufacturing value added contributed only 7.73% of ICT sector value added totalling 0.31% of GDP. Since 2006, the share of ICT manufacturing value added has dropped significantly from 12.18% in 2006 to 7.73% in 2012.

Table 8-2: Turnover, production value and value added of ICT manufacturing enterprises

Manufacturing	2005	2006	2007	2008	2009	2010	2011	2012
Turnover value in million EUR								
Electronic components and boards	:	:	:	74,310	:	70,000	67,663	58,734
Computers and peripheral equipment	:	:	:	46,838	37,392	30,000	30,226	31,032
Magnetic and optical media	:	:	:	:	281	271	245	330
Total	:	:	:	:	:	100,271	98,222	90,096
Production value in million EUR								
Electronic components and boards	:	:	:	65,888	47,708	:	59,470	51,846
Computers and peripheral equipment	:	:	:	41,101	:	27,065	26,403	:
Magnetic and optical media	:	:	:	:	270	231	226	265
Total							86,114	
Value added in million EUR								
Electronic components and boards	:	:	:	19,431	:	19,000	:	16,437
Computers and peripheral equipment	:	:	:	7,260	5,463	5,795	5,350	5,867
Magnetic and optical media	:	:	:	:	74	77	77	70
Total						24,872		22,374

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

The value-added of ICT manufacturing decreased significantly in the period 2008 – 2012 (annual growth rates between -6% and -23 %), with only a small recovery in 2010. This shows that ICT manufacturing has suffered more from the downturn of economic activity than ICT services, and it continued to decrease in 2012 after a short revival in 2010.

Within the ICT manufacturing, as defined above, the manufacturing of electronic components and boards has the largest share with a value added share of 0.13% of GDP in 2012.

[327] Matilde Mas and Juan Fernández de Guevara Radoselovics (2015) THE 2015 PREDICT REPORT. An Analysis of ICT R&D in the EU and Beyond, EUR 27510 EN – Joint Research Centre – Institute for Prospective Technological Studies

8.1.3 Employment in EU ICT manufacturing

PREDICT 2015 reports that the *total* ICT sector in 2012 employed 6.18 million people, representing 2.76% of total employment. This employment is highly concentrated in ICT services (87%), implying an employment of about 800,000 in manufacturing. Overall, ICT sector employment increased by 0.97% from 2011 to 2012, but this figure represents job losses in ICT manufacturing (-3.96%) and job creation in ICT services (1.75%).

Also the three ICT manufacturing subsectors considered in this report show substantial job losses in the period 2008 –2012 (see table below) amounting to 380,000 people employed in 2012.

In 2012, the large enterprises (employing 250 or more people) in the ICT manufacturing (three subsectors) employed 52% (1,963,000 people) of the total ICT manufacturing (three subsectors) workforce in the EU28 and generated 68% of the total turnover and 63% of the total value added in 2012.

Table 8-3: Employment in EU manufacturing enterprises involved in ICT

Manufacturing	2005	2006	2007	2008	2009	2010	2011	2012
Number of people employed (‘00s)								
Electronic components and boards	:	:	:	3,400	3.010	3.080	3,010	2,928
Computers and peripheral equipment	:	:	:	1,154	947	930	870	859
Magnetic and optical media	:	:	:	28	21	17	:	16
Total	:	:	:	4,582	3,978	4,027	:	3,803

According to the PREDICT 2015 report, Germany (24.98%) dominated ICT manufacturing (full sub-set), followed by Italy (15.80%), the UK (13.28%), Sweden (9.00%) and France (7.09%). The thirteen new Member States contributed more to ICT sector value added in ICT manufacturing (12.23%) than in ICT services (7.36%), probably because of the offshoring of activities towards these new Member States.

For the three ICT manufacturing subsectors discussed in this report, the highest value added came from Germany (25%), France (15%), United Kingdom (12%), Italy (11%) and Ireland (9%) in 2012. Ireland was the most specialised Member State with both manufacturing of electronic components and boards and manufacturing of computers and peripheral equipment, contributing 1.5% of the Irish non-financial business economy value-added in 2010. The Czech Republic is the most specialised Member State in the manufacturing of magnetic and optical media. Germany employed the largest number of people with over 99,500, followed by France (52,200), Italy (45,000) and the United Kingdom (37,600). Hungary, Poland, Romania and the Czech Republic also have a relatively large share in employment (3% to 6%).

8.1.4 EU Business R&D expenditures in ICT manufacturing

The PREDICT 2015 report shows that in 2012, the total ICT sector business R&D expenditures (BERD) amounted to 28.87 billion euros, 3.42% more than in 2011 in nominal terms, which meant a growth of 1.05% in real terms. This amount was divided between manufacturing (EUR 11.80 billion) and services (EUR 17.07 billion).

The ICT sector is one of the most R&D-intensive sectors in the EU economy. In 2012, the total ICT sector BERD made up 16.87% of total BERD, while ICT sector value added represented only 3.99% of GDP. The ICT manufacturing sector is much more R&D intensive than ICT services; more than 8 times higher.

Looking at business R&D expenditures (BERD) in the three subsectors relevant for this report, these subsectors spent EUR 4.67 billion on R&D in 2012 (based on figures for individual Member States). In 2012, 35% of ICT manufacturing BERD was invested in Manufacturing of electronic components and boards (EUR 4.12 billion). The manufacture of electronic components and boards has the second highest R&D intensity (24%, BERD/value added) in the total ICT sector.

According to Eurostat[328], the German ICT manufacturing industry (three subsectors) had the largest EU business R&D expenditures (EUR 2.14 billion), followed by France (EUR 968 million) and Italy (EUR 589 million).

According to the PREDICT 2015 report, in 2012, 10% of employees in the EU ICT manufacturing were R&D personnel. Manufacture of computers (9.59%) and Manufacture of electronic components (8.59%) belong to the ICT subsectors that have the highest R&D intensity.

8.1.5 Innovative EU ICT manufacturing enterprises

From the Community Innovation Survey (CIS) 2012[329], the EU28 includes 8,259 firms in manufacturing of computer, electronic, and optical products (NACE Rev 2. 26) that considered themselves to be innovative firms (80% of these manufacturing firms in the CIS data). Of these innovative firms, 7,339 are product and/or process innovative firms (of which 2,192 are only product and/or process innovative firms).

8.2 Nanotechnology in the ICT industry

The use of nanotechnology in ICT and in electronic components and devices (such as computer processors, memory storage), is also referred to as nano-electronics. Micro- and nano-electronics are selected as one of the six Key Enabling Technologies. Micro- and nano-electronics are often mentioned as semiconductor manufacturing, but it is also very much related to design technology, cyber-physical systems and systems integration. Nevertheless, when discussing the value and impact of micro- and nano-electronics, it is mainly referring to the semiconductor ecosystem.

In its European Industrial Strategic Roadmap for Micro- and Nano-Electronic Components and Systems (2014), the Electronic Leaders Group presents the micro- and nano-electronic system value chain and its breakdown into sub-systems, components and their materials, along with the value of production and market share won by Europe (see figure below). According to them, the industry in Europe has a 20% share at level 1 (equipment and materials) and a 9% at level 2 (semiconductors and other components).

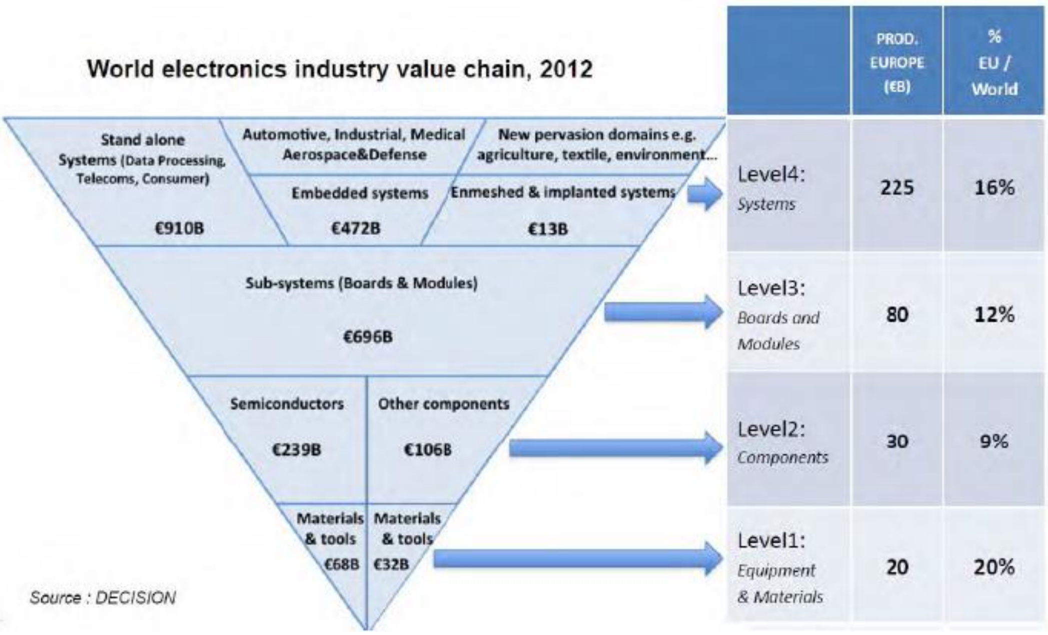
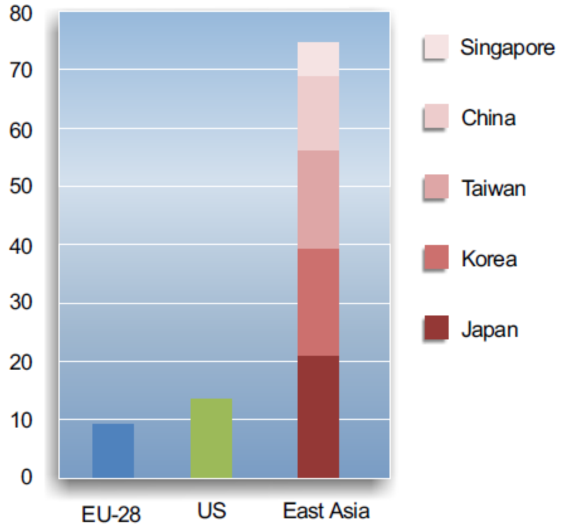


Figure 8-1: Europe in the electronics value chain

[328] EUROSTAT (2015) Business enterprise R&D expenditure (BERD) by economic activity (NACE Rev. 2)
[329] http://ec.europa.eu/eurostat/web/science-technology-innovation/data/database

Moreover, in terms of value generated from the whole supply chain (including design, equipment, and material as well as from fab-less and virtual components activities), Europe's share of value produced in 2012 is between 10 and 11% of the world market (see also figure below).



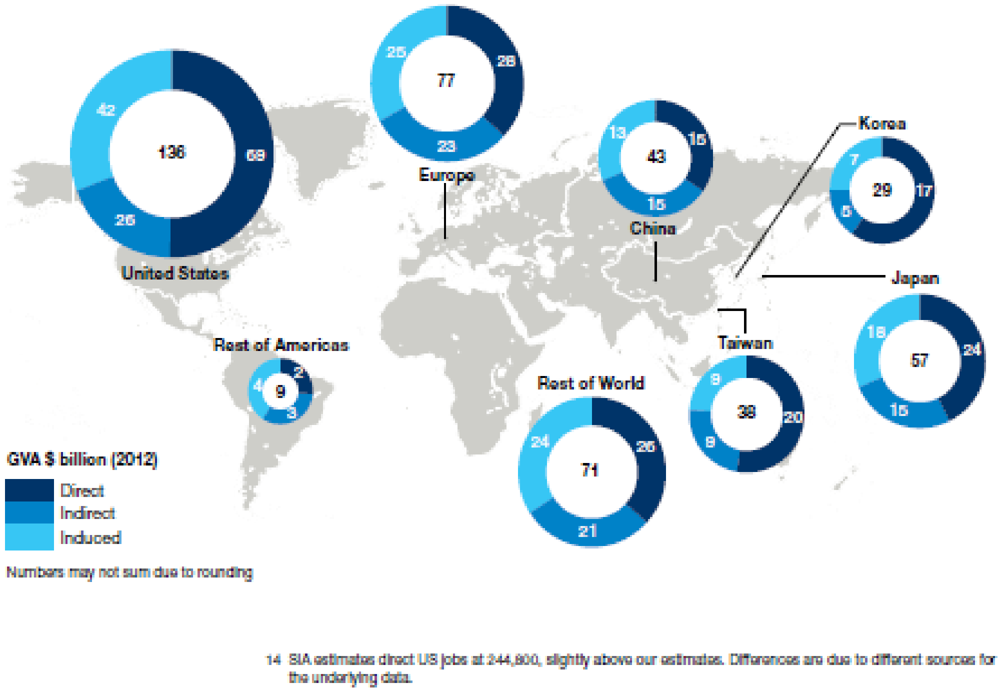
Source: SEMI Fab Database – Special Evaluation for the KETs Observatory - NIW illustration

Figure 8-2: Share of production capacity by country of Fab Location in 2013

(in Waferstarts per month; 8 inches equivalent) – KETs Observatory – First Annual Report, May 2015

Oxford Economics[330] calculated the value added of European semiconductor industry at USD 24.2 billion, but when including the indirect (in the value chain) and induced impact (on other industries) the value added is estimated at USD 77 billion in 2012. The figure below puts the European position in a global perspective. Europe has a share of 13.8% in the global value added directly generated by the semiconductor industry.

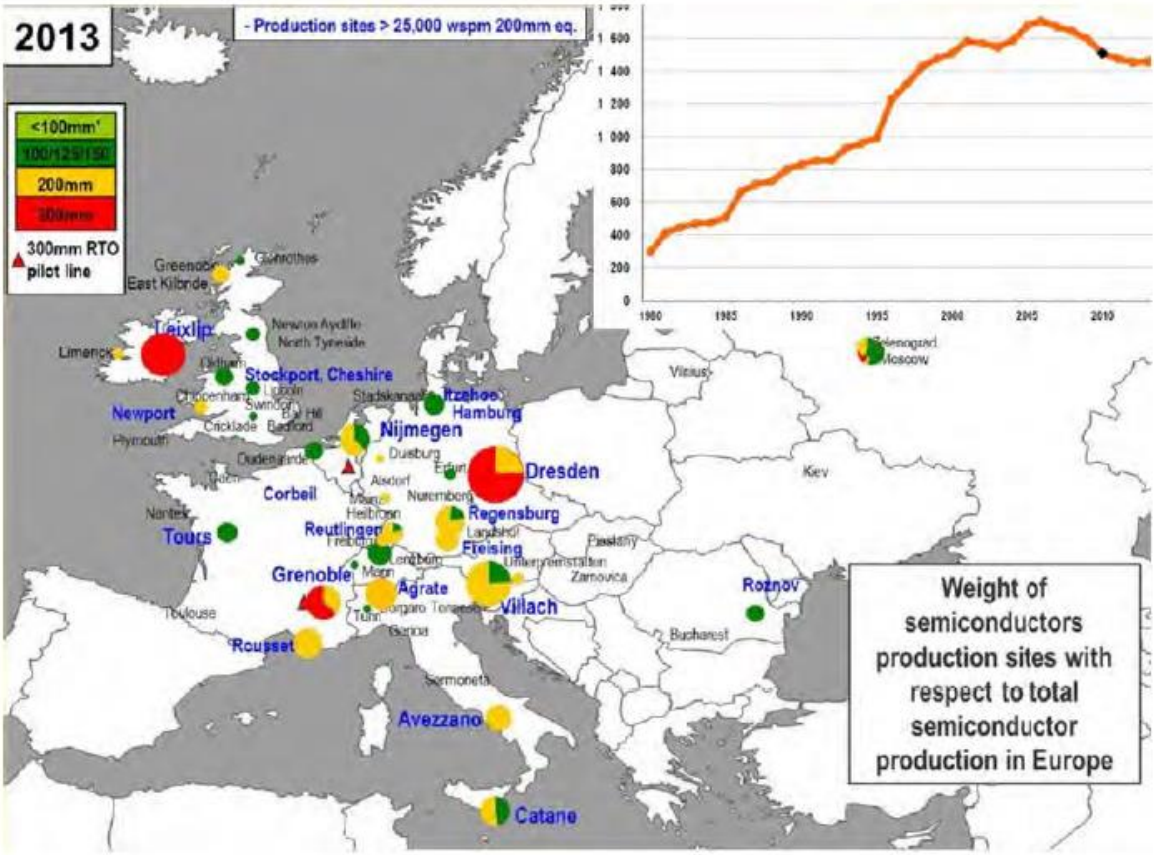
Oxford Economics (2014) Enabling the Hyperconnected Age: The role of semiconductors, prepared for the Global Semiconductor Alliance



Source: Oxford Economics

Figure 8-3: GDP impacts of semiconductor industry worldwide

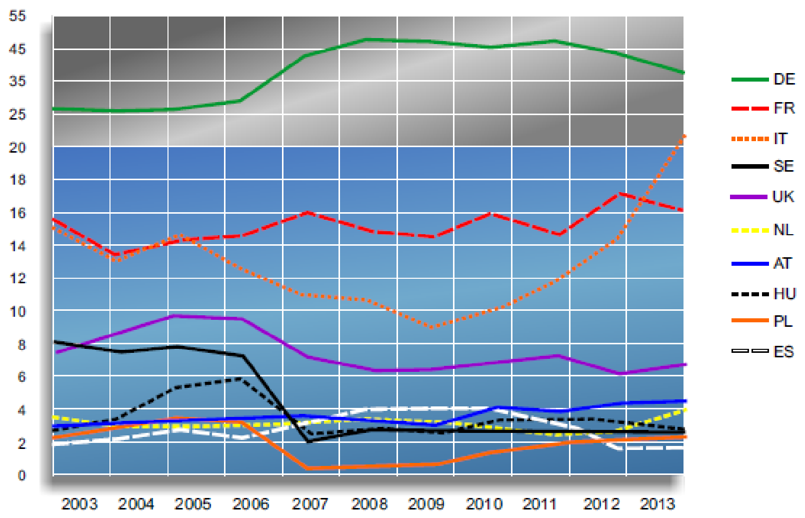
According to the European Industrial Strategic Roadmap for Micro- and Nano-Electronic Components and Systems (2014), the European semiconductor manufacturing industry is based in a large number of sites, but high volume manufacturing of leading edge technologies is centred on a few clusters (see the figure below). The inset in the figure below shows that the annual output in equivalent 200mm wafer starts per months in Europe has grown over two decades, but is now in decline.



Source: European Industrial Strategic Roadmap for Micro- and Nano-Electronic Components and Systems (2014), the Electronic Leaders Group: based on Gartner, Yole, SEMI.

Figure 8-4: Semiconductor manufacturing landscape in Europe in 2013

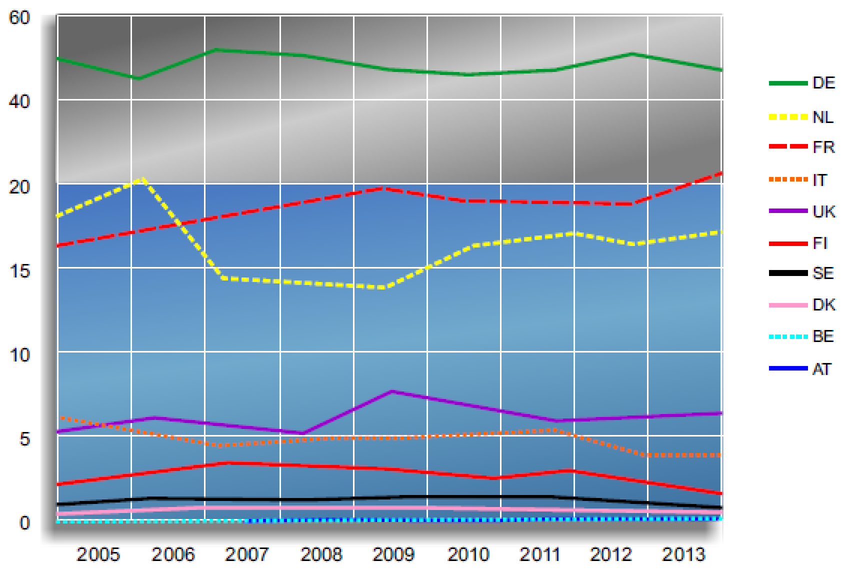
According the first Annual Report of the KETs Observatory (May 2015), Germany holds the highest share of production in micro-and nano-electronics, although they experienced a decline in 2012 and 2013 mainly due to the lower production of photosensitive semiconductor devices as used in photovoltaics as a result of lower public subsidies for PV panels in several EU countries. Italy has increased its share of production, surpassing France. The production share of the UK and Sweden is getting smaller (see figure below).



Source: KETs Observatory – First Annual Report, May 2015[331]

Figure 8-5: Share of production for the top 10 EU-28 countries in Micro- and Nanoelectronics (%)

Germany has also the largest European share in turnover in micro- and Nano electronics (50% in 2013) (turnover at headquarters level). France follows with 20% with the Netherlands in the third position with 17.5%. See also the figure below.



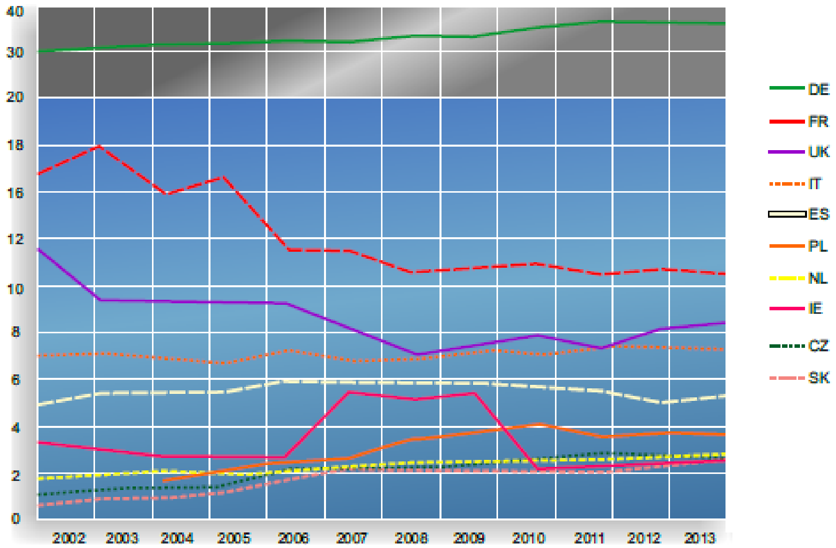
Source: KETs Observatory – First Annual Report, May 2015[311]

Figure 8-6: Share of turnover for the top 10 EU-28 countries in Micro- and Nanoelectronics (%)

In its second report (December 2015), the KETs Observatory focused on the extent to which the EU is using the potential of KETs to manufacture KETs-based products and applying KETs in production processes, covering a large part of the value chain. Following this approach, micro- and nano-electronics enabled an EU production volume of EUR 306 billion in 2013. Germany, France, the UK

[331] Including the 10 EU-28 countries with the highest share of production in the respective KET with respect to the production of all 28 countries. Original source: PRODCOM database – IDEA Consult calculation

and Italy hold the top positions in terms of share of production. Spain and Poland also show considerable activity in this area.



Source: KETs Observatory – Second Report, December 2015[332]

Figure 8-7: Share of KETs-enabled production for the TOP 10 EU-28 countries in Micro- and Nanoelectronics (%)

Estimates of the European workforce employed by the semiconductor industry differ substantially, depending on which part of the value chain is included. Oxford Economics estimates the semiconductor workforce at 105,000 employees, which is similar to the workforce in Japan and Korea, but half the workforce in China or the US. The figure below shows the global distribution of the semiconductor workforce in 2012, according to Oxford Economics (2014).

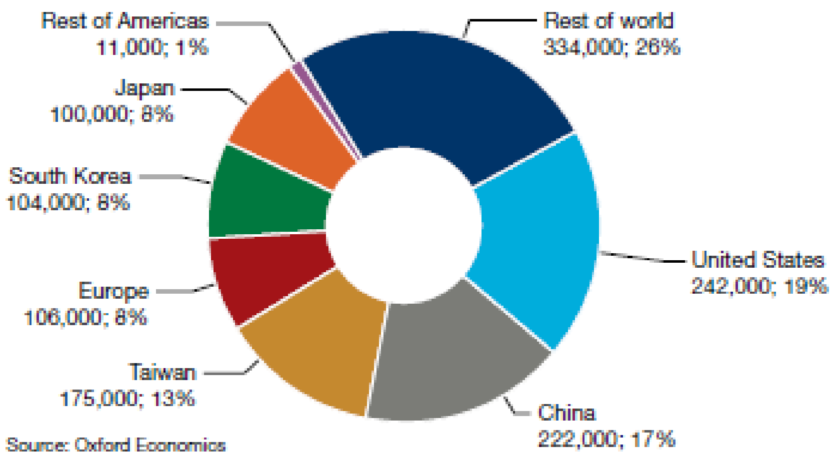


Figure 8-8: Geographic distribution of direct employment in the semiconductor industry

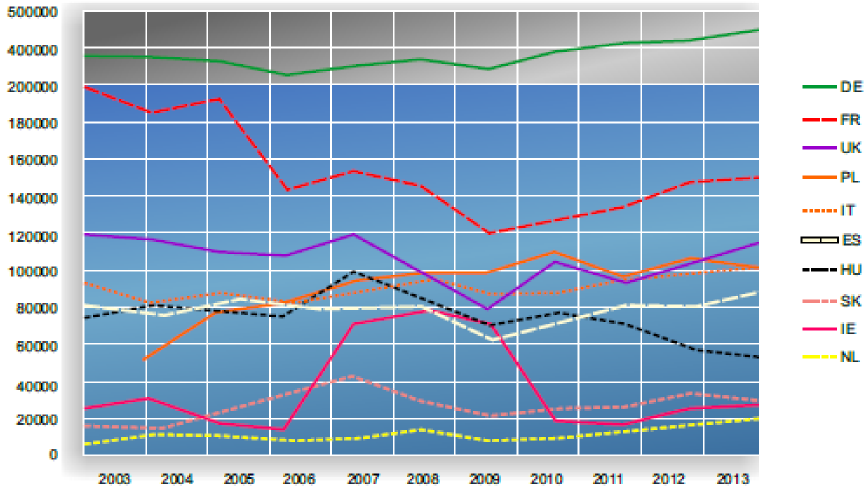
Other estimates, mentioned in various European industry strategy reports, amount to 200,000 to 250,000 people employed in the European semiconductor 'ecosystem' and 800,000 people engaged in the integration of components into systems, applications and services, and further 2,500,000

[332] Original source: PRODCOM database and Eurostat – TNO calculation

people involved in the complete components value chain[333].

The KETs Observatory also calculated employment figures. In its second report (December 2015), it estimated KETs-enabled employment[334] in the micro- and nano-electronics to be around 1.4 million jobs in 2013. Germany has the highest absolute employment (430,000 employees), followed by France (150,000). France lost about 25% of KETs employment in the last decade.

The UK, Poland, Italy and Spain also have relatively high employment figures. In addition, Hungary and Slovakia are also among the top ten leading countries in terms of absolute employment. Together with Ireland, these countries also lead when looking at the share in employment (dividing the total employment in the respective KET in a certain country by the total employment of all countries). This implies that micro-and nano-electronics is rather important compared to overall industrial activity taking place in these countries.



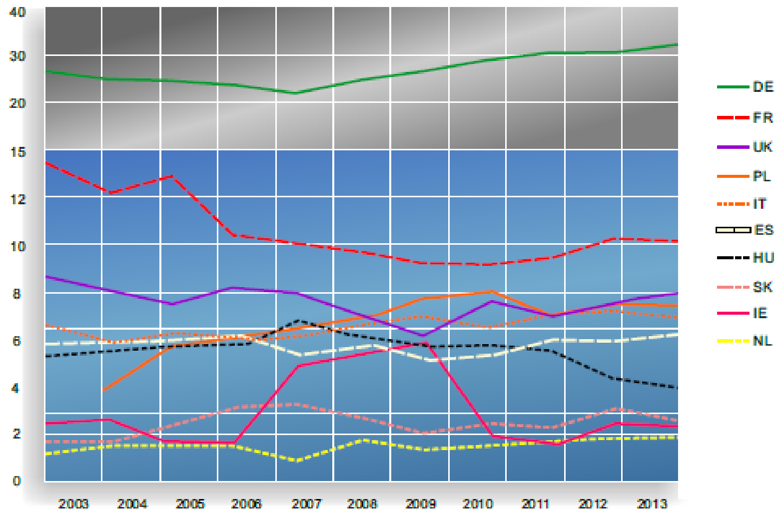
Source: KETs Observatory – Second Report, December 2015[335]

Figure 8-9: Absolute KETs-enabled employment for the TOP 10 EU28 countries in in Micro- and Nano-electronics

[333] E.g.: European Industrial Strategic Roadmap for Micro- and Nano-Electronic Components and Systems (2014), the Electronic Leaders Group; Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (2013) A European Strategy for Micro- and Nano-electronic Components and Systems; Aeneas & Catrene (2012) Innovation for the future of Europe: Nano-electronics beyond 2020; http://europa.eu/rapid/press-release_MEMO-13-451_en.htm ;

[334] Direct employment linked to manufacturing of KETs based products and Indirect employment linked to research activities performed in companies and technical services. Upstream R&D jobs of service providers or public R&D institutes are excluded.

[335] Original source: PRODCOM database and Eurostat –Fraunhofer ISI calculations



Source: KETs Observatory – Second Report, December 2015[335]

Figure 8-10: Share in KETs-enabled employment, top ten EU28 countries in micro- and nano-electronics

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

9 PRODUCTS AND MARKETS FOR ICT THROUGH NANOTECHNOLOGY

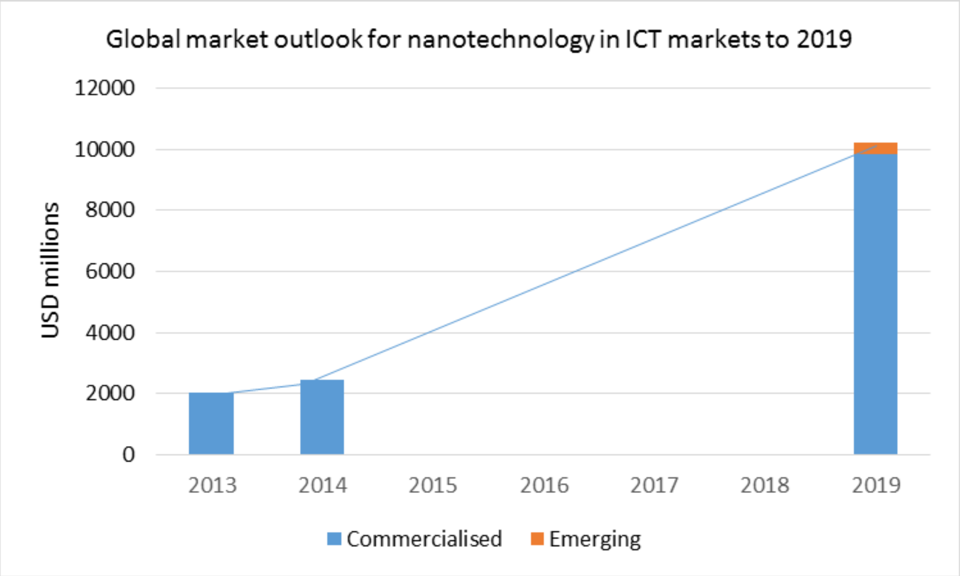
9.1 Introduction

The commercial applications of nanotechnology in the field of ICT include: nanotechnology-enabled data storage technologies (e.g. hard disc media and computer memory); materials to make ICT (e.g. conductive inks for printed electronics); materials to enhance ICT (e.g. electro-conductive coatings); and nanotechnology-enabled components (e.g. multilayer ceramic capacitors and magnetic nanocomposites). A future market is anticipated in novel technology applications such as spin waves, spintronics, and quantum dot technologies.

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

9.2 Global markets and forecasts for ICT products using nanotechnology

Global sales for nanotechnology products in the ICT sector were estimated to be USD 2 billion in 2013 and are forecast to be USD 10.2 billion in 2019. The figure below shows the forecast growth in commercialised products (USD 9.9 billion in 2019) and the expected growth in emerging products (USD 373 million in 2019). It is seen that much of the growth is expected to be driven by products that have already been commercialised.



Source: BCC Research, 2014

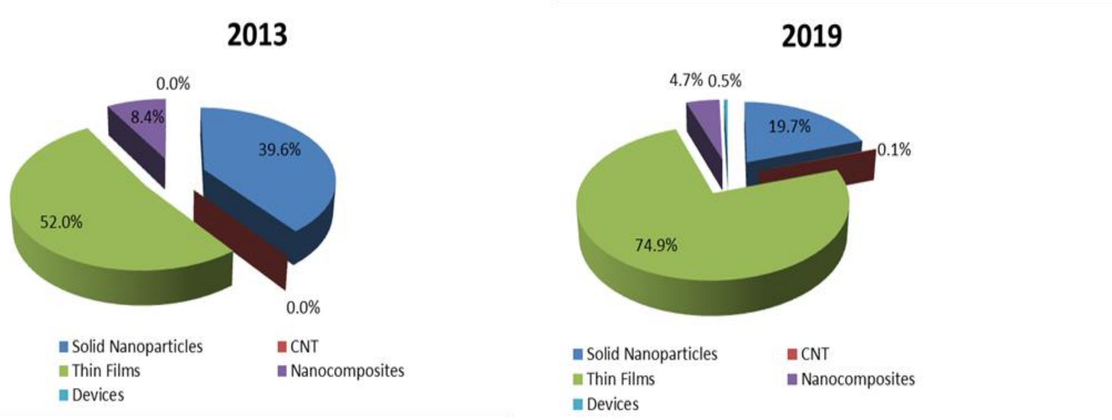
Figure 9-1: Global market outlook for nanotechnology in ICT to 2019

Related to the markets for ICT are the markets for electronics, details of estimates and forecasts for some of which are given in the table below.

Table 9-1: Global market values for electronics (multiple sources)

	Market value USD (year specified)	Future market value USD (year specified)	CAGR %
Total semi-conductor market (global)[336]	290bn (2013)	366bn (2017)	5 %
CMOS technology (22, 32/28 and 45/40 nm)[337]	226bn (2013)[338]	n/a	n/a
Compound semi-conductors[339]	27bn (2012)	47.4bn (2017)	12 %
Flexible electronics via roll-to-roll production[340]	10.8bn (2012)	22.7bn (2017)	16 %
Printed electronics[341]	4bn (2013)	15bn (2018)	30 %

The market data presented there is based mainly on reports by BCC Research[342]. A comparison of global sales estimates for ICT by type of nanomaterial shows that thin films accounted for the largest share in 2013, with further increases expected to 2019. The main driver of this trend is the expected growth in the market for low-k dielectric coatings.



Source: BCC Research, 2014

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

The market share of solid nanoparticles is expected to decrease by 2019 to about half of its size in 2013, while the share of the sales of thin films is projected to almost triple in the same timeframe.

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336 ZVEI-Fachverband "Electronic Components and Systems; Mikroelektronik-Trendanalyse bis 2017"; April 2013 http://www.zvei.org/Verband/Pub likationen/Seiten/Mikroelektronik-Trendanalyse-bis-2017.aspx

337 VDI TZ 2013: Unternehmensbefragung nano. DE-Report 2013, June 2013

338 This breaks down into approximately one third of the total monetary value each for (i) 22nm; (ii) 32/28 nm; and 45/40 nm.

339 BCC 2012: "Global Markets and Technologies for Compound Semiconductors", press release, 12 September 2012 http://www.bccresearch.com/pressroom/smc/global-compound-semiconductor-component-sales-reach-$47.4-billion-2017

340 BCC 2013: "BCC Research Projects the Flexible Devices Manufactured by Roll-to-Roll Technologies to Reach Nearly $22.7 Billion by 2017", Market report abstract https://bccresearch.wordpress.com/2013/05/23/roll-to-roll-technologies/

341 IDTechEx 2012: "Conductive Ink Markets 2015-2025: Forecasts, Technologies, Players", Market report abstract http://www.giiresearch.com/report/ix235628-conductive-inks-markets-2012-2018.html

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

Carbon nanotubes are currently forecast to play only a marginal role in terms of shares of sales.

9.3 Commercialised products for ICT through nanotechnology

9.3.1 Overview

To date, 84 ICT-related products using nanotechnology have been identified as being commercially available on the market. The figure shows a rough breakdown of the types of products, albeit that some categories overlap and a decision has been taken as to which category to put them in. The main message is that nanotechnology occurs most in components but also strongly in materials.

Components (53%) account for the biggest share of these commercialised products. Materials to make and to improve ICT show almost equal shares (17% and 18%), while products for data storage represent 8% of the products. Noteworthy are products in the subsector novel methods (4%), these are quantum computers and spintronics-based sensors.

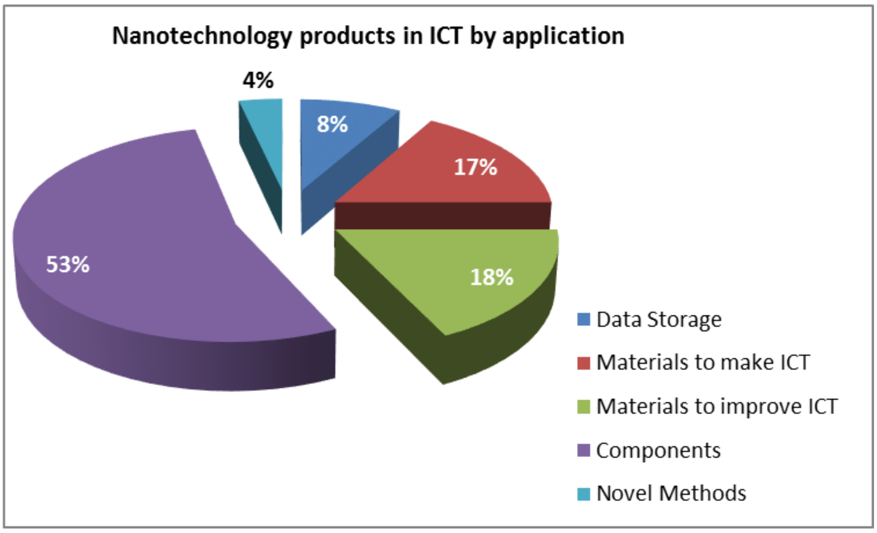

Figure 9-3: Nanotechnology products in ICT by application

9.3.2 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. Company case studies and company snapshots provide additional information. Existing applications and emerging applications are considered. There is also a section on novel technologies (e.g. spintronics).

9.3.2.1 Data storage

This section looks first at existing applications (hard disc media and heads; magnetic recording tapes; and optical recording media) and then at emerging applications (computer memory; and holographic memory).

EXISTING APPLICATIONS

A HARD DISC MEDIA AND HEADS

Digital information can be stored in different types of device depending on the use and how frequently the required access. For example, data to be stored for a long time with infrequent access are normally stored in hard disc drives. These are magnetic devices with high data density — nowadays on the order of terabytes — in which information is encoded in the direction of magnetisation of small areas of a magnetic medium. Each of these magnetic 'bits' stores a logic '0' or '1', and is written or read by a recording head that traverses the disc at a distance of a few nanometres. The information stored in hard disc drives is non-volatile as it persists after power to the device has been cut off. The speed of access to the data is relatively slow (milliseconds) because the read/write procedures are mechanical[343].

Hard disc drives using magnetic recording are likely among the most complex devices using nanotechnology. Today's commercial hard disc drives can store information at > 600 Gbit/in^2, with data bits < 60nm x 15nm, read sensor dimensions < 50nm x 30nm, and the recording head "flying" a few nanometres (nm) above the nanostructured recording disc. To maintain this technological evolution, every facet of the magnetic recording system must be continuously reduced in dimensions while maintaining adequate signal-to-noise ratio for writing and reading information[344]. Each disc surface is made from a complex structure of thin metal films. These layers work together to store magnetic data which can be written with and read by a recording head. Technological advances have enabled the amount of data that can be stored per square centimetre to double each year for the last decade. The 'read head' of a current hard disc drives uses the effect of giant magneto-resistivity (GMR) to sense the magnetic data. GMR sensors use metallic strips, less than 2nm thick, which are extremely sensitive to changes in magnetic fields. These are connected electrically to the disc drive electronics[345].

In 2013, Western Digital announced a nanotechnology breakthrough that will allow the company to double data storage capacity on hard disc drives (HDD). The discovery was made by HGST Labs, a company owned by Western Digital (WD), using nanolithography to imprint patterns on the thin film of hard drive platters where data is to be stored. The discovery allows for twice the bit density of today's disc drives[346].

MARKET DATA AND FORECASTS [347]

The total materials cost of the sputtered magnetic coatings used on hard discs is estimated at USD 416 million in 2013 and USD 429 million in 2014. It is forecast to grow at a compound annual growth rate (CAGR) of 6.4% to USD 585 million in 2019.

Company snapshot: Western Digital

Founded in 1970, Western Digital Corp.[348]*, Irvine, California (US) is a global provider of solutions for the collection, storage, management, protection and use of digital content, including audio and video. As a storage technology leader, the company produces hard disc drives (HDDs) and solid state drives (SSDs) and also home entertainment and networking products. Its products are marketed under the HGST and WD brands to original equipment manufacturers (OEMs), distributors, resellers, cloud infrastructure providers and consumers.*

As of July 3, 2015, WDC employed a total of over 76,000 employees worldwide, excluding temporary employees and contractors and had approximately 9,700 engineers. It had a net revenue in 2014 of USD 14,572 million and a gross profit of USD 4,221 million. Its research and development expenses totalled USD 1,646 million. The company has one of the industry's largest patent portfolios with more than 7,000 active patents worldwide.

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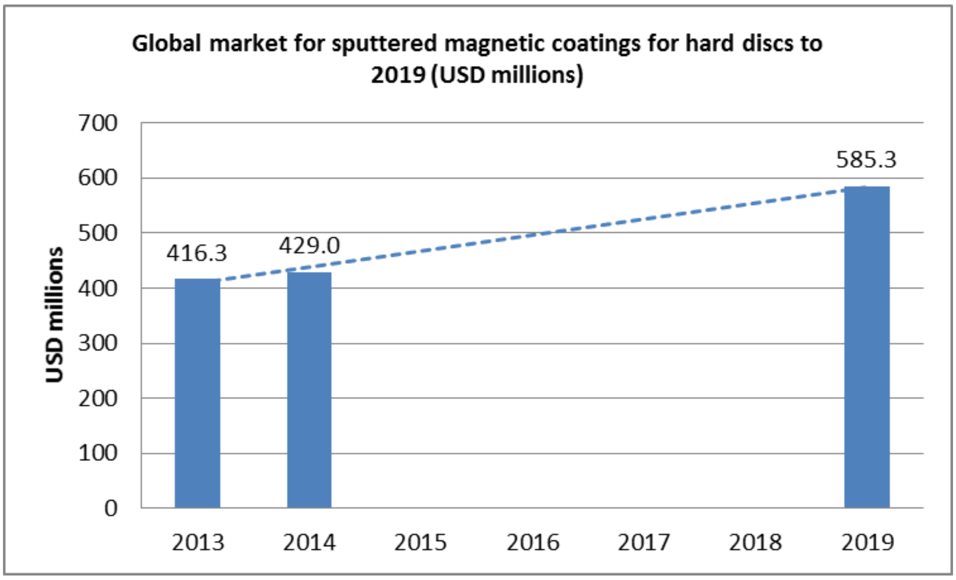
[343] Nature Nanotechnology Editorial: Memory with a spin, Nature Nanotechnology 10, (2015): 185
[344] http://www.mse.engin.umich.edu/about/events/nanotechnology-and-future-of-the-hard-disk-drive
[345] https://www.conted.ox.ac.uk/courses/professional/nanobasics/nano/accessWeb/technology.html
[346] COMPUTERWORLD: Western Digital claims HDD capacity doubled with nanotech breakthrough, March 1, 2013
[347] BCC Research (2014), Nanotechnology: A Realistic Market Assessment
[348] http://www.wdc.com/



Source: BCC Research 2014

Figure 9-4: Global market for sputtered magnetic coatings used on hard discs to 2019

B MAGNETIC RECORDING TAPES

Magnetic recording tapes used for video, audio and digital data storage consist of a magnetic coating deposited onto a non-magnetic support by either a particulate coating process or vapour deposition (evaporation). Traditionally, the magnetic particles used to form magnetic recording layers have been gamma-iron oxide (γ-Fe2O3 or maghemite), cobalt-modified gamma-iron oxide (Co-γ-Fe2O3) or cobalt-modified magnetite (Co-Fe3O4). Generally speaking, the more demanding the storage requirements, the smaller the particle size required. Particles of γ-Fe2O3 or Co-γ-Fe2O3 about 200 nm to 400 nm in length and 25 nm to 50 nm in width are commonly used to form magnetic coatings on audio and video recording tapes, which do not require extremely high recording densities. High-density storage applications tend to use metallic iron or iron-cobalt particles of less than 100 nm in length in order to increase the signal-to-noise ratio and the film smoothness[349]. In addition to magnetic iron/iron oxide nanoparticles, the magnetic layer of recording tape typically includes alumina nanoparticles as an additive to reduce tape wear[350]. Some of the company activities in this include:

- In 2001, Fuji Film introduced its NANO CUBIC technology, an ultra-thin layer coating that results in higher resolution for recording digital data, ultra-low noise and high signal to-noise ratios that are ideal for magneto resistive (MR) heads. Two types of magnetic particles were developed for NANO CUBIC technology, both tens of nanometers in size: acicular ferromagnetic alloy particle and tabular ferromagnetic hexagonal barium ferrite particle[351].
- Also in 2014, Sony Corporation announced that, by independently developing a soft magnetic underlayer with a smooth interface using sputter deposition, it had succeeded in creating a nano-grained magnetic layer with fine magnetic particles and uniform crystalline orientation. This enabled Sony to achieve the highest areal recording density for tape storage media of 148 Gb/in^2 (gigabits per square inch). This areal recording density is equivalent to approximately 74 times the capacity of current mainstream coated magnetic tape storage media, and makes it possible to record more than 185 TB (terabytes) of data per data cartridge[352].

[349] Also because metallic particles exhibit higher coercivities, i.e. the intensity of the applied magnetic field required to reduce the magnetisation of a ferromagnetic material to zero from its magnetic saturation state.
[350] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.63
[351] FUJI Film: Product Information
[352] http://www.sony.net/SonyInfo/News/Press/201404/14-044E/

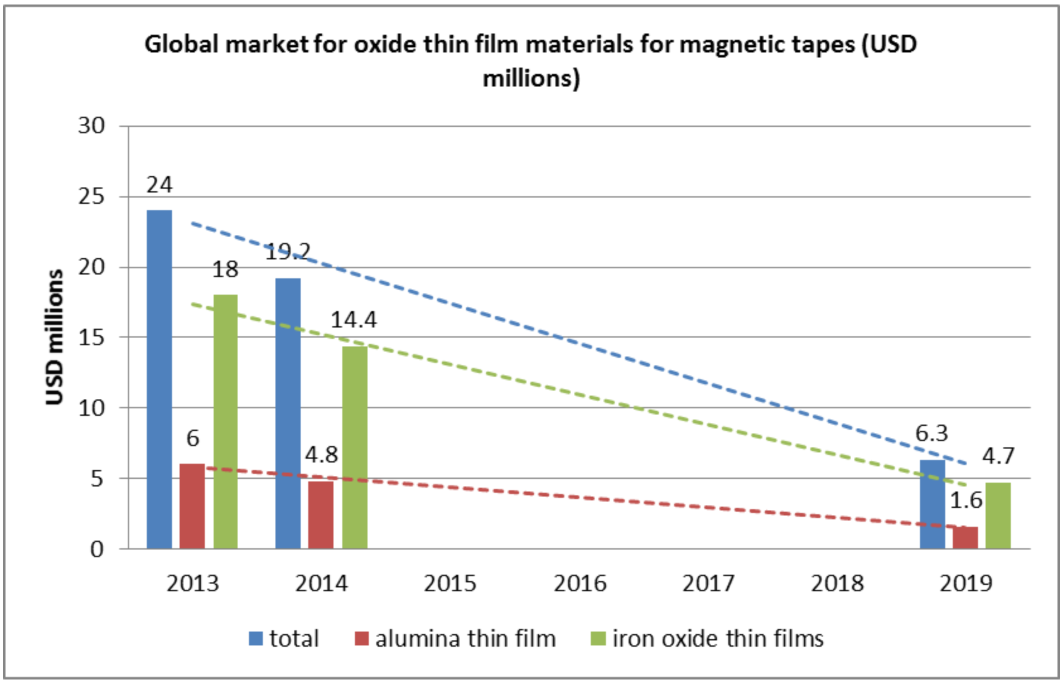
Company snapshot: Fujifilm

Fujifilm Recording Media U.S.A., Inc[353]. is the US-based manufacturing, marketing and sales operation of Fujifilm Corporation for professional broadcast video and data tape recording media, with branches also in Europe[354] including Germany. The company provides broadcast and data centre customers and industry partners with a wide range of data centre accessories, services and archival solutions. Fujifilm has developed innovative data storage products based on thin-film engineering and magnetic particle science such as Fujifilm NANOCUBIC technology, an ultra-thin layer coating introduced in 2001. In 2013, Fujifilm surpassed the 100 million LTO Ultrium data cartridges manufactured and sold since introduction.

Fujifilm Holdings Corporation was founded in 1939 in Tokyo, Japan. Originally a photographic film maker company, nowadays it works in the areas of: highly functional materials, such as flat panel display materials; optical devices, such as broadcast and cinema lenses; digital imaging; graphic systems; and healthcare, with medical systems, pharmaceuticals and cosmetics. In the year ended March 31, 2015, the company had over 79,000 employees and global revenues of USD 20.8 billion[355].

MARKET DATA AND FORECASTS

Magnetic recording media consume significant but declining amounts of alumina and iron oxide thin film materials, as shown in the figure below.



Source: BCC Research, 2014

Figure 9-5: Global market for oxide thin film materials used in magnetic tapes

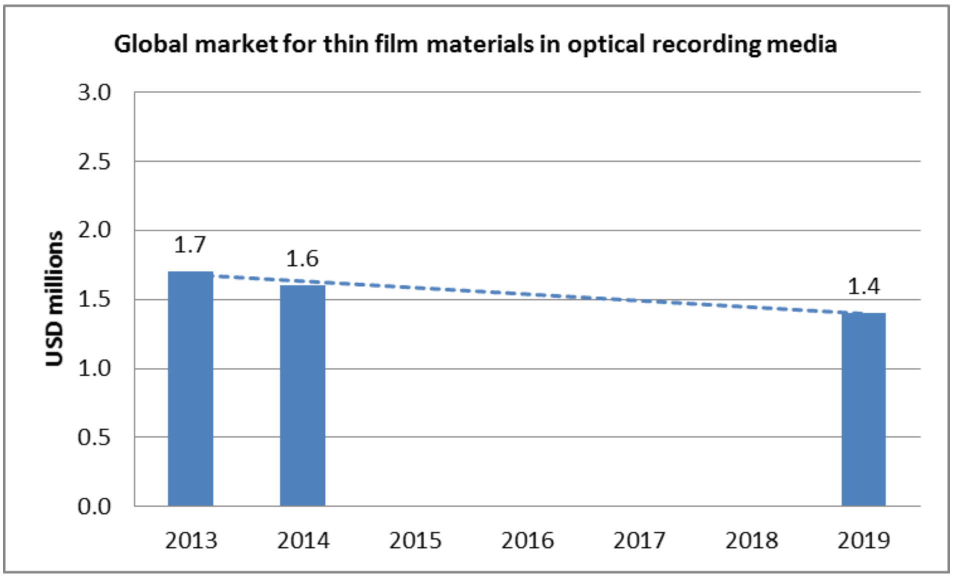
353 http://www.fujifilmusa.com/gateway/recording_media/
354 http://www.fujifilm.eu/eu/products/recording-media/
355 https://www.fujifilmholdings.com/en/investors/annual_reports/2015/pack/pdf/Annual-Report-2015.pdf (USD figures at an exchange rate of 120 yen to the USD)

C Optical recording media

The most common types of optical recording media (i.e. audio CD and video DVD) generally have a 50-nm thick reflective aluminium film layer that is sputtered onto a polycarbonate substrate and spin-coated with a protective lacquer coating. The newer blu-ray discs (BD) contain a similar reflective layer[356].

Market data and forecasts [357]

In 2013, global consumption of nanostructured aluminium film materials in the production of optical recording media (e.g., CD and DVDs) was about 52 metric tons, with a value of USD 1.7 million. In the near to mid-term, consumption of nanostructured aluminium film materials for CDs and DVDs will be driven by projected trends in unit disc sales. Data on total global shipments of optical recording media (e.g., CDs, DVDs and Blu-Ray discs) are hard to obtain, but are projected to trend downwards as alternative content delivery and storage technologies gain market share. The figures in the table below assume that shipments of optical storage media are decreasing at a CAGR of -3.8%, with a proportional reduction in consumption of nanostructured aluminium thin film materials.



Source: BCC Research, 2014

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

Emerging applications

A Computer memory

In the information storage industry, there is now an effort to develop new concepts for memory devices that combine two key aspects: cheap, non-volatile, high-density information storage (as in hard disc drives) and robust, fast access (as in random access memory (RAM)). Flash memory is an example, as it is a solid-state yet non-volatile memory, and is currently used in mobile applications. However, Flash is slow and has low endurance. Some development activities in the area of new solid-state technologies[358] are as follows:

- Non-volatile random-access memory (NRAM) is a carbon nanotube-based technology developed by Nantero Inc. (Woburn, MA, USA). The memory is reported to be hundreds of times faster than current memory for mobile devices[359]. In the production of NRAM, a film of carbon nanotubes (CNTs) is deposited onto a silicon substrate that contains an underlying cell select

[356] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.63
[357] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.153
[358] Nature Nanotechnology Editorial: Memory with a spin, Nature Nanotechnology 10, (2015): 185
[359] PCWorld: Nantero's radical carbon-nanotube memory could replace SSDs and DRAM, Jun 2, 2015

device and array lines (typically transistors or diodes) that interface the NRAM switch[360]. Advantages of NRAM are that it operates at the speed of DRAM (dynamic RAM) and is nonvolatile, meaning it can store data when the power is switched off. The small size of carbon nanotubes allows more data to be stored in smaller volumes, and the storage chips will consume significantly less power than flash storage and DRAM. Using this technology, it should be possible to increase the amount of storage and increase the battery life of laptops and mobile devices.

- Carbon-nanotube chips are just one of a number of new memory types with the potential to replace DRAM and NAND flash. As devices get smaller, it is becoming difficult to add more storage capacity while reducing the size of NAND flash chips. Possible DRAM and NAND flash replacements like RRAM (resistive RAM) and MRAM (magnetoresistive RAM) are already being used on a limited basis, and phase-change memory (PCM) — backed by IBM and Samsung — is still being refined[361].
- In 2011, scientists at Purdue University developed a computer memory using nanotechnology that could be faster than current technology and use far less power than flash memory devices. The new technology is called FeTRAM, for ferroelectric transistor random access memory. It combines silicon nanowires with a "ferroelectric" polymer, a material that switches polarity when electric fields are applied. The FeTRAM is nonvolatile storage, meaning information stays in memory when the computer is powered down[362].

B Holographic memory

In holographic data storage a 'data beam' holding information is crossed with a 'reference beam' to produce an interference pattern on a light-sensitive material, thereby storing the data. To download the data, the reference beam is shone onto the material at a given point, and the original data beam is reconstructed through the interaction of the reference beam and the material. The data is read by a detector that converts the beam into electrical signals.

The most common recording materials for holographic storage are inorganic crystals and polymers. While polymers are more sensitive and require less powerful lasers than inorganic crystals, they have a greater tendency to deform, thereby corrupting the data[363].

Holographic memory can potentially store 1 terabyte[364] (TB) of data in a crystal smaller than one centimeter cubed. 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[365]. Developments in the area include:

- In 2014, a collaboration between researchers from the University of California, Riverside Bourns College of Engineering and the Russian Academy of Science demonstrated a holographic memory device using spin waves – a collective oscillation of spins in magnetic materials – instead of the optical beams. Spin waves devices have the advantage of being compatible with the conventional electronic devices and could operate at a much shorter wavelength than optical devices, enabling the production of smaller electronic devices with greater storage capacity. The research combines the advantages of the magnetic data storage with wave-based information transfer[366].
- Several promising technologies have been developed by companies such as InPhase Technologies, Colossal Storage and GE Global Research. The Colossal Storage system is apparently the only one that uses nanophotonic technology, in which light interacts with nanoscale structures. In other holographic technologies, the light interacts with the storage medium on a macroscale (> 100 nm) level. The Colossal Storage technology uses a UV laser to write data spots as small as 30 nm in a ferroelectric perovskite thin film[367].

By 2019, sales of nano-devices currently under development, primarily nanostructured holographic

[360] http://nantero.com/technology/
[361] Ibid
[362] UPI Science News: New computer memory uses nanotechnology, Sept. 27, 2011
[363] MIT Technology Review: Holographic Memory, September 1, 2005
[364] A terabyte of data equals 1,000 gigabytes, 1 million megabytes or 1 trillion bytes.
[365] How Stuff Works Tech: How Holographic Memory Will Work,
[366] University of California, Riverside, UCR Today: Using Holograms to Improve Electronic Devices, February 19, 2014
[367] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.104

memory, are projected to reach USD 50 million by 2019[368].

Case study: Nantero

Located in Woburn, Massachusetts, Nantero[369] is a nanotechnology based semiconductor company with a large presence in Sunnyvale, California. Nantero was founded in 2001 with an idea of making memory chips based on carbon nanotubes to address the existing challenge with respect to flash and digital random access memory (DRAM) such as storing data with high speed without any losses. To meet the industry needs and address the existing challenges, Nantero has leveraged the carbon nanotubes (CNT) to develop low power, super-fast and high density non-volatile random access memory (NRAM).

Nantero's NRAM is developed based on the proprietary concepts of CNT and it is derived from the leading edge research in nanotechnology. NRAM is developed by depositing a thin film made up of CNT on a silicon substrate. CNT memory cells are in the matrix form and it is deposited on the substrate in such a way that it can be either separated or touching each other depending on the position of CNT cells. The substrate also comprises of array lines which are made of transistor and diodes and acts as the interface to the NRAM switch. Carbon nanotubes are sandwiched between metal electrodes. Depending on the resistive state of the CNT film, NRAM can be placed in two or more resistive modes. The resistance state of the film is high when the CNTs are not in contact and it is represented by 0. In addition, resistance of the film is low when CNTs are in contact with each other and it is represented with 1.

CNT tubes are rod-shaped and bind together due to the atomic scale force, thereby increasing the conductive path between electrodes at low resistance. When a reset pule is transmitted, the CNT changes back to the matrix form at a high-resistance state. With the NVM size reduced to as low as 20-30 nm and the speed of operation measured in picoseconds, the read-write operation using CNT NRAM functions very fast. The company is working on the critical dimensions of the CNT and expects to further reduce the size of each cell to 5nm, making the size of the storage device even smaller and enabling it to operate at a much higher speed.

Nantero NRAM technology has high endurance levels. It works 100 times faster compared to the NAND flash, with the memory cell switching at speeds that are 20 picoseconds faster than in a regular flash without losing data and keeping it secured for a long time. CNT-based NRAM (Nano Random Access Memory) can be used as a solid-state device, as a replacement of a flash storage device in consumer electronics and also, in enterprises for centralised data storage in a cloud storage system. It can also serve as NVM that can store data at low power. NRAM can have a significant impact in industries such as medical science, automation, aerospace, and defence, where data is required to be stored even when the power is switched off.

CNT consumes little or no power in the standby mode. This technology is being tested with NASA at a temperature of 300 degrees Celsius for more than 10 years, and has proved to be highly reliable and unaffected by radiation. This feature makes the CNT NRAM highly innovative. The CNT NRAM technology is touted to change the future of the NVM industry. Its applicability is expected to expand to cover a broad spectrum of industries. Nantero's CNT NRAM finds application in chemical sensors, avionics, embedded in-printable electronics, solar cells, and in power transmission in energy. Nantero aims to license the technology to device makers and manufacturers. The first NRAM chips are expected to appear as DRAM-compatible modules that can be plugged directly into memory slots on motherboards[370].

Nantero has gone through five rounds of funding from series A to series E. In the recent substantially oversubscribed funding round (series E), Nantero has managed to close at USD 31.5 Million (EUR 23.68 million). For more than a decade now, Nantero has been funded by major corporates from North America and has raised USD 78 Million (EUR 58.64 million) in total. The company is expected to be valued at USD 1 Billion. The company has nearly 50 employees most of whom are focused on R&D. In 14 years of research, multi-millions have

[368] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.195
[369] http://nantero.com/technology/
[370] PCWorld: Nantero's radical carbon-nanotube memory could replace SSDs and DRAM, Jun 2, 2015

been invested in R&D, exact figure was not revealed but the company main focus was to drive the investment from government organisations to support R&D. Some of Nantero's strategic investors include Charles River Ventures, Globespan Capital Partners, Harris and Harris Group, and Draper Fisher Jurvetson. Nantero is expected to experience a significant growth opportunity in the future. With many deals still underway, Nantero's strategy of targeting the commercial electronics market is expected to pay rich dividends.

Licensing is the key revenue strategy at Nantero. The company is planning to license its intellectual property of unique NRAM design using CNT technology to foundries, chip manufacturers and electronic companies around the world. Nantero targets embedded and standalone markets with an IP (Intellectual Property) licensing business model. It has a robust patent portfolio of about 175+ granted US patents and more than 200 pending patent applications. The company's technology has been leveraged in 2 of the top 5 foundries in the world. This will help Nantero to finance itself through recurring income, making it capital efficient in the long term. Nantero is also leveraging the strategic partnership model to commercialise its CNT NRAM technology. The company has engaged in long-term partnerships with major tier participants including Lockheed Martin, Schlumberger, ON Semiconductor, and Novati Technologies.

9.3.2.2 Printed electronics

Printed electronics are electronic circuits, components and devices manufactured with conventional printing methods using, for example, electrically functional inks on different substrates to create active or passive devices, such as thin film transistors (TFT), capacitors or resistors. Such printing processes have the potential to produce very low-cost and simple electronics for applications that do not require high performance such as flexible displays, smart labels, decorative and animated posters, and active clothing [371].

At present, most conductive inks are based on silver nanoparticles, since silver both has high electrical conductivity and is resistant to oxidation. The main challenge in replacing silver with cheaper metals such as copper and aluminium is in avoiding their oxidation at ambient conditions. This usually requires rather sophisticated reaction conditions with the use of hydrocarbon solvents, low precursor concentrations and inert atmospheres[372]. Some activities in this technology application area include:

- NanoMas Technologies (Endicott, N.Y.) currently produces nanosilver and nanogold conductive inks. NanoMas is also developing inorganic nanoparticle and polymer semiconductor inks, as well as electroluminescent inks for printed electronics applications.
- Other producers of nanoparticle-based silver inks for printed electronics include UT Dots Inc. (Champaign, Ill.), PChem Associates (Bensalem, Pa.), Kemco International (St. Petersburg, Fla.), and SunRay Scientific (Mt. Laurel, N.J.), among others.
- Xerox (Norwalk, Conn.) has developed a high-performance, semi-conductive ink that uses a new class of polythiophene semiconductor nanoparticles. These nanoparticles not only possess improved air stability, but also exhibit excellent self-assembly behavior. Air stability is needed for the semiconductor to be processed and fabricated at or near ambient conditions. In a liquid-processed organic-transistor semiconductor layer, proper molecular self-assembly leads to formation of molecular structural orders that are conducive to efficient charge-carrier transport and faster transistor performance[373].
- In October 2015, Nano Dimension Ltd. (Ness-Ziona, Israel), a leading printing electronics company in the area of 3D printing, announced its AgCite™ line of conductive silver nanoparticle inks for inkjet deposition. AgCite inks are applicable to a wide variety of advanced printed electronics applications, including RFID, OLED lighting, circuits, screen bezels, solar, sensors and other applications requiring high conductivity[374].
- Promethean Particles at Printed Electronics 2015 in Berlin showcased a new material as an

[371] Aijazi A T (2014), Printing Functional Electronic Circuits and Components, Dissertation at Western Michigan University
[372] Kamyshny A, et al. (2011), Metal-based Inkjet Inks for Printed Electronics, The Open Applied Physics Journal, 2011, 4: 20
[373] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.37
[374] Business Wire, October 21 2015

alternative to the use of silver for conductive inks in printed electronics. The dispersed copper concentrate (for ink manufacture) can be used as a raw material for conductive inks that can be printed using a variety of techniques. The "pre-ink", which can be thought of as a conductive "pigment" for ink formulators, remains stable as non-oxidised copper metal for a period of several months and contains only copper and an antioxidant. By using copper particles, the ink requires a lower sintering temperature than silver making it possible to deposit conducting tracks onto less substrates such as flexible polymer-based materials that do not have high thermal stable. In addition, conductivity has been achieved when sintering the deposited material in air, without the need for inert atmospheres[375].

- DuPont Innovalight makes silicon inks and licenses proprietary technology for solar cells to manufacturers. The silicon nanoparticles are suspended in a chemical mix. When applied to silicon solar cells during the manufacturing process, the ink boosts the cells' absorption of sunlight at lower wavelengths, generating more electricity[376]. The proprietary material is comprised of silicon nano-particles formulated into a screen printable ink. The material is compatible with low-cost, industry standard screen printers normally used in the printing of metal contacts[377].

Company snapshot: BASF

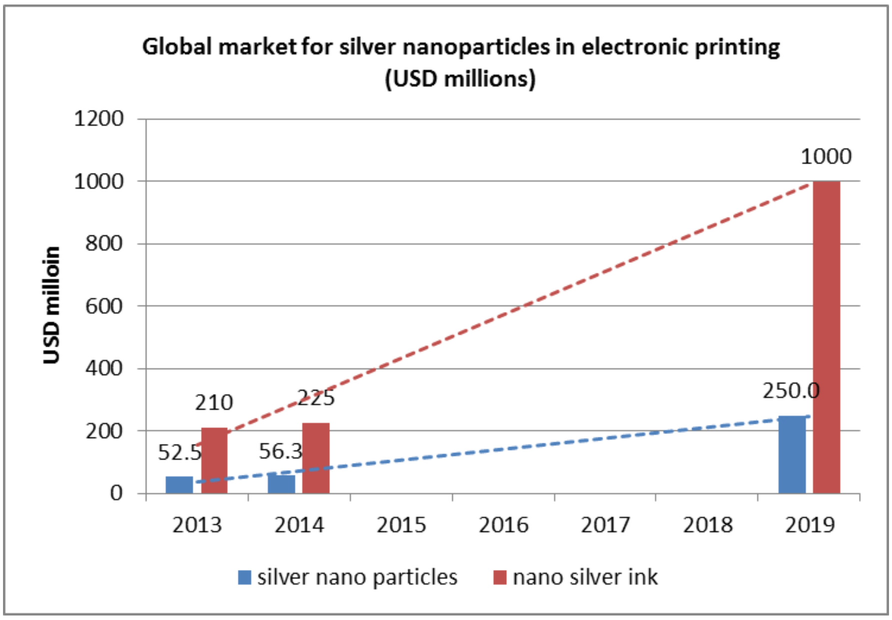
BASF SE[378] is a chemical company operating in six segments: Chemicals, Plastics, Performance Products, Functional Solutions, Agricultural Solutions and Oil & Gas. It was founded in 1865 in Mannheim, Germany. Nowadays it has more around 113,000 employees and has headed the Patent Asset Index™ rankings for six times in succession with a portfolio of 1,200 patents worldwide. With six Verbund sites (the Verbund principle involves intelligent inter-linking of production plants, energy flows and infrastructure) and 353 additional production sites worldwide, BASF has companies in more than eighty countries and supplies products to a large number of business partners in nearly every part of the world. Their Verbund site in Ludwigshafen is the world's largest integrated chemical complex. BASF offers products for the chemical, automotive, construction, agriculture, oil, plastics, electrical / electronics, furniture and paper industries, and provides a range of system solutions and services.

In 2014, BASF posted sales of EUR 74 billion and income from operations before special items of approximately EUR 7.6 billion. The company has around 10,700 research and development employees and spent EUR 1,884 million on this in 2014.

MARKET DATA AND FORECASTS

Available estimates and forecasts concentrate on silver conductive nano-ink. The market for all types of conductive silver ink was worth USD 1.4 billion in 2013 and USD 1.5 billion in 2014, and is expected to grow to USD 2 billion by 2019.

375 http://www.prometheanparticles.co.uk/copper-ink-for-printed-electronics/
376 DuPont (2012): "DuPont Microcircuit Materials Introduces Highest Efficiency Solamet® Photovoltaic Metallisation Pastes to Date."
377 http://www.dupont.com/products-and-services/solar-photovoltaic-materials/silicon-inks.html/
378 www.basf.com



Source: BCC Research

Figure 9-7: Global market for silver nanoparticles in electronic printing to 2019

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 2013 to 2014. However, by 2019, the nanotechnology share of the conductive silver ink market is expected to increase to at least 50% of the total. If materials account for about 50% of the final value of the inks and silver nanoparticles represent about half of the total material cost on average[379], the market for silver nanoparticles for these inks can be estimated at one quarter of the total for conductive silver inks (i.e. USD 250 million for silver nanoparticles of USD 1 billion for nanotechnology silver inks in 2019).[380]

Case study: Nano Dimension Ltd.

Israel-based Nano Dimension Ltd[381] was founded in 2012 and focuses on the development of nanotechnology based 3D printing technology for electronics. The company is listed on the Tel Aviv Stock Exchange and OTCQX as an ADR (American depositary receipt). Since its listing in August 2014, the company has raised USD 17 Million. Prior to that, the company had raised a total of USD 13.1 Million (EUR 9.84 million).

Nano Dimension's AgCite™ nanoparticle inks are suitable for inkjet deposition. The company is able to reliably extract nanometre particles of pure silver and control their shape, size and dispersion. The ability to accurately manipulate the physical dimensions of the nanoparticles enables optimisation of properties such as flexibility, conductivity and adhesion. The inks can sinter at low temperatures making them suitable for use on a wide range of substrates (e.g. glass, polymer, paper and films of indium tin oxide. The high conductivity of the inks enables small amounts to be used for any application making their use economical. The conductive inks, along with inkjet printing and 3D printing of printed circuit boards (PCBs) are the key focus areas of Nano Dimension.

The company is in the advanced product development phase for a 3D printer to print PCBs. The product, DragonFly 2020, enables the development of multi-layer PCBs using a versatile inkjet deposition technology. The first unit of the DragonFly 2020 will be shipped to an

379 The percentage can vary considerably, according to the unit price of silver
380 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.133
381 http://www.nano-di.com/about-nano-dimensions

undisclosed Indian customer in the second half of 2016.

The AgCite line of inks forms an integral part of this printer. Apart from using the inks in the DragonFly 2020, the company also sells the inks separately. The distinct feature of this product is that it enables the manufacturing of complex PCBs in small batches. This is ideal for rapid prototyping as well as supplying for niche areas where the demand is limited. Key opportunities for this product thus lie in the military and defence sector, where the requirement is of low volume but complex and sophisticated electronics. Other key areas include maintenance of electronic devices where damaged PCBs can be replaced swiftly at low costs. Nano Dimension is working on advancing the printing technology to enable development of PCBs that could be printed on both sides. The company also believes that the printers can be deployed for high volume production in the long term. However, the adoption could be limited, considering the high cost of silver inks.

In a recent development, Nano Dimension has filed a patent application with the USPTO for a nanoparticle based copper ink that can be used for printing electronic conductors. Copper provides a low cost alternative to silver in conductive inks. However, copper nanoparticles are susceptive to oxidation which is detrimental to the conductive property. The patent application presents a novel approach of addressing this challenge. The development of this copper ink has the potential to enable low cost, large scale manufacturing of PCBs using Nano Dimension's 3D printing technology.

Nano Dimension has two fully-equipped laboratories dedicated to R&D on inks, one for conductive silver inks, one for dielectric nano-particle inks. Development is primarily targeted towards the use of inks for the DragonFly 2020 3D printer.

As of 31 December, 2014, the company had 16 employees conducting research and development, and four employees in senior management roles. The R&D cost in 2014 was approximately NIS 3,339,000 (equivalent to USD 862K, EUR 648 K) while in 2013 it was approximately NIS 806,000 (equivalent to USD 208K, EUR 156K).

EMERGING APPLICATIONS

GRAPHENE PRINTED ELECTRONICS

Conductive inks rely for their conductivity on the inclusion of silver, carbon, graphite, or other precious metal-coated base materials. Common conductive inks can be classified into three categories: noble metals, conductive polymers, and carbon nanomaterials. A selection of conductive inks is offered on the market, to meet the demands of many applications: 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 has been demonstrated for a number of applications in printed electronics including chemical and thermal sensors and supercapacitors. While graphene inks open up potential applications such as printed electronics and packaging, they often need to be specially formulated or adjusted for specific uses, requiring unique substrates or processing/printing methods (rotogravure, flexo, or screen printing processes etc.)[382]. Some ongoing activities in the area include:

- In 2012, Vorbeck Materials (Jessup, MD, USA) partnering with MeadWestvaco Corp. a global packaging company has brought the first commercially available graphene product to market. The product is an anti-theft retail package product called Siren™, which is part of MWV's Natralock™ product packaging line. The packaging design prevents theft or tampering by setting off an alarm on an individual package if it is torn open or upon attempted theft. Vorbek's Vor-ink™ provides the package with a sensor that can detect when the package has been moved, taken out of the building or cut open[383].
- In 2015, researchers at the University of Cambridge in collaboration with Cambridge-based technology company Novalia, developed a low-cost, high-speed method for printing graphene inks using a conventional roll-to-roll printing process. The method would allow graphene and other electrically conducting materials to be added to conventional water-based inks and printed

[382] http://www.graphene-info.com/graphene-inks
[383] Nanlyze: Vorbeck's Commercially Available Graphene Products, April 1, 2014

using typical commercial equipment at the high speed associated with printing presses for newspapers. Silver-based inks in current use cost GBP 1000 or more per kilogramme. This new graphene ink formulation would be 25 times cheaper. In addition, graphene and other carbon materials are recyclable, unlike silver. Once dry, the 'electric ink' is also waterproof and adheres to its substrate extremely well. In the short to medium term, the researchers hope to use their method to make printed, disposable biosensors, energy harvesters and RFID tags[384].

Market data and forecasts [385]

Vorbeck Materials is currently the sole commercial producer of graphene-based inks. While it does not publish sales data, it is estimated that its sales of graphene inks were significantly less than USD 1 million in 2013 and 2014. By analogy with other nanotechnology-based inks, it has been estimated that sales of graphene inks could exceed USD 12 million by 2019. If the component of the inks is the same as for silver nanoparticles as outlined previously, their overall market value would be USD 3.5 million by 2019.

9.3.2.3 Chemical-mechanical polishing compounds (CMP compounds)

Chemical mechanical polishing (CMP) technology was first used by Monsanto in 1965 as a process step in semiconductor device fabrication. It is a common technique for wafer polishing (for dynamic memory and microprocessor applications) and mechanical glass polishing, producing mirror like surfaces with no measurable surface structure flaws[386].

CMP and other polishing slurries typically consist of 10-wt% to 25-wt% silica or alumina nanoparticles in an aqueous solution, although other types of oxide particles, such as ceria and zirconia, are being evaluated or used for certain polishing applications. The particle size of the abrasives is usually in the range of 10 nm to 150 nm, and the chemistry of the particle surface is carefully controlled to provide a stable dispersion. Approximately 90% of the nanoparticles used in CMP slurries consist of silica. Most of the remaining 10% of the nanoparticles are alumina; other types of nanoparticles such as ceria and zirconia reportedly account for less than 1% of the market. The particle size of the abrasives is usually in the range of 10 nm to 150 nm[387].

Company snapshot: Baikowski Group

Based in France, Baikowski[388] started its operations in 1904 to grow sapphire crystals using the Verneuil process. This activity was discontinued in 1982 to focus on high purity alumina markets. Since then, it has expanded quickly through successful diversifications of its applications and customer portfolio. Baikowski is now a major player on high quality applications such as technical ceramics, precision polishing, functional additives & coatings, and crystals.

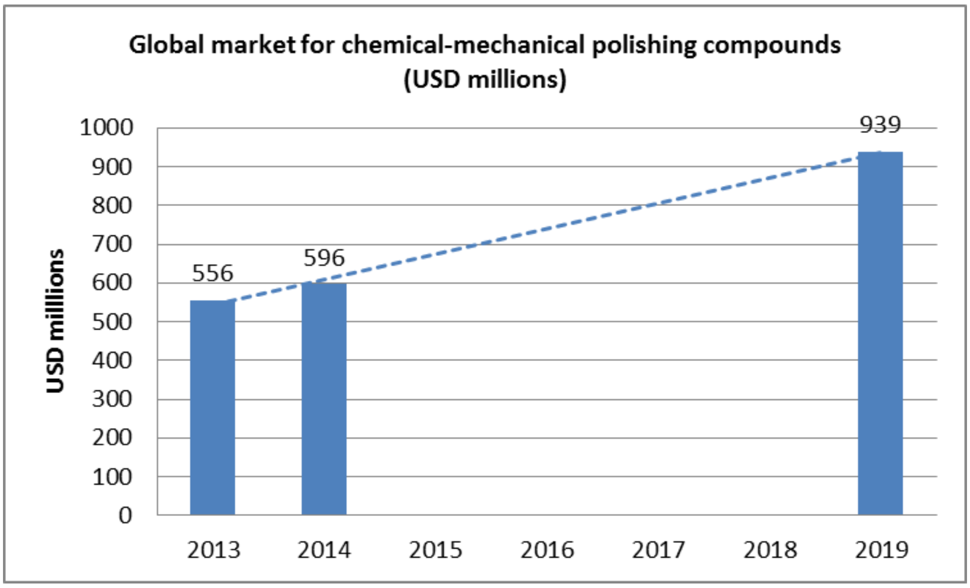
The company focuses on tailoring high purity alumina powders & formulations, as well as other fine oxides & composites such as spinel, ZTA, YAG & ceria for technical ceramics, precision polishing, crystals, and additives/coatings applications. Their market areas are lighting (high intensity discharge lamps, fluorescent tubes, LED), watches & phones (sapphire tops, ceramic parts), electronics (semiconductors), automotive (car polish, Li batteries), defence (armoured windows, precision optics) and medical (prostheses, imaging, intraocular lenses, and pacemakers).

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

384 http://www.aipia.info/news-Low-Cost-High-Speed-Graphene-Inks-for-Printed-Electronics-486.php
385 BCC (2014), Nanotechnology: A Realistic Market Assessment p.139
386 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
387 BCC Research, (2014), Nanotechnology: A Realistic Market Assessment, p.26
388 http://www.baikowski.com/

MARKET DATA AND FORECASTS

Global consumption of silica and alumina nanoparticles used in CMP compounds was estimated to be about 36,400 metric tons, with a value of USD 556 million, in 2013. Of this, silica accounted for about 87%. CMP nanoparticle consumption was estimated to be USD 596.4 million in 2014 and is forecast to grow to USD 938.9 million by 2019, for a CAGR of 9.5% from 2014 through 2019.[389]



Source: BBC Research, 2014

Figure 9-8: Global market for chemical-mechanical polishing compounds to 2019

9.3.2.4 Electrostatic discharge protection and prevention (ESD)

Carbon-based static dissipative plastics are widely used in electronic industries for electrostatic discharge protection and prevention. Plastics containing carbon nanotubes offer many superior properties to the electronics industry, such as greater cleanliness and surface finish[390]. Equipment made with nanotube-filled plastics include ESD shipping trays, wafer cassette holders, removable media cartridges, clean room equipment, front opening unified pod (FOUP) and standard mechanical interface (SMIF) pods[391].

Arkema (Colombes, France) sells its Graphistrength® thermoplastic masterbatches for electrostatic discharge protection. Graphistrength Masterbatches are particularly suited to applications where stringent requirements, in terms of cleanliness, permanent electrostatic dissipation, and perfect surface finish, must be met, such as for semi-conductors and ESD-sensitive components handling, and housings of electronic devices[392].

Company snapshot: Trek Inc.

Trek Inc.[393] provides innovative electrostatic measurement and high-voltage power solutions. It was established in 1968 in Lockport, New York, US, based upon the needs of the electrophotographic industry for highly accurate, stable, cost-effective electrostatic measurement instrumentation and devices. Trek's products are used by original equipment manufacturers to enhance the operational precision of their equipment and by researchers on electrostatics, materials, nanotechnology, piezoelectrics and plasmas.

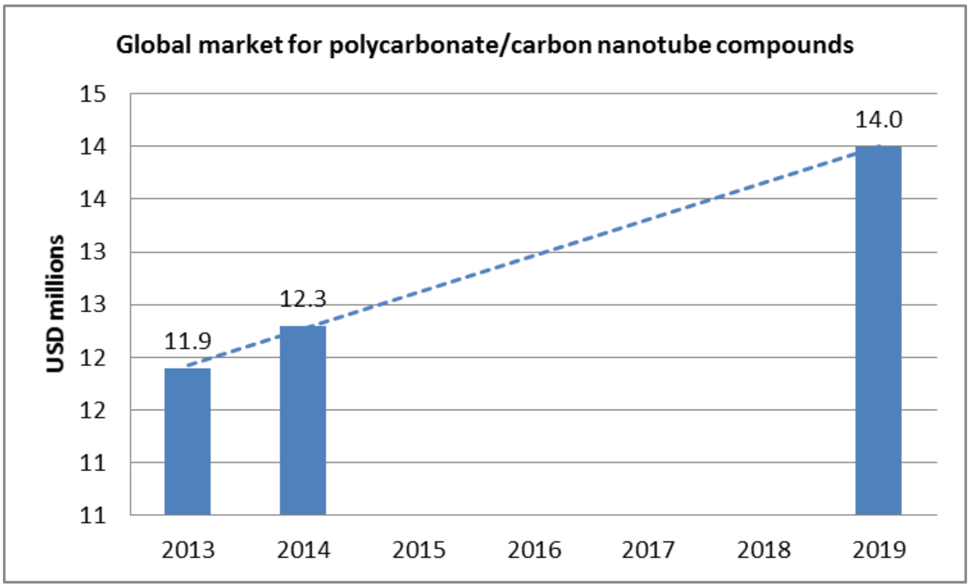
[389] BCC Research, (2014), Nanotechnology: A Realistic Market Assessment, p.116
[390] Zhang Y, et al. (2008), Carbon nanotube plastic-packaging material for class 0 device ESD protection -Real life electrical performance comparison for carbon-filled plastics, Electrical Overstress/Electrostatic Discharge Symposium, 2008
[391] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.85
[392] Arkema: Graphistrength® thermoplastic masterbatches, product information
[393] http://www.trekinc.com/

Trek designs and manufactures high-voltage amplifiers, piezo drivers, power supplies & generators and high performance electrostatic measurement instruments (including electrostatic sensors and detectors, electrostatic discharge (ESD) instruments, electrostatic voltmeters, charged plate monitors, and surface resistance/resistivity meter).

Trek Japan KK was founded in 1987 in Tokyo, Japan, for the purpose of providing Japanese and other Pacific Rim local application engineering support, sales, and service. The Trek Holding Company Ltd., Japan, announced the acquisition in 2006 of U.S. based Trek Inc. and Trek Japan KK. This acquisition was part of the overall Succession Plan of the Trek Group and allows for both Trek Inc. and Trek Japan KK to maintain its current operations and management structures.

MARKET DATA AND FORECASTS [394]

In 2013, global consumption of polycarbonate/carbon nanotube compounds, most of which are used to make ESD electronics products and clean room equipment, was USD 11.9 million. Global consumption of all types of filled electrostatic control products is projected to grow in volume at a CAGR of 7.3% through 2019, a rate of increase expected to apply to polycarbonate/carbon nanotube composites electrostatic control products as well. However, after factoring in a projected decline in the average cost of polycarbonate/carbon nanotube composites through 2019 as a result of improvements in production technologies and increased scale of production, the value of the market is projected to increase at a CAGR of only 2.6%, reaching USD 14 million by 2019, as shown below.



Source: BCC Research

Figure 9-9: Global market for polycarbonate/carbon nanotube compounds to 2019

9.3.2.5 Low-k dielectric coatings

The characteristic trend of the semiconductor industry over the last several decades has been the continual miniaturisation of microelectronic devices. Integrated circuit density per unit area has doubled every one-and-a-half to two years, a relationship commonly known as Moore's Law. Density increases have been accompanied by comparable increases in device performance. In recent years, however, it has become necessary to introduce new technology elements in order to maintain historical trends. The appearance of porous dielectrics in microelectronic devices represents one of the significant materials changes required to keep performance improvements on pace with device density increases[395].

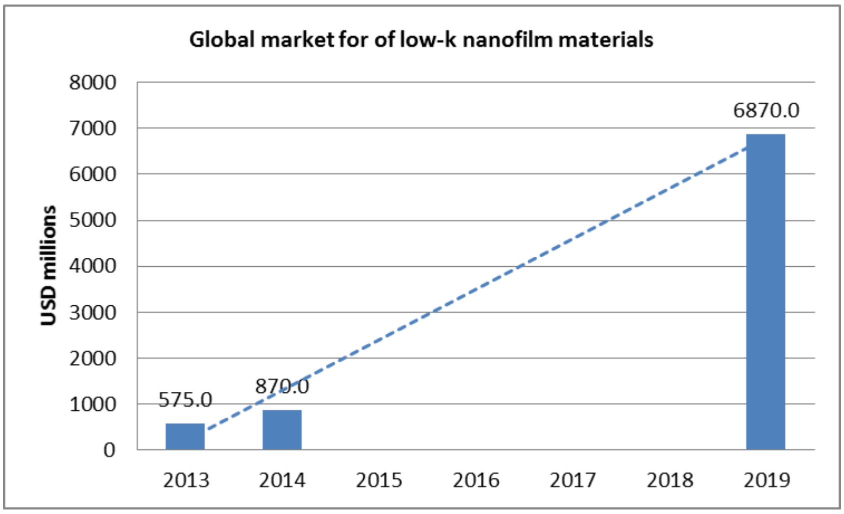
[394] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, pp.177-178
[395] McGahay V (2010), Porous Dielectrics in Microelectronic Wiring Applications, Materials 2010, 3: 536

Nanoporous polymer thin films such as Dow Chemical's SiLK are used in leading-edge computer chips because of their low dielectric constant, but they are competing with a variety of other materials, including inorganics and aerogels. While Dow is reportedly the leader in the low-k dielectric market, its market dominance is by no means assured[396]. IBM Corp. decided to switch from SiLK to the rival small molecule chemical vapor deposition (CVD) technique. Similarly, the world's second largest foundry, Taiwan-based United Microelectronics Corp. (UMC), dropped SiLK in favor of the small-molecule CVD Coral process from Novellus Systems Inc. (San Jose, Calif.)[397].

Market hurdles that SiLK must overcome are reported to include relatively high materials costs and the need to incorporate additional steps in the semiconductor production process. In the longer term, there is also the possibility of using aerogels as a semiconductor dielectric material[398].

Market data and forecasts

In 2013, global consumption of low-k nanofilm materials was about 16 metric tons with a value of USD 575 million. Polymeric materials, notably Dow's SiLK resins, dominate the market but their market share is expected to decline amid growing materials for 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. It is difficult to quantify directly the impact of these trends on future consumption of low-k dielectrics. However, based on information provided by industry sources, a plausible estimate of the total market for low-k dielectric films by 2019 is likely to be at least 275 tons, or about USD 6.9 billion[399].



Source: BCC Research

Figure 9-10: Global market for of low-k nanofilm materials to 2019

> ***Company snapshot: Dow Chemical***
>
> *Founded in Midland, Michigan (US) in 1897, The Dow Chemical Company[400] manufactures and supplies products that are used primarily as raw materials in the manufacture of customer products and services worldwide. Dow operates in chemical, advanced materials, agrosciences and plastics businesses areas and delivers a broad range of technology-based products and solutions to customers in approximately 180 countries and in high-growth sectors such as*

396 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.69
397 IEEE Spectrum: SiLK Slips - IBM follows industry trend, chucks spin-on chip insulator, 1 December 2003
398 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.69
399 BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.
400 http://www.dow.com/

packaging, electronics, water, coatings and agriculture.

In 2014, Dow had annual sales of more than USD 58 billion and employed approximately 53,000 people worldwide. The Company's more than 6,000 product families are manufactured at 201 sites in 35 countries across the globe.

9.3.2.6 Electro-conductive coatings

Electro-conductive 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 electro-conductive coating applications including CRT screens, photographic films, and electronic device packaging and parts[401].

Umicore Zinc Chemicals (Brussels, Belgium) sells Zano® Al-10, a microfine aluminium-doped zinc oxide with a typical aluminium content of 1wt%. Since Zano® Al-10 is electrically conductive, it can be used to provide permanent anti-static properties or can be used in other applications where electrical conductivity is needed, such as a (partial) replacement for indium tin oxide and other conductive oxides[402].

Company snapshot: Umicore Zinc Chemicals

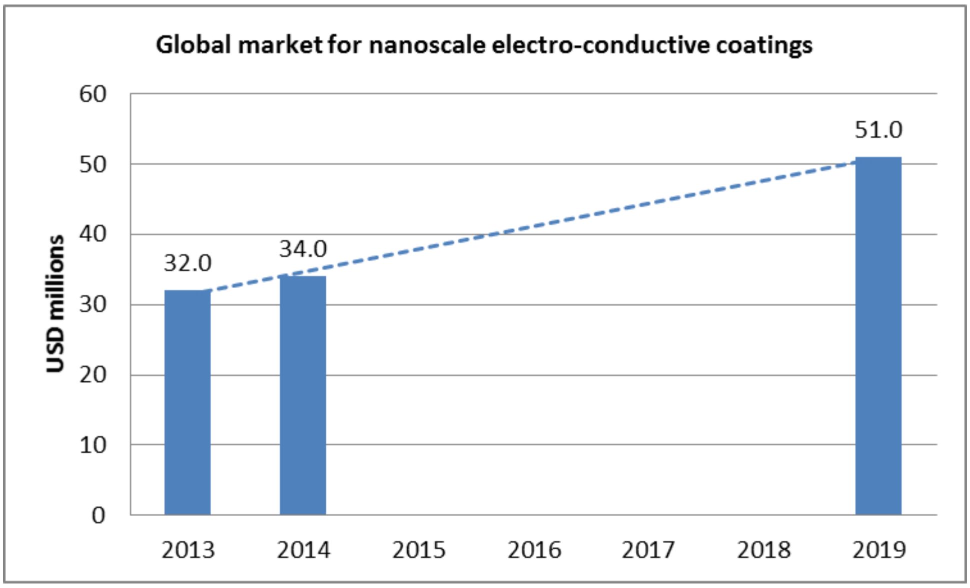
Umicore Zinc Chemicals[403] is the leading recycler of galvanising residues in the world. The company is headquartered in Angleur, Belgium, and has 9 worldwide production sites which deliver over 170,000 tons of end products and have more than 600 employees. Over 100,000 tons of recyclable materials are refined and transformed through proprietary processes into high quality products. The company has three product lines (zinc battery materials, fine zinc powders, zinc oxides), and is also the global leader in the production of zinc compounds.

Its specialty chemicals are used in a wide variety of applications for consumer goods and industrial applications. For example, the product Zano® (Umicore's specialty zinc oxide which combines broad-band UVA/UVB absorption properties with high levels of transparency) is used in a wide range of fields such as personal care and sun-care applications, plastics applications and electronic applications. Within the electronics applications of Zano®, the company produces Zano®Al, a specialty aluminium-doped nano sized zinc oxide with electro conductive properties which provides infra-red light blocking properties, combined with broad-band UVA/UVB absorption.

MARKET DATA AND FORECASTS

The global market estimate for nanoscale electro-conductive coatings was USD 32 million in 2013, and growing at a CAGR of 8.4% (between 2014 and 2019), to reach USD 51 million by 2019[404].

[401] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.66
[402] Umicore Zinc Chemicals, product info on Zano® Al-10
[403] http://www.umicore.com/
[404] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.159



Source: BCC Research

Figure 9-11: Global market for nanoscale electro-conductive coatings to 2019

9.3.2.7 Electronic shielding (POSS nano-composites)

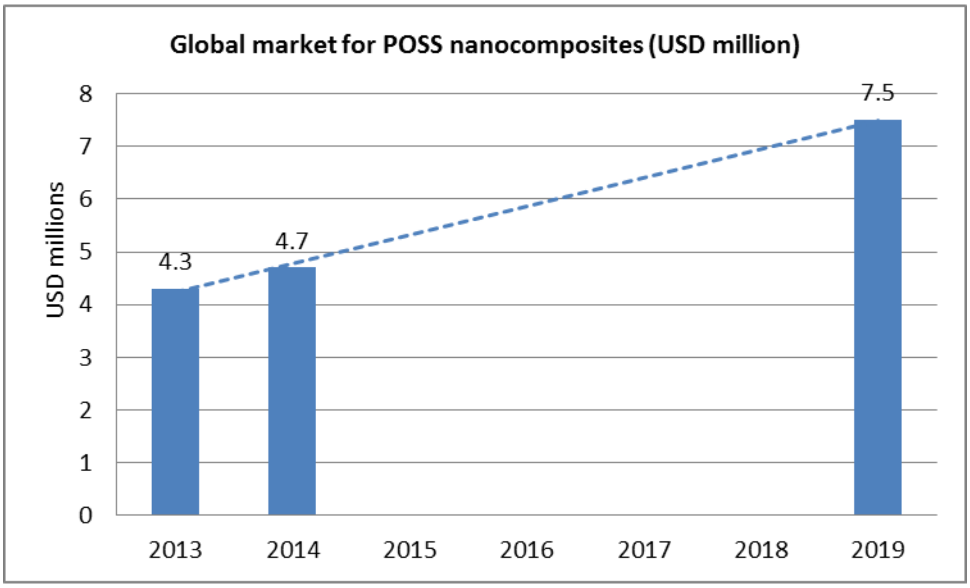
One of the most marketable products of Hybrid Plastics (Hattiesburg, Miss.) has been its polyhedral oligomeric silsesquioxanes (POSS)-based NeuShield plastic chip cap that fits over a computer chip to reduce the effects of neutron-induced memory upsets. These chip caps also can reduce possible memory corruption in X-ray equipment used for treating tumours. The products are much more attractive in terms of cost than off-the-shelf rad-hard chips also used for mitigating radiation effects. The price difference is USD 1-3 per caps for NeuShield (depending on volume) versus USD 20,000 to USD 100,000 each for traditional 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[405].

Company snapshot: Hybrid Plastics

Hybrid Plastics Inc.[406] was founded in 1998 as a spin-out of the Air Force Research Laboratory (ARFL) and it is based in Hattiesburg, Mississippi (US). The company manufactures polyhedral oligomeric silsesquioxane (POSS) nanostructured chemicals, flow aids, dispersion aids, and thermoset resins. Its products include various R&D chemicals and bulk chemicals; thermosets, such as formulated thermosetting resins for coatings, adhesives, and composites; thermoplastics, including masterbatch formulations of common thermoplastics; various POSS chemicals and formulated materials for use in electronics applications; and POMS and nanopowders, which include POSS chemicals with a metal in one corner for catalysis, and predispersed pigments/fillers. The company also provides dispersion, compounding, and formulation services. It sells its products in the United States and internationally (with 40% of its sales overseas). Hybrid Plastics had sales of USD 4.3 million in 2013. Its plant in Mississippi, which was completed in 2007, has the capacity to produce up to 500,000 pounds per year of POSS nanocomposite.

405 BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.87
406 http://hybridplastics.com/

MARKET DATA AND FORECASTS



Source: BCC Research

Figure 9-12: Global market for POSS nanocomposites to 2019

If Hybrid Plastics achieves full production capacity at its plant in Mississippi, US, and is the sole supplier, the market value of olyhedral oligomeric silsesquioxanes (POSS) for electronic shielding would be USD 7.5 million in 2019 (given an estimated price of USD 15/pound)[407].

EMERGING MARKETS

GRAPHENE HEAT SPREADERS

Silicon-on-insulator (SOI) wafers and designs offer major advantages over traditional silicon device structures such as improved electrical isolation, reduced parasitic capacitances, improved radiation hardness and higher packing density. Traditional devices can also suffer from unwanted thermal effects that can lead to performance degradation and premature thermal breakdowns. The smaller components become and the higher the circuit speeds, the greater the problems associated with heat generation, power densities and temperature rise. Efficient thermal management becomes an integral part of the device design for long-term reliability and optimum performance. One possible solution for removing heat from the localised hot spots is to incorporate chips with materials that have very high thermal conductivity, i.e. high-heat flux (HHF) thermal management such as graphene which exhibits extremely high intrinsic thermal conductivity[408]. Developments in this area include:

- A North Carolina State University researcher in 2012 developed a technique that uses a heat spreader made of a copper-graphene composite, which is attached to the electronic device using an indium-graphene interface film, both of which have higher thermal conductivity, allowing the device to cool efficiently. The copper-graphene film's thermal conductivity allows it to cool approximately 25% faster than pure copper, which is what most devices currently use[409].
- A research team led by scientists at Chalmers University of Technology in Sweden found in 2013 that multiple layers of graphene— a two-dimensional material comprised of carbon atoms arranged in a hexagonal pattern—demonstrate strong heat conducting properties that could be used to remove heat from inside electronic devices. In their study, the researchers focused on altering the temperature in the most heat-intensive areas of an electronic device—such as inside

[407] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.179
[408] Subrina S, et al. (2009), Graphene Heat Spreaders for Thermal Management of Nanoelectronic Circuits, University of California – Riverside (UCR), p.1
[409] Electronics Cooling: Researcher Finds Cheaper Way To Cool Electronic Devices, April 20 2012

a processor—reducing it by as much as 25%[410].

- CVD diamond film coatings, produced since the early 1990s, can be used as heat-spreading materials similar to what is proposed with graphene. It is estimated that worldwide sales of CVD diamond for thermal management applications had reached about USD 15 million five years after their introduction to the market. By analogy, sales of graphene thermal management technologies could reach similar levels in 2019, if commercialisation takes place in the coming year[411].

9.3.2.8 Components

EXISTING APPLICATIONS

A MULTILAYER CERAMIC CAPACITORS

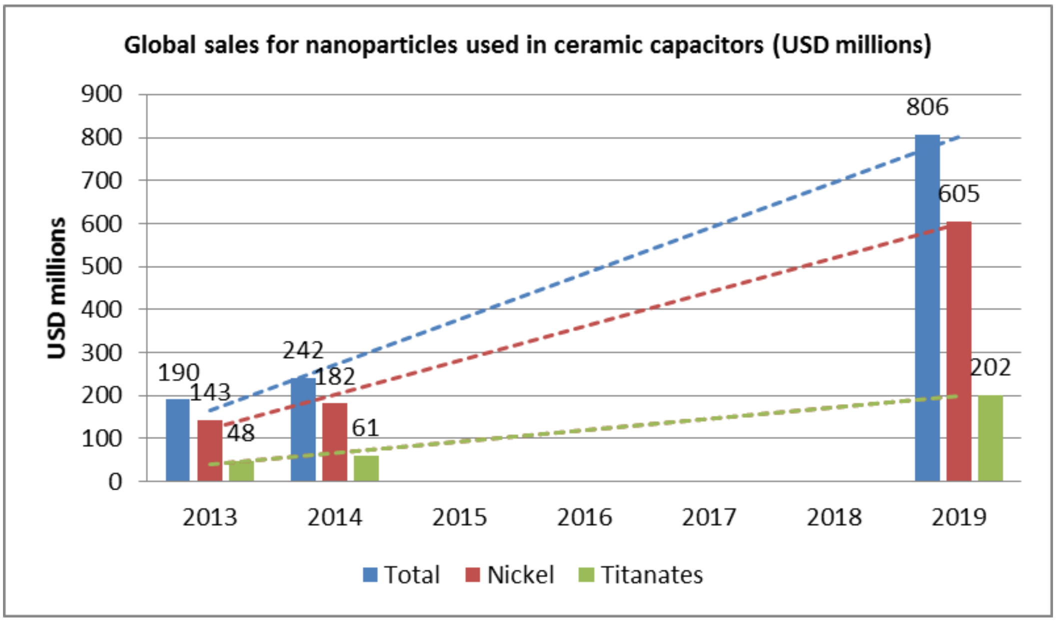
Multilayer ceramic capacitors, or MLCCs, are important building blocks in modern electronics and make up approximately 30% of the total components in a typical hybrid circuit module. Multilayer capacitors consist of a monolithic ceramic block with comb-like sintered electrodes. These electrodes come to the surface at the face ends of the ceramic block where an electrical contact is made by burnt-in metallic layers[412].

Nanoscale barium titanate or strontium titanate powders are typically used to form the dielectric ceramic layers and noble metals (e.g. platinum or silver-palladium) the internal electrode layers of MLCCs. Given the rising costs of noble metal powders, substitutes are being sought, using base metal powders such as nickel to form the internal electrodes. To produce the capacitor from the powders, the dielectric powder is 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. A stack of green sheets interspersed with conductive paste layers is formed and then fired to obtain the multilayer ceramic capacitor[413].

MARKET DATA AND FORECASTS [414]

It has been estimated that global MLCC output was 1.7 trillion units in 2013, 5% of the units (i.e., 85 billion units) being fabricated using nanoscale powders. Given that materials costs are estimated to represent 28% of the selling price of an MLCC and, in 2013, the average MLCC selling price was USD 0.01, the average materials cost is USD 0.0028 per MLCC. The total materials cost of the estimated 85 billion MLCCs fabricated using nanoparticulate materials in 2013 was thus USD 238 million. It is estimated that 20% of that market is titanate-based (USD 143 million) and 60% is nickel-based (USD 143 million) as shown in the figure below.

[410] Electronics Cooling: Graphene Heat Spreader Reduces Hotspot Temperatures, July 8 2013
[411] Ibid
[412] Future Electronics: What is a ceramic capacitor
[413] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.37
[414] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.132



Source: BCC Research

Figure 9-13: Global sales for nanoparticles used in ceramic capacitors to 2019

Global consumption of MLCCs has increased at a CAGR of 12.9% since 2004. The projections in the figure above assume that MLCC consumption continues to grow at a CAGR of 12.9%, reaching nearly 3.6 trillion units by 2019. The projections further assume that 10% (360 billion) of the MLCCs produced in 2019 incorporate titanate and nickel nanoparticles.

B 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). Their magnetic properties give the nanocomposites several existing and potential applications[415].

Various magnetic nanocomposites are in commercial use, under study or in development. Commercial products include several "nanomagnetic alloys" such as Hitachi's Finemet and Magnetec GmbH's Nanoperm. Despite being called alloys, these nanomagnetic materials fit the definition of nanocomposites. They are composed of nanoscale single-domain nanocrystalline iron particles in an amorphous matrix. At present, nanomagnetic alloys are manufactured by crystallisation of rapidly solidified amorphous ribbons. Other potential methods of fabrication include electrodeposition. Electrodeposited magnetic alloys reportedly are being developed in Canada. The structure of materials such as Finemet and Nanoperm gives them unique magnetic properties, including the lowest energy losses of any known materials along with very high permeabilities. These materials can also exhibit nearly zero or zero magnetostriction. These properties create a wide range of potential applications for nanomagnetic alloys including low-loss transformers as well electronic devices, where they provide superior electromagnetic noise suppression. Another potential application includes spintronics[416].

Company snapshot: Magnetec GmbH

Founded in 1984 in Langenselbold, Germany, Magnetec GmbH[417] is a company developing and producing high grade tape wound ring cores and components made of soft magnetic alloys NANOPERM® and MAGNEPERM®. The main application areas are mains-independent (mechanical) earth leakage circuit breakers (ELCB), current transformers for modern

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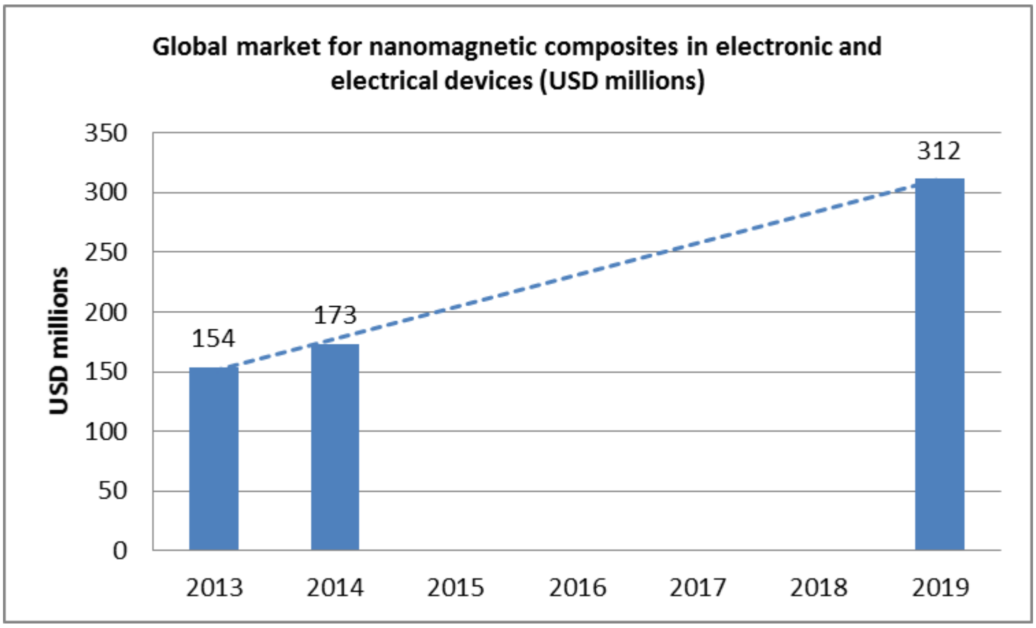
415 Erokhin S, et al. (2011), Magnetic nanocomposites: new methodology for micromagnetic modeling and SANS experiments, Cornell University,Working paper, p.1
416 BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.85
417 http://www.magnetec.de/

electronic metering and the full range of power electronics/EMI. Magnetec currently has around 400 employees and worldwide facilities (in Hungary since 1989 and in China since 2009). The turnover of the company in 2013 was c. EUR 26 million. MAGNETEC supplies to companies such as ABB, Siemens, GE and Schneider Group.

MARKET DATA AND FORECASTS

Total consumption of nanomagnetic composites in low-loss transformers and other electrical and electronic devices was 4,820 tons with a value of USD 153.9 million in 2013. It has been forecast[418] that the overall market for nanomagnetic materials will at a CAGR of 12.5% between 2014 and 2019. Applying this growth rate to 2013 consumption of nanomagnetic composites and assuming it continues through 2019 yields the projections shown in the following figure[419].



Source: BCC Research

Figure 9-14: Global market for nano-magnetic composites in electronic and electrical devices to 2019

EMERGING MARKETS

This section looks at the emerging applications of:

A. Photonic add/drop filters;
B. Optical switches;
C. Optical amplifiers (op amps);
D. Digital image sensors; and
E. Transparent electrodes.

A PHOTONIC ADD/DROP FILTERS

An important device for optical communications and in many other applications is a channel-drop filter. Given 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

418 BCC Research, Nanomagnetics: Materials, Devices and Markets
419 BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.178

another waveguide (called the drop waveguide)[420].

A number of technologies are used in 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. While there is no nanocomposite add/drop filters are currently on the market, they are seen as one of the most promising applications of these materials in photonics applications[421].

The market for photonic crystal add/drop filters is projected to grow from zero in 2013 and 2014 to USD 43.3 million in 2019 (with sales of all types of optical add/drop filters approaching USD 1.4 billion by 2019). If companies developing photonic crystal add/drop filters can bring a commercial project to market in the next few years, it is forecast that they could capture 10% of the total market by 2019, for total sales of USD 140 million. For the optical industry as a whole, material costs represent nearly one-third of the total value of deliveries, implying that consumption of PBG nanocomposites used to manufacture add/drop filters might be approximately USD 43 million in 2019[422].

B OPTICAL SWITCHES

Optical switches are all-optical fibre-optic switching devices that maintain the signal as light from input to output. In this they differ from traditional switches that connect optical fibre lines which are electro-optic. Electro-optic switches convert photons from the input side to electrons internally in order to do the switching and then convert back to photons on the output side. Although some vendors call electro-optical switches "optical switches," true optical switches support all transmission speeds. Unlike electronic switches, which are tied to specific data rates and protocols, optical switches direct the incoming bit stream to the output port no matter what the line speed or protocol (IP, ATM, SONET). Optical switches may also separate signals at different wavelengths and direct them to different ports[423]. Quantum dots can further help to improve the performance of all-optical switches by allowing for higher switching speeds, smaller size and lower power consumption.

In 2003, Evident Technologies, Inc. issued a United States Patent (Number 6,571,028) for an all-optical switch or optical transistor. The optical transistor is based upon a saturable absorber or switch using the company's EviDots semiconductor nanocrystal quantum dot technologies. The optical switch has the potential to switch at speeds up to thousands of times faster than current generation optical switching[424]. The quantum dots, which are manufactured of lead sulphide or lead selenide via a thermal precipitation or colloidal growth process, are contained in a matrix or glass, silicon or other material. The intensity of light required to saturate the absorber depends on the size and composition of the quantum dots, and the concentration of dots determines how thick a slab of matrix material is required to produce a given change in intensity of the signal[425].

No quantum dot optical switches are currently on the market, and the timing of their eventual commercial introduction is unknown. However, given their advantages versus competing technologies, it is forecast that quantum dot switches could reach the market before 2019 and the overall optical switch market could exceed USD 1.2 billion by 2019. It is difficult to quantify quantum dot switches' potential share of the 2019 optical switch market with any certainty, especially in view of uncertainty about the timing of their introduction. However, if they capture 2% to 5% of the optical switch market, the market value would be USD 24 million to USD 60 million (or a mean of USD 42 million) by 2019. If material costs represent nearly one-third of the total cost of these devices, the market for PBG nanocomposites in optical switches could reach USD 14 million by

[420] http://ab-initio.mit.edu/photons/ch-drop.html
[421] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.91
[422] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.184
[423] http://www.pcmag.com/encyclopedia/term/48554/optical-switch
[424] ScienceBlog: Evident Technologies Granted US Patent for Optical Switch based on Quantum Dots, Jun 9, 2003
[425] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.91

2019[426].

C OPTICAL AMPLIFIERS (OP AMPS)

In order to transmit signals in optical communication systems over long distances (>100 km) it is necessary to compensate for attenuation losses within the fibre. Initially this was accomplished with an optoelectronic module consisting of an optical receiver, a regeneration and equalisation system, and an optical transmitter to send the data. Although functional, this arrangement is limited by the optical to electrical and electrical to optical conversions. Optical amplifiers have been developed to overcome these drawbacks. Currently the two types of optical amplifiers in most common use are semiconductor optical amplifiers (SOA) and rare earth doped fibre amplifiers (erbium – EDFA 1500 nm, praseodymium – PDFA 1300 nm)[427].

Optical amplifiers having nano-sized semiconductor particles, called quantum dots, show attractive features such as an ultra-wide operating wavelength range, suppressed waveform distortion in high power output, and capability of noise reduction (signal regeneration) by limiting amplification. With these features, the quantum-dot devices have been developed targeting applications in optical communication systems such as inline, booster, and preamplifiers, and are presently in the stage of commercialisation. 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-tunable lasers and mode-locked lasers[428]. 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, especially erbium amplifiers[429].

Nanoparticle-based optical amplifiers were not yet available commercially in 2013 and 2014. Global sales of all types of optical amplifiers are projected to reach USD 2.8 billion by 2019. If quantum dot PBG nanocomposite devices can capture 10% of this market, the forecast sales would be USD 280 million in 2019. At one-third of the total cost of optical amplifiers for materials, the related consumption of quantum dot PBG nanocomposites is projected to reach USD 93.3 million by 2019[430].

D DIGITAL IMAGE SENSORS

Digital image sensors can be used to record electronic images. The most commonly recognised application of the digital image sensor is the digital camera. In digital cameras, the image sensor is used in conjunction with a colour separation device and signal processing circuitry to record images. The two main technologies used to fabricate the sensors are CCDs (Charge Coupled Devices) and CMOS (Complementary Metal-Oxide Semiconductors)[431].

InVisage Technologies (Menlo Park, Calif.) is commercialising QuantumFilm (QF) technology to replace the conventional complementary metal-oxide semiconductor (CMOS) image sensor. QF technology works by suspending quantum dots within a special polymer film. The film is then "spun" or painted on top of a traditional CMOS wafer. The quantum dot film captures all the light that hits the top of the chip and sends it directly to the silicon chip. In a conventional CMOS image sensor, light typically has to pass through layers with metal connections before it hits a photo detector, which blocks out about half the photons. By putting the film on top of the chip, and by having more efficient materials, InVisage proposes to create a sensor that is four times more sensitive to light with twice the dynamic range of the typical CMOS sensor. According to InVisage, its new technology will enable higher resolution for cameras and much better low-light performance, particularly in contrast to the sensors used in today's camera phones.

InVisage Technologies' first QuantumFilm image sensors, targeting high-end mobile handsets and smartphones, are scheduled to be deliverd sometime after 2014. It is estimated that 100 million QuantumFilm sensor-equipped handsets will be sold in 2019. QuantumFilm sensors are expected to

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[426] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.184
[427] Kostuk R (2006), Optical Amplifiers, mimeo
[428] 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
[429] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.92
[430] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.185
[431] https://illumin.usc.edu/101/the-digital-image-sensor/

cost the same as the CMOS sensors they replace (c. USD 5 each) making a total market value of USD 500 million in 2019. 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 to fabricate the USD 500 million worth of QuantumFilm sensors it is estimated that the market will require in 2019[432].

E TRANSPARENT ELECTRODES

Transparent conducting oxides (TCOs), or transparent electrodes, are electrically conductive materials with a comparatively low absorption of light. They are usually prepared using thin-film technologies and are used in opto-electrical devices such as solar cells, displays, opto-electrical interfaces and circuitries. Glass fibres are nearly lossless conductors of light, but electrical insulators; silicon and compound semiconductors are wavelength-dependent optical resistors (generating mobile electrons), and dopant-dependent electrical conductors[433]. To date, the industry standard in TCOs is ITO, or tin-doped indium-oxide.

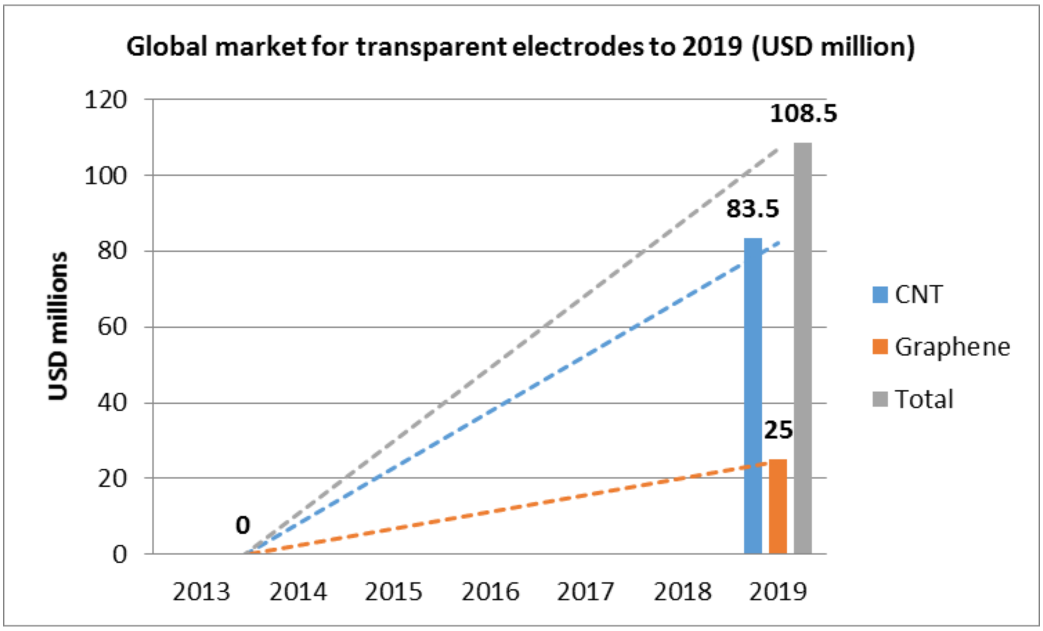
Unidym (Sunnyvale, Calif.) has developed a carbon nanotube-based transparent electrode intended to replace the indium tin oxide (ITO) currently used in such products as touch screens, LCD displays, solar cells and OLEDs. Unidym's CNT-based films are reportedly more mechanically- and chemically-robust than ITO and can be deposited using a variety of low-cost methods. Unidym has been providing samples to potential customers in the touch screen, LCD display, OLED and solar industries. While no date has been set for commercial production of CNT-based films, it is forecast that commercialisation is likely to take place in the 2014 through 2019-time frame[434].

Graphene is another promising material to replace ITO as a TCO in transparent electrodes. The project GLADIATOR, which is funded by the European Commission, has reached its mid-term point and has already achieved some successes. The aim of the project is the cost-effective production of high quality graphene over large surface areas, which can then be used for numerous electrode applications. The usability of such applications will be demonstrated by Fraunhofer FEP by integrating this graphene in OLEDs. With graphene as an electrode, the researchers at the Fraunhofer FEP hope to create flexible devices with higher stability. The GLADIATOR project will run until April 2017. By this time, several types of OLEDs will have been made using graphene electrodes: a white OLED with an area of about 42 cm^2 to demonstrate the high conductivity, and a fully-flexible, transparent OLED with an area of 3 cm^2 to confirm the mechanical reliability[435].

In March 2013, the Chinese firm Chongqing Morsh Technology Co. Ltd received an order from Guangdong Zhengyang Technology Incorporated Company to supply at least 10 million graphene conducting film products per year for five years[436].

Two nanomaterial-based thin film technologies are candidates to replace the indium tin oxide (ITO) currently used in touch screens, LCD displays, solar cells, OLEDs and other electronic devices. Annual consumption of ITO for these applications is approximately USD 1 billion for the material alone (i.e. excluding deposition costs). These new technologies are 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 109 million by 2019, as shown in the figure below[437].

[432] BCC Research (2014), Nanotechnology: A Realistic Market Assessment p.138
[433] Andreas Stadler (2012), Transparent Conducting Oxides — An Up-To-Date Overview. Materials 2012, 5: 661
[434] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.69
[435] http://cordis.europa.eu/news/rcn/128114_en.html
[436] Investorintel: Chinese Firms to launch First Mass Produced 15" Single-layer Graphene Film, March 27, 2013
[437] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.163



Source: BCC Research, 2014

Figure 9-15: Global market for transparent electrodes to 2019

Case study: Luxtera Inc.

Luxtera Inc.[438] was established in Carlsbad, California in 2001. It is a Caltech spin-out with funding from venture capital, its business partners, and DARPA. Luxtera has also received funding from leading venture capitalists including August Capital, New Enterprise Associates, Sevin Rosen Funds and Lux Capital. In 2010, Luxtera was selected as one of MIT Technology Review's 50 Most Innovative Companies.

Luxtera is a fabless semiconductor company that is using silicon photonics technology to develop electro-optical systems in a production silicon CMOS process. It was the first company on the market with a product that monolithically incorporates active optics for data communications manufactured with low-cost silicon-based chip processing. This sort of technology (which has been largely industrialised by companies like IBM or Intel) is widely expected to accelerate the development of large portions of the existing photonics industry that rely on distinct assemblies of electronic and photonic devices. Luxtera's partner is Freescale Semiconductor (fabricates Luxtera's chips).

Luxtera is well-positioned to address three main market needs by providing low cost, long reach optics, leveraging its silicon photonics technology:

1. The network market: Networks are changing to more flattened networks and now have a need for low cost, long reach optics. Cloud data centres are becoming "hyper scale", meaning they are growing to a massive size and in some cases, require multiple massive structures in a campus location.
2. The server market: Data rates are increasing, and there is a shift in the market to disaggregate servers into pieces that consist of processors (CPUs), memory, and networking interfaces. Once the server is disaggregated, the individual pieces are best interconnected via optics.
3. The mobile infrastructure market: The demand for smartphones is creating great demand for high bandwidth in mobile devices. Base stations are becoming more complex and require a rapidly increasing number of long distance optical connections

438 http://www.luxtera.com/

Luxtera has currently two main products, among the most advanced on the market:

The LUX62608 OptoPHYs™ are 200G (8 x 26 G) embedded optical modules. OptoPHY offers customers the flexibility of field replaceable, pluggable optical transceivers by interfacing to systems via a 100-pin small form factor connector. The OptoPHY optical transceiver sub-assembly contains eight parallel fibre optic transceivers, each operating at data rates from 1 Gbps up to 26 Gbps and supporting a reach up to 2000 meters over standard single mode fibre.

The LUX42604 QSFP optical modules are faceplate pluggable optical transceivers that meet the 100G (4x26G) PSM4 MSA technical specifications. The LUX42604 delivers full performance up to 25.78 Gbps per channel.

Key figures for Luxtera:

- *Luxtera employs typically 120 people, including at least 30 working in R&D.*
- *The average revenue of the company is USD 22 million (EUR 19.6 million).*
- *2001-2014 fund raising summary: USD 110.6M (EUR 83.2 M) in 6 rounds from 6 investors, last funded on: March 24, 2014 (see below)*
- *2008-2011: Public IPO Secured USD 68 million (EUR 48.9 million) of equity funding for Luxtera, from venture capital and strategic investors during critical 2008/2009 period in difficult financial markets*
- *2011: Molex Inc. (MOLX) acquires Luxtera Inc's "active optical cable" business for more than USD 20 million (EUR 14.4 million). Luxtera rises over USD 22 million (EUR 15.8 million) in venture capital funding from such firms as Austin Capital, Lux Capital, New Enterprise Associates, Sevin Rosen Funds and Western Technology Investment*
- *2012: Horizon Technology Finance Partners on $7.5 million (EUR 5.8 million) Venture Loan Facility for Luxtera.*
- *2015: Horizon Technology Finance: New loans in the third quarter of 2015, USD 833,000 (EUR 744,000) to Luxtera Inc, an existing portfolio company.*
- *2008: Luxtera won a second grant from the Advanced Research Projects Agency (DARPA) to further develop its high-bandwidth CMOS photonics transceiver technology*

Future trends, prospects and expansion: Currently, Luxtera has a partnership with Molex, which ships 40Gbp/s active optical cables, recognised widely for its best in class power consumption, performance and reliability. It also entered into a partnership with STMicroelectronics in 2012. Luxtera's CMOS Photonics™ technology platform is high-performance, low-cost and scalable for decades to come.

The next section looks at technologies that have the potential to develop into markets for nanotechnology in ICT.

9.3.3 Novel technologies for ICT through nanotechnology

Technologies that are expected by stakeholders to have the potential to develop into markets for nanotechnology in ICT are discussed below. They are:

- Quantum computing;
- Spintronics; and
- Valleytronics.

A Quantum computing

A quantum computer operates according to the principles of quantum mechanics, the physics of very small things, such as electrons and photons. In a classical computer, a transistor stores a single "bit" of information which can either be in an on (1) or off (0) configuration. By virtue of the superposition principle, a quantum computer holds information (as a 'qubit') such that it can exist in two states, as a 1 and a 0, at the same time. As one qubit can hold two values (1,0) and two qubits can hold four values, and at any given time (00, 01, 10, and 11) and so on, by increasing the number of qubits, the computing power of the system increases exponentially. Quantum computing is limited by its coherence, its ability to retain its multiple states without reverting to a classical bit with only a single value[439]. While quantum computers are better in terms of capacity (useful for image and speech recognition, real-time language translation, and data-crunching on a large scale the data from sensors, medical records and stockmarkets), they do not offer improvements in the speed of downloads or the quality of graphics[440].

D-Wave Systems (Burnaby, Canada) is reported to be the world's first quantum computing company. On May 11, 2011, D-Wave Systems announced D-Wave One, described as "the world's first commercially available quantum computer," operating on a 128-qubit chipset using quantum annealing (a general method for finding the global minimum of a function by a process using quantum fluctuations) to solve optimisation problems[441]. Major clients of D-Wave Systems include Lockheed-Martin, Google, NASA, and USC. D-Wave has been granted over 110 US patents and has published over 80 peer-reviewed papers in leading scientific journals.[442] [443]

Company snapshot: D-Wave Systems

D-Wave Systems Inc.[444] was founded in 1999 and is based in Burnaby, Canada. The company develops, fabricates, and integrates superconducting quantum computers. The company offers The D-Wave Two System, a commercial quantum computer. Its quantum computers are used in various applications, including mission planning/scheduling and logistics, software/hardware validation and verification, pattern recognition and anomaly detection, network science and graph theory applications, image and pattern recognition, machine learning, communication, advanced search, optimisation problems, graph theory problems, material science, climate modelling, bioinformatics, weather predictions, exploring quantum computing, risk modelling, trading strategies, financial analysis and forecasting, energy exploration, seismic survey optimisation, reserve and spot trading optimisation, and reservoir optimisation. It also provides professional services, training, and customer support services. The company's products are also used in water network optimisation, radiotherapy optimisation, protein folding, object detection, labelling news stories, Monte Carlo simulation, and video compression applications. The company serves defence, Web, national laboratories, universities, finance, and energy industries.

D-Wave Systems Inc. has raised USD 123.83 million in 10 Rounds from 14 Investors, with the most recent venture investment in January 2015 (USD 29 million). The company had around 60 employees in 2013.

In June 2015, QuTech, an initiative by TU Delft and TNO developing quantum technology, received the approval for a 10-year investment of EUR 135 million from a group of six private and governmental parties. The aim of the tech-institution is to develop a quantum computer. In 2014, QuTech was nominated as National Icon in the category of innovative projects that provide extra support for the citizens of the Netherlands. Since 2010, the company has been receiving financial support from Microsoft. QuTech has approximately 100 scientists in its employment, a figure they hope to double in the coming years[445]. In October 2015, Intel announced its support for QuTech, albeit that it has been said that, from Intel's perspective, practical applications of quantum computing are still several years away[446].

B SPINTRONICS

Spintronics, or spin electronics, refers to the study of the role played by electron (and more generally nuclear) spin in solid state physics, and possible devices that specifically exploit spin properties instead of, or in addition, to charge. The prototype device that is already in use in industry as a read

[439] WIRED: Google's Quantum Computer Just Got a Big Upgrade, September 28, 2015
[440] The Economist: Quantum computers - A little bit, better, June 20, 2015
[441] Gosh A, Mukherjee S (2013), Quantum Annealing and Computation: A Brief Documentary Note, SCIENCE AND CULTURE (Indian Science News Association), vol. 79: 485
[442] http://www.dwavesys.com/our-company/meet-d-wave
[443] EXTREMETECH: Did Google's quantum computer just get the biggest processor upgrade in history? October 1, 2015
[444] http://www.dwavesys.com/
[445] DAFNE: QuTech Receives €135 Million to Build Quantum-Computer, June 3 2015
[446] Forbes Tech: Quantum Computing: From Theory To Reality, September 4, 2015

head and a memory-storage cell is the giant-magnetoresistive (GMR) sandwich structure which consists of alternating ferromagnetic and nonmagnetic metal layers. Depending on the relative orientation of the magnetisations in the magnetic layers, the device resistance changes from small (parallel magnetisations) to large (antiparallel magnetisations). This change in resistance (also called magnetoresistance) is used to sense changes in magnetic fields[447].

Current efforts in designing and manufacturing spintronic devices involve two different approaches. The first is perfecting the existing GMR-based technology by either developing new materials with larger spin polarisation of electrons or making improvements or variations in the existing devices that allow for better spin filtering. The second, which is more radical, focuses on finding novel ways of both generation and utilisation of spin-polarised currents. These include investigation of spin transport in semiconductors and looking for ways in which semiconductors can function as spin polarisers and spin valves[448]. Activities in this technology area include:

- NVE Corporation (Eden Prairie, MN, USA) manufactures spintronic products including sensors and couplers that are used to acquire and transmit data. Their designs use one of two types of patented spintronic nano-scale structures: spin-dependent tunnel junctions and giant magnetoresistors (GMR). Both structures produce a large change in electrical resistance depending on the predominant spin of electrons in a thin metal layer. In this way electron spin can be converted to an electrical signal compatible with conventional electronics[449].
- QuantumWise recently announced the 2015 version of their Virtual NanoLab and Atomistix ToolKit atomic-scale modelling platform software. This is a research tool to help in the modelling of spintronics. The new version includes added features such as electron-phonon interaction, analysis functions for molecular dynamics simulations. Specifically, for spintronics research, there are improvements for non-collinear and spin-orbit calculations. In addition, spin-orbit coupling has been updated to perform better. The company also announced that Virtual NanoLab (but not ATK) is now available free of charge to academic users.[450]
- Researchers from the Lomonosov Moscow State University together with British scientists discovered recently that superconductivity is able to promote magnetisation in certain conditions. Using this effect may lead to faster spintronic devices. The researchers say that superconducting spintronic devices will demand far less energy and emit less heat compared to current devices. The superconductors may be useful in the process of spin transportation while ferromagnetics may be used to control spins[451].

C Valleytronics

Valleytronics is cutting-edge electronics research using the wave quantum number of an electron in a crystalline material to encode data. The "valley" in valleytronics comes from the shape of the graph when the energy of electrons is plotted relative to their momentum: the resulting curve features two valleys. Electrons move through the lattice of a 2D semiconductor as a wave populating these two valleys, with each valley being characterised by a distinct momentum and quantum valley number. If the two valleys can be manipulated so that one is deeper than the other, the electrons populate one valley more than the other. When the electrons are in a minimum energy valley, the quantum valley number associated with it can be used to encode information[452]. Developments in this area include:

- Researchers at the Lawrence Berkeley National Laboratory (LBL) have recently developed a new pathway to achieving "valleytronics" using two-dimensional (2D) semiconductors. The LBL researchers believe that this new approach could make valleytronics a more stable alternative to "spintronics" as a replacement for traditional electronics. The team used the 2D material called tungsten diselenide in conjunction with a phenomenon known as the "optical Stark effect" to selectively control photoexcited electrons/hole pairs—excitons—in different energy valleys. The Stark effect involves the shifting and splitting of spectral lines of atoms and molecules when

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[447] http://www.physics.umd.edu/rgroups/spin/intro.html
[448]Ibid
[449] http://www.nve.com/spintronics.php
[450] http://www.spintronics-info.com/quantumwise-releases-new-version-their-atomic-scale-modeling-platform-software
[451] http://www.nanotech-now.com/news.cgi?story_id=52350
[452] IEEE Spectrum: Is "Valleytronics" the Next Big Thing in Quantum Computing? Februar 5 2015

exposed to an external electric field[453].

- In November 2015, researchers from the University of Tokyo demonstrated an electrically controllable valleytronic device. The device converts regular electrical current to valley current and then passes it through a 3.5 micron channel. The valley current is then converted back to electrical current that can be detected (via its voltage). To create this new device, the researchers used a bi-layer graphene that is placed between two insulator layers made from hexagonal boron nitride (hBN). This structure is then placed between two conductive layers (or gates) which control the valley. This device operates at -203 degrees Celsius - much higher than expected, and the researchers hope that in the future devices such as this could operate at room temperature[454].

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

[453] Ibid
[454] http://www.eurekalert.org/pub_releases/2015-11/uot-vcc111215.php

10 THE WIDER ENVIRONMENT FOR NANOTECHNOLOGY AND ICT

10.1 Regulation and standards for nanotechnology

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.

10.1.1 European regulations for nanotechnology

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. The European Union is well-advanced but not alone in seeing the need for greater scrutiny on the use of nanotechnologies. With the *first Regulatory Review on Nanomaterials SEC (2008) 2036* and the *Second Regulatory Review on Nanomaterials SWD (2012) 288 final*, the EC has given *Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)* a central role in regulating nanomaterials. *"There are no provisions in REACH referring explicitly to nanomaterials. However, nanomaterials are covered by the 'substance' definition in REACH",* states the 2008 Communication. A third Regulatory Review is planned in 2016.

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

To facilitate regulation, inter alia, a definition of nanomaterials has been defined by the European Commission in its Recommendation on the Definition of a Nanomaterial - 2011/696/EU. This non-binding document has also been used by other pieces of regulation to define the term 'nanomaterial'.

The definition is the following:

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

Developed in 2011, this definition is undergoing a review process that should have been concluded in December 2014; an outcome of this review could be a revision of the definition.

The table below lists some key regulatory documents within the European Union as a whole and within Member States. Nano-specific regulations–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 including ICT).

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

Status	Name of the document	Country/ Region	Scope	Nano-specific
Implemented	Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) - 1907/2006(EC)	EU	Chemicals & Raw Materials,	No, but 'substance' covers nanomaterials
Implemented	European Commission Recommendation on the Definition of a Nanomaterial	EU	Substances at the Nanoscale	Yes
Implemented	Decree on the annual declaration on substances at nano-scale - 2012-232	France	Substances at the nano-scale)	Yes
Implemented	Royal Decree regarding the Placement on the Market of Substances manufactured at the Nano-scale	Belgium	Substances Manufactured at the Nano-scale	Yes
Implemented	Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register – BEK no. 644	Denmark	Nanomaterials	Yes

There are also efforts underway within the research community to develop a testing strategy for engineered nanomaterials. 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.[455]

While the European Union has been developing a regulatory framework for nanomaterials under REACH, some European Member States (as in the table above) have sought to find additional ways to regulate nanotechnologies e.g. through databases and reporting schemes for nanomaterials.

Under the Belgian Presidency of the European Union, in 2010, the European Union opened the discussion on a 'harmonised database of nanomaterials'; it was followed by a 2012 letter to the European Commission calling for a European Reporting Scheme, signed by 10 then European Member States, plus Croatia.

The French *Grenelle Acts (Lois Grenelle I & II)* led to the creation of a mandatory reporting scheme for nanomaterials. In 2012, the Decree[456] 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 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[457]. The registration of substances will begin from 1 January 2016, while mixtures will be registered from 1 January 2017.

In June 2014, the Danish *Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register - BEK nr 644* came into force. With this Order, the Ministry of the Environment created a national mandatory database of nanomaterial-containing products that will register the first products (for 2014) in 2015.

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

10.1.2 Nanotechnology regulation 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'.

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)*.

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[458]),

[455] http://www.its-nano.eu
[456] 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
[457] *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*
[458] US Food and Drug Administration http://www.fda.gov/

Canada, Australia, China and Japan.

10.1.3 Standardisation and nanotechnology

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

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.

10.2 Environment, health and safety and nanotechnology

This section presents an analysis of the human health and safety aspects of eight of the more commonly used materials for ICT: gallium arsenide, gallium nitride, molybdenum disulphide, tungsten selenide, silica (amorphous and crystalline), graphene and silver. The selection was based on their common usage and/or likely future usage in ICT. It was not intended that the review be exhaustive and more materials can be added at a later date if required.

The basis for the evaluation was "Stoffenmanager Nano" application[459, 460], a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios.

The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in production facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries[461]. In view of the nature of the products in this sector, oral exposure of consumers is also considered to be minor.

The dermal route may be the main route of exposure for some substances or exposure situations, and cause local effects on the skin or systemic effects after absorption into the body[462]. However, nanoparticles as such are very unlikely to penetrate the skin[463] and consequently nano-specific systemic toxicity via the dermal route is improbable. Therefore, when evaluating risks from nanotechnology for the respiratory route, the most important aspects of occupational and consumer safety are covered.

10.2.1 Hazard assessment of nanoparticles

In Stoffenmanager Nano, the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). The table below presents an overview of selected nanoparticles of the ICT sector and their hazard bands, either taken from le Feber et al. (2014)[464] or van Duuren et al. (2012)[465] or derived in this project.

Table 10-2: Hazard bands for the specified nanoparticles

Nanoparticles	Hazard band	Source
Gallium Arsenide	D	This report
Gallium Nitride	n/a	no data
Graphene	E	This report
Molybdenum Disulphide	C	This report
Silicon Dioxide (silica), Synthetic Amorphous	C	le Feber et al. (2014)
Silicon Dioxide (silica), Crystalline	E	van Duuren et al. (2012)
Silver	D	le Feber et al. (2014)
Tungsten Selenide	n/a	no data

[459] Marquart, H., Heussen, H., Le Feber, M., Noy, D., Tielemans, E., Schinkel, J., West, J., Van Der Schaaf, D., 2008. 'Stoffenmanager', a web-based control banding tool using an exposure process model. Ann. Occup. Hyg. 52, 429-441.

[460] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

[461] ECHA, 2012. Chapter R.14: Occupational exposure estimation in: Anonymous Guidance on Information Requirements and Chemical Safety Assessment., Version: 2.1 ed. European Chemicals Agency, Helsinki, Finland.

[462] Ibid

[463] Watkinson, A.C., Bunge, A.L., Hadgraft, J., Lane, M.E., 2013. Nanoparticles do not penetrate human skin - A theoretical perspective. Pharm. Res. 30, 1943-1946

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

[465] M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

Details of the hazard bands derived for each material are given below, except for silica. The hazard banding of silica nanoparticles has already been reported[466] [467].

GALLIUM ARSENIDE

No toxicity studies on nano-GaAs were encountered in public literature. According to data from the REACH dossier of GaAs, (powdered) GaAs has limited solubility in water (based on released As3+ ions). GaAs is marketed as an article made from very pure (99.9999%) crystalline bulk material, predominantly in the shape of wafers[468], implying an even lower water solubility. Therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent material are used.

GaAs is classified as carcinogenic, but not mutagenic (based on sufficient evidence) by the EU. It should be noted that the classification for carcinogenicity was based on inhalation studies with micronised powdered GaAs, and that the relevance of these studies for human exposure to crystalline GaAs is questioned[469]. Based on the classification of the bulk material, nanoGaAs is attributed hazard band D.

GALLIUM NITRIDE

No relevant toxicity studies on nano-gallium nitride were encountered in public literature. Gallium nitride wafers are virtually insoluble in water, even in dilute acid[470], and therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent material are used.

Gallium nitride is not classified for any toxicity by the EU. However, this absence of classification was based on the lack of data. Besides the gallium ions, which are not considered relevant for gallium nitride since it is insoluble in water[471], only one structurally-similar compound was found using the on-line ChemID database: gallium phosphide, which was characterised as being 80% similar with gallium nitride. For this compound also no relevant toxicity data were found, meaning read-across could not be employed. Therefore, no hazard banding could be derived.

GRAPHENE

Graphene is composed of sp2-hybridised carbon atoms arranged in a two-dimensional structure. The various forms of graphene include few-layer graphene, reduced graphene oxide, graphene nanosheets and graphene oxide (GO)[472].

The UK government body, the Medicines and Healthcare Products Regulatory Agency (MHRA), and the US Food and Drug Administration (FDA) are now reviewing all forms of graphene and functionalised graphene oxide (GO) because of their poor solubility, high agglomeration, long-term retention, and relatively long circulation time in the blood[473].

Currently, limited information about the *in vitro* and *in vivo* toxicity of graphene is available (Seabra, et al. 2014). The toxicity profiles of graphene and graphene oxide (GO) nanoparticles remain difficult to separate, since their characterisation, bulk and chemical composition are very similar at the nanometre length scale (Nezakati, et al. 2014).

In vitro graphene has been demonstrated to be cytotoxic, be it overall to a lesser degree than carbon nanotubes (Seabra, et al. 2014). However, the reliability of this conclusion can be doubted since Seabra et al. stated that graphene showed an inverse dose-relationship, being more cytotoxic than

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

[467] M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

[468] Bomhard, E.M., Gelbke, H.-., Schenk, H., Williams, G.M., Cohen, S.M., 2013. Evaluation of the carcinogenicity of gallium arsenide. Crit. Rev. Toxicol. 43, 436-466

[469] Ibid

[470] Jewett, S.A., Makowski, M.S., Andrews, B., Manfra, M.J., Ivanisevic, A., 2012. Gallium nitride is biocompatible and non-toxic before and after functionalisation with peptides. Acta Biomater. 8, 728-733

[471] Foster, C.M., Collazo, R., Sitar, Z., Ivanisevic, A., 2013. Aqueous stability of Ga- and N-polar gallium nitride. Langmuir 29, 216-220.

[472] Seabra, A.B., Paula, A.J., De Lima, R., Alves, O.L., Durán, N., 2014. Nanotoxicity of graphene and graphene oxide. Chem. Res. Toxicol. 27, 159-168.

[473] Begum et al. 2011 cited in Nezakati, T., Cousins, B.G., Seifalian, A.M., 2014. Toxicology of chemically modified graphene-based materials for medical application. Arch. Toxicol. 88, 1987-2012.

carbon nanotubes at low concentrations. The only elaborate comparative study reported by Seabra et al., refers to genotoxicity towards human fibroblast cells. GO proved to be the most potent genotoxic agent compared to iron oxide (Fe304), titanium dioxide (Ti02), silicon dioxide (Si02), zinc oxide (ZnO), indium (In), tin (Sn), core—shell zinc sulphate-coated cadmium selenide (CdSe(3)ZnS), and carbon nanotubes.

Intratracheal instillation of 50 µg GO in mice caused severe pulmonary distress after inhalation causing excessive inflammation, while the amount of non-functionalised graphene instilled did not[474]. Single intravenous (i.v.) injection of graphene oxide into mice at a dose of 10 mg/kg bw accumulated in the lung resulting in pulmonary oedema and granuloma formation, with NOAEL of 1 mg/kg bw[475]. Furthermore, surface functionalised graphene (PEGylated) appears to be far less toxic: no toxic effects after single i.v. injection of 20 mg/kg bw (Yang, et al. 2011). In mice, PEGylated GO materials showed no uptake via oral administration, indicating limited intestinal absorption of the material, with almost complete excretion. In contrast, upon i.p. injection in mice, PEGylated GO was found to accumulate in the liver and spleen[476].

The toxicity of graphene is dependent on the graphene surface (the chemical structure or the nature of the functionalised coatings), size, number of layers, cell type, administration route (for in vivo experiments), dose, time of exposure, and synthesis methods (Seabra, et al. 2014). Generalisations are therefore hard to make, but graphene nanostructures are not fibre-shaped and theoretically may be assumed to be safer than carbon nanotubes (Seabra, et al. 2014).

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

MOLYBDENUM DISULPHIDE

No relevant toxicity studies on nano-molybdenum disulphide were encountered in public literature. It is insoluble in water and therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent material are used. Molybdenum disulphide is not classified for any toxicity by the EU. Based on this absence of classification, the nanoforms should be assigned hazard band C, the lowest category a nanoparticle can be assigned just based on toxicity data for its non-nano parent compound[477].

TUNGSTEN SELENIDE

No relevant toxicity studies on nano-tungsten selenide were encountered in public literature. Tungsten selenide is also not classified for any toxicity by the EU. However, this absence of classification was based on lacking data. Also on the top five similar compounds retrieved by ChemID (rhenium selenide, tantalum selenide, tungsten telluride, manganese selenide and molybdenum selenide, similarity ranging from 85 to 95%) no relevant toxicity data were found, meaning read-across could not be employed. Therefore, no hazard banding could be derived.

10.2.2 Exposure assessment

Manufacturing of the applied nanomaterials in ICT is a crucial phase regarding health and safety, due to relatively high potentials for exposure of employees. However, the production phase was earlier described in the sector "manufacturing" and will not be evaluated in this sector report.

Most of the engineered nanomaterials are present in the products as part of a matrix. During the manufacture of ICT products engineered nanomaterials may be used and are applied mainly as coatings. For the majority of these coatings, only a low percentage of engineered nanomaterials are

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[474] Duch, M.C., Budinger, G.R.S., Liang, Y.T., Soberanes, S., Urich, D., Chiarella, S.E., Campochiaro, L.A., Gonzalez, A., Chandel, N.S., Hersam, M.C., Mutlu, G.M., 2011. Minimising oxidation and stable nanoscale dispersion improves the biocompatibility of graphene in the lung. Nano Letters 11, 5201-5207.

[475] Zhang, X., Yin, J., Peng, C., Hu, W., Zhu, Z., Li, W., Fan, C., Huang, Q., 2011. Distribution and biocompatibility studies of graphene oxide in mice after intravenous administration. Carbon 49, 986-995

[476] Yang, K., Wan, J., Zhang, S., Zhang, Y., Lee, S.-., Liu, Z., 2011. In vivo pharmacokinetics, long-term biodistribution, and toxicology of pegylated graphene in mice. ACS Nano 5, 516-522. (Cited in Seabra, et al. 2014)

[477] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

present. Some of the identified substances may not necessarily be engineered nanomaterials.

The production phase of ICT products on industrial scale consists mainly of automatic processes, with employees only engaged in product quality control or system engineering. In addition, most processes are performed in cleanrooms and/or under well-controlled conditions, as dust is a major threat to the quality of the products. Nevertheless, spray scenarios for coating normally result in high exposure concentrations, so potential exposure cannot be neglected. In the situation of a manual process without proper exposure control measures (e.g. local exhaust ventilation, cleanroom), employees may be exposed to relatively higher concentrations. Lastly, during the end-of-life phase several metals may be present in the ICT product, which can be worthwhile to recycle. Recycling of these metals may involve, for example, shredding of ICT products, and any engineered nanomaterials could become airborne. However, as the shredded products only will contain a small amount of engineered nanomaterials, potential exposure to engineered nanomaterials during this process will be relatively low.

In conclusion, the use of nanotechnology ICT products results in exposure band 1 (consumers and workers), whereas during the production of nanotechnology ICT products exposure band 2 (workers) is believed to be realistic. Furthermore, during the end-of-life phase an exposure band 1 (workers) is realistic.

10.2.3 Risk assessment

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table below. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures ort to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 10-3: Priority bands in the Stoffenmanager system

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Risks based on the hazard and exposure banding applied to the ICT sector are listed the table below.

Table 10-4: Priority bands for the ICT sector

		Exposure Band	
		Production Phase of ICT Product	Use and End-of-life Phase ICT Products
Nanoparticle	**Hazard Band**	2	1
Gallium arsenide	D	2	2
Gallium nitride	n/a	n/a	n/a
Graphene	E	1	1
Molybdenum disulphide	C	2	3
Silicon dioxide (silica), synthetic amorphous	C	2	3
Silicon dioxide (silica), crystalline	E	1	1
Silver	D	2	2
Tungsten selenide	n/a	n/a	n/a

The highest priority is for graphene and crystalline silica during the production, use and end-of-life phases, while gallium arsenide and nanosilver have intermediate priority in those phases. Molybdenum disulphide and amorphous silica also have intermediate priority in the production phase, but low priority during use and end-of-life phase in view of a lesser potential of exposure in those phases. For gallium nitride and tungsten selenide no adequate data were available to perform hazard and exposure banding.

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

The next section looks at communication and societal attitudes.

10.3 Communication, public attitudes and societal issues

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

10.3.1 Printed and online media

A search on the web and in news media of terms related to nanotechnology and ICT[478] shows (see table below) that ICT related nanotechnology is reported in the media, though some terms are more common than others, e.g. neuromorphic relative to nano-electronics. Neuromorphic engineering is a multi-disciplinary research field encompassing nanotechnology, along with biology, computer science and electronic engineering. The popularity of the term and/or the field has ballooned since the start of the decade, and has evidently captured the imagination of the media with its goal to mimic neural networks. Conversely nano-electronics is technical term for a narrow field of research that the public might not relate to.

While these data are approximate, they may be useful in identifying where the public can find the most information, relatively speaking, on a given nanotechnology topic. The number of news items is an indication of where the media perceive that the interest of the public lies.

Table 10-5: Frequency of articles on the web, in the news for nanotechnology ICT topics

Select ICT keywords	Web, thousands	News, thousands	News / Web, %
Network-on-chip	344	0.44	0.1%
Nano-electronics	311	0.82	0.3%
Spintronic	287	1.1	0.4%
Neuromorphic	265	7.6	2.9%
Giant Magnetoresistance	197	0.45	0.2%
Total of 30 ICT keywords[479]	**3,200**	**30**	**0.9%**

A second search was done to obtain an indication of where the interests of academics lie. Using Google Scholar[480], it was found that nano-electronics appears to be a more active research area than neuromorphic engineering. Actually, it is more likely that researchers working in both fields, but neuromorphic engineering in particular, use specialist terms in describing their work, not the broad terms covering the entire field.

[478] The search was carried out using a selection of nano-ICT related keywords: "Network-on-chip", "D-RAM", "Biocomputing", "Nanoelectronic", "Spintronic", "Neuromorphic", "Giant magnetoresistance", "Microelectromechanical system", "Quantum computing" Nano, "Avalanche diode", "Magnetic tunnel junction", "Spin torque", "Graphene electronics", "Valleytronics", "Photonic crystal cavity", "Tunnel FET", "Spin transistor", "Nanoelectromechanical system", "Programmable metallisation cell", "Nanoresonator" "Nanowire MOSFET", "Nanowire electronic", "Semiconductor nanodevices", "Nano-optomechanical", "Silicon-on-insulator FET", "Nano-ICT", "Nano-electronic memory", "Nano-optomechanical system", and "Nanoribbon heterojunction".

[479] Ibid

[480] Google Scholar is an online database of many of the peer-reviewed online journals of Europe and the US, plus books and non-peer reviewed journals, containing an estimated 160 million documents in 2014 (Orduña-Malea, E, *et al.* (2014). About the size of Google Scholar: playing the numbers. Granada: EC3 Working Papers, 18: 23 July 2014.)

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

Select ICT keywords	Scholar, thousands	Scholar/Web %
Network-on-chip	23	6.6%
Nano-electronics	36	12%
Spintronic	34	12%
Neuromorphic	15	5.7%
Giant magnetoresistance	28	14%
Total of 30 ICT keywords	**258**	**8.0%**

The types of news articles that have used the terms neuromorphic and nano-electronics was analysed using a sample of the top 100 news articles from 2014 and 2015 as identified using the Google search engine. A higher proportion of articles using the term neuromorphic are from general interest of general science type publications (e.g. daily newspapers, wired magazine, articles in financial magazines) than those articles using the term nano-electronics. This supports the fact that neuromorphic engineering, though a booming research field has also become a media "buzz-word" while nano-electronics has not.

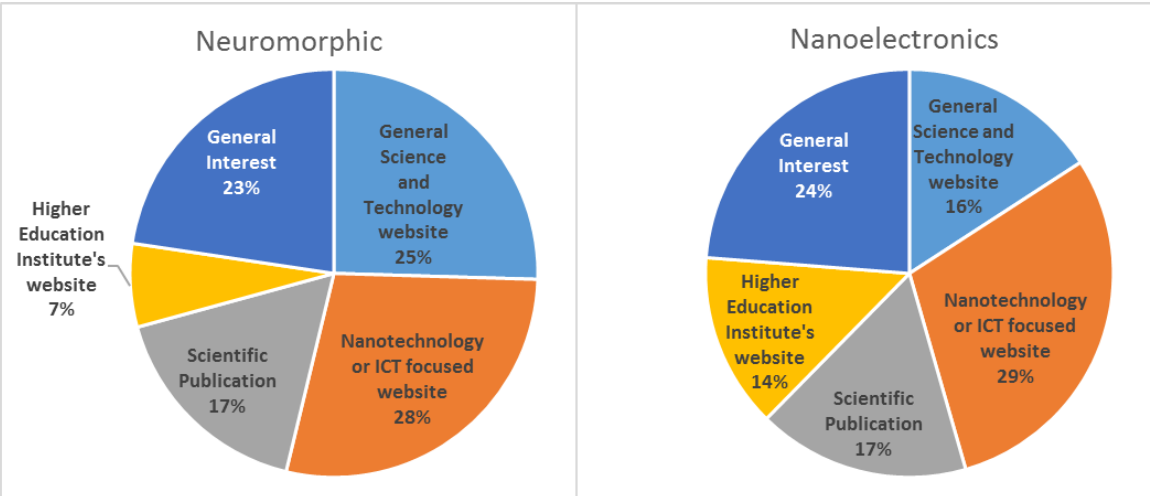

Figure 10-1: Type of website for the top 100 news items for neuromorphic and nano-electronics

Graphene is a nanomaterial with huge and growing potential for ICT applications due to its superior conductive and other properties which researchers are increasingly manipulating and exploiting. Research in graphene is driven by electronic applications as evidenced by the share of academic publications related to "graphene" and "graphene electronics" applications, as shown in the figure below[481].

[481] Note: 2015 data only to early December.

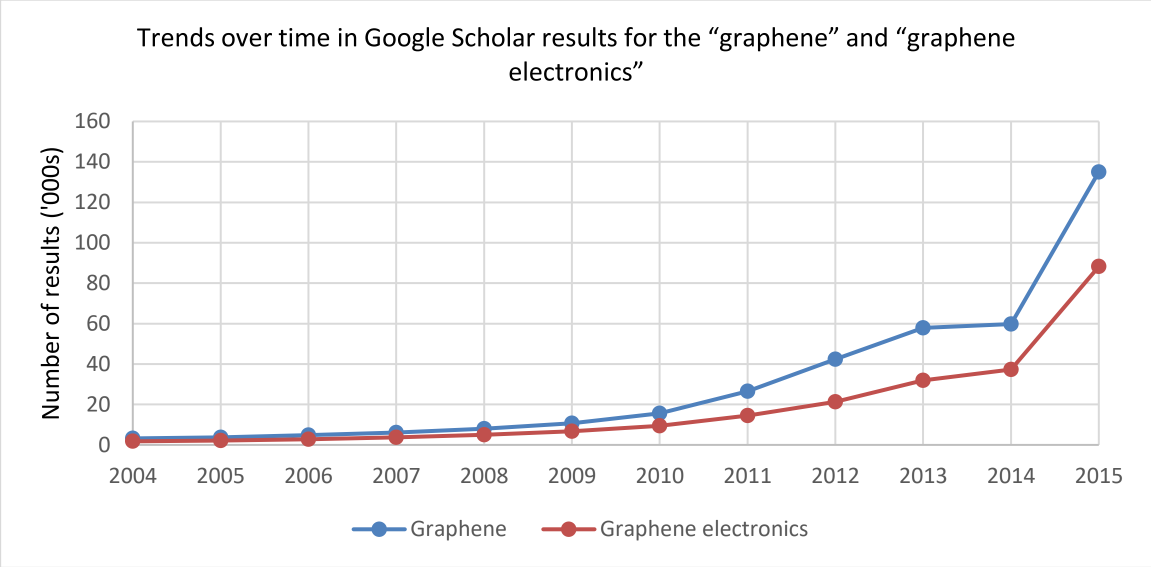

Figure 10-2: Trends over time in Google Scholar results for the "graphene" and "graphene electronics"

10.3.2 Surveys of the public

More rigorous measures of public awareness, attitudes and communication can be seen through surveys. Although not representative for the 'average' EU-citizen, the results provide some indications of trends in attitudes.

NanOpinion was an FP7 project, which ran from 2012 to 2014, focused on monitoring public opinion on nanotechnology in Europe[482]. An online hub, social media, education and information booths in public spaces and special events were used to develop a dialogue with the general public about nanotechnology. Over 1,500 questionnaires were completed in which participants answered questions designed to gauge their understanding and opinions on nano.

Analysis of the responses revealed that Europeans in general have little understanding of nanotechnology but are generally interested in and positive about it. Respondents expected information on nanotechnology to be honest and balanced and wished there was more information available, particularly in the popular media. Across all educational backgrounds, they would be interested in buying products containing nanomaterials, including food containers, clothing and sun creams. However, they would like to see nano-containing products labelled with detailed information and the testing and regulation of these products carried out by independent national or international bodies rather than profit-oriented companies. Their main policy recommendations were to promote consistent and detailed product labelling carried out by an independent body, to update teachers' knowledge of nanotechnology and to encourage more interdisciplinary science, technology, engineering and mathematics curricula.

The objectives of *NanoDiode*, an FP7 project running from mid-2013 to mid-2016, is to develop a co-ordinated and innovative strategy to engage EU civil society in a dialogue about responsibility around nanotechnologies[483]. As part of their approach, they reviewed the experiences and outputs of previous European projects on nanotechnology dialogue and outreach in order to identify best practices they could adopt for educational workshops and other activities[484]. The scope of NanoDiode is more ambitious than NanOpinion in as much as they aim to facilitate dialogue across all levels of the nanotechnology value chain, from the general public to policy makers. Through outreach, education and specific events they will involve a cross-section of researchers, industrialists, citizens, scientific advisers and policy makers with the aim of learning where and how society wish

[482] www.nanopinion.eu
[483] www.nanodiode.eu
[484] Analysing previous experiences and European projects on nanotechnology outreach and dialogue and identifying best practices, Daan Schuurbiers and De Proeffabriek, March 2014, (Accessed at http://www.proeffabriek.nl/uploads/media/NanoDiode_WP1_Best_Practices.pdf in November 2015)

nanotechnologies to be applied. For example, they aim to bring groups of potential nanotechnology 'users' (industrial customers as well as consumers) together with researchers working on near-market products in order to facilitate discussions which could help steer the research towards social values and user needs.

In addition to these FP7 projects, two *population surveys in Germany* provide some data on the public's attitudes (Zimmer et al, 2009)[485], as well as a survey among young people conducted within the framework of the NANOYOU project (NANOYOU, 2010)[486] and a recent survey in the USA (Shipman, 2010)[487]. OECD work on public engagement with nanotechnology has led to the production of a guide to assist policymakers (OECD, 2010)[488].

Table 10-7: Assessments by the public of various applications of nanotechnology
From German online discourses and a questionnaire survey (Böl et al. 2010)

Application	Ratio of positive to negative assessments	
	Online discourses	Population survey
Cancer therapies	90 : 10	(not asked)
"Other serious medical applications"	88 : 12	87 : 13
Surface treatment (textile & vehicle)	67 : 33	93 : 7 (paints) 91 : 9 (textile)
Cosmetics (excl. sunscreens)	59 : 41	51 : 49
Textile; other than surface treatment	56 : 44	76 : 24
Food packaging	25 : 75	81 : 19 (detection) 64 : 36 (foil quality)
Foodstuffs	10 : 90	25 : 75 (lump prevention) 10 : 90 (appearance)
Sunscreen products	10 : 90	78 : 22
Dietary supplements	0 : 100	not asked

Relatively favourable situations may exist if citizens have concrete experiences with, or expectations towards specific applications; they tend to support applications "that are linked to a wider social good or perceived individual benefit" (Böl, 2010; Fleischer et al., 2012)[489,490].

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[485] Zimmer, R., Hertel, R., Böl, G.F., 2009, "Public perceptions about nanotechnology: Representative survey and basic morphological-psychological study", Bundesinstitut für Risikobewertung (BfR)
[486] Nanoyou, 2010 http://cordis.europa.eu/publication/rcn/15319_fr.html
[487] Shipman, M., 2010, "Hiding risks can hurt public support for nanotechnology", News Services NCSU
[488] http://www.oecd.org/sti/biotech/49961768.pdf
[489] Böl, G.F., Epp A., Hertel, R., 2010, "Perception of nanotechnology in internet-based discussions", Bundesinstitut für Risikobewertung (BfR)
[490] Fleischer, T., Jahnel J., Seitz S.B., 2012, "NanoSafety – Risk governance of manufactured nanoparticles", European Commission

11 CONCLUDING SUMMARY

Nanotechnology is seen to be contributing to the goals of making smaller, faster and more robust devices that can process and store more, faster and better.

Policy supports in Europe include the EU RTD Framework Programmes projects, ERA-NET[491]s, European Technology Platforms and Networks of Excellence, as well as the Digital Agenda for Europe. Member States support nanotechnology within broad science and technology initiatives (e.g. the United Kingdom, the Netherlands) and through special initiatives such as IMEC[492] in Belgium and the Iberian Nanotechnology Laboratory[493] in Portugal.

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

The leading EU28 countries for nanotechnology and ICT are Germany, France and the United Kingdom in the Framework Programmes (FP6 and FP7) are also the leaders in publication output 2000-2014 and, together with the Netherlands, are the top four for patent applications (as measured by patent families in 1993-2011). Belgium also performs strongly in all three areas.

In terms of individual organisations in the EU28, the CNRS[494] (FR), the CEA[495] (FR) and IMEC (BE) perform the most strongly in projects and patents while the strongest publishers are generally universities such as Cambridge, Paris XI Sud, Dresden and Manchester (albeit with IMEC in third place).

The global market for products in nanotechnology and ICT is expected to grow from USD 2 billion in 2013 to over USD 10 billion in 2019. 84 ICT-related products using nanotechnology are commercially available on the market. Nanotechnology occurs mostly in components including data storage but also strongly in materials such as electrostatic dissipative coatings.

The strongest companies in nanotechnology and ICT in projects are STMicroelectronics, Philips and Infineon; and in publications they are IBM, Samsung and NTT. In EPO patents, companies from the US and Korea lead while European company Infineon Technologies (DE, AT) appears in fourth place and is joined by Philips (NL, DE), both strong FP project performers.

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[491] Also ERA-NET plus
[492] Interuniversitair Micro-Electronica Centrum, http://www2.imec.be/be_en/about-imec.html
[493] http://inl.int/
[494] Centre National de la Recherche Scientifique
[495] Commissariat à l'énergie atomique et aux énergies alternatives

ANNEXES

ANNEX 1: METHODOLOGIES FOR LANDSCAPE COMPILATION REPORTS

The outline of this report is as follows:

- Introduction;
- Development of keywords;
- Methodology by task and sector: projects, publications, patents and products;
- Methodology for additional information: markets, wider economic data, environmental health and safety, regulation and standards; and
- Concluding remarks.

A Introduction

This paper outlines the main methodologies used in the NanoData project.

The data were in large part identified using keywords to search existing databases (e.g. for publications and patents) and to select projects (from eCorda) and products (e.g. from product databases). The report explains how the keywords were identified and what quality control measures were put in place.

It should be noted that eight sectors were included in the work – construction, energy, environment health, ICT, photonics, manufacturing and transport. Thus, the data are not comprehensive across all of nanotechnology. They are, instead, representative of the sectors selected within the context of the overall project for the European Commission.

B Development of keywords

The keywords were identified from known data sources, web searches and expert input. They were validated through discussions with consortium members[496] (where they had expertise and experience in the area concerned) and other experts. Following that validation process, the keywords were also tested by one or both of the following methods:

- The word 'nano' and the keywords were used to select the FP projects relevant to the sector (and sub-sectors if appropriate). The projects identified were checked manually for false positives. False negatives were also identified (projects that were expected to be selected that were not). The keywords were refined to optimise the number of projects correctly selected.
- The keywords were used to select publications. The lists of publications were checked, in part manually and in part semi-automatically using the CWTS VOSViewer bibliometric mapping tool (http://www.vosviewer.com/Home). Using the tool, it was possible to see how terms group together in publication space (by their proximity on a VOSViewer map) and how often they occur (by their size on the VOSViewer map). Thus, it was possible to determine which terms would be the most significant in the sector and also which terms would be likely to cause false positives. For example, in the partial map for nanotechnology and health below (bottom left corner) it can be seen that a very important term is 'scaffold', and related terms are about tissue and bone engineering. Moving further to the right, the related term 'biocompatibility' is seen and nearby the significant and related but more generic terms 'surface', 'morphology' and 'synthesis'.

[496] Partners of the Joint Institute for Innovation Policy for this project i.e. CWTS, Frost & Sullivan, Joanneum Research, Oakdene Hollins, the Nanotechnology Industries Association, Tecnalia and TNO.

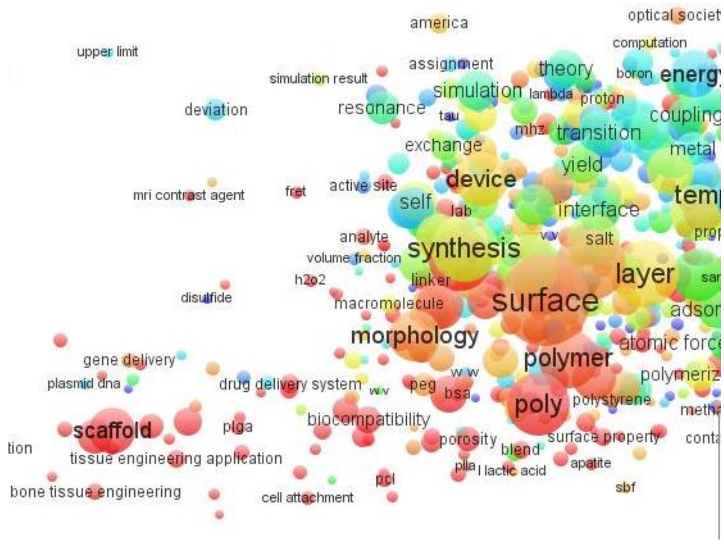

Figure A: Partial VOSViewer map for nanotechnology and health

Additional terms could also be identified for inclusion in the keyword list.

It should be noted that, where the use of a keyword could lead to false results, the keyword was omitted. This inevitably leads to some data of relevance being omitted from the resource base of the project, the alternative being the inclusion of much irrelevant information. For example, some words (e.g. photodetector, laser, photolithography) were omitted from the keywords for photonics as they have much wider applications that photonics alone.

In the searches, keywords were truncated to maximise the possible results. For example, in energy, "thermoelectric*" could identify data related to "thermoelectric", "thermoelectrics", "thermoelectrical" and "thermoelectricity", the * indicating the truncation.

Where possible, both British and American spellings were included (e.g. tumour and tumor) as were alternative spellings (e.g. orthopaedic and orthopedic).

Methodology by task and sector

C Framework Programme projects

The Framework Programme (FP) project details were provided by the European Commission from the eCorda database for FP6 and FP7. Abstracts for the FP6 projects were provided separately as these were not in the original database received. The total number of FP projects in eCorda database is 35,365 of which 25,238 are FP7 projects and 10,027 FP6 projects. These projects involved 210,177 participations by researchers of which 76,562 are in FP6 and 133,615 in FP7.

The table below presents an overview of the data for FP6 and FP7 according to the variables used in the NanoData analysis. It also identified the number of missing values per variable. It shows that the eCorda database is a nearly complete source of FP6 and FP7 project data and participant data with only relatively few data missing (between 2.4% and 0% of the total for FP6 and FP7 depending on the variable).

Table A: Number of actual observations and missing values for each of the eCorda variables used for the NanoData analysis.

Variable	Number of observations						
	FP6		FP7		Total		
	Actual	Missing	Actual	Missing	Actual	Missing	% Missing
Project ID	10,027	0	25,238	0	35,265	0	0.0%
Start date	9,966	61	24,906	332	34,872	393	1.1%
End date	9,965	62	24,906	332	34,871	394	1.1%
Duration	10,027	0	25,238	0	35,265	0	0.0%
Number of partners	10,027	0	25,238	0	35,265	0	0.0%
Specific Programme	10,027	0	25,238	0	35,265	0	0.0%
Sub-Programme[497]	10,027	0	25,238	0	35,265	0	0.0%
Call	9,989	38	25,238	0	35,227	38	0.1%
Instrument	1,0027	0	25,238	0	35,265	0	0.0%
EC contribution	10,027	0	25,238	0	35,265	0	0.0%
Project total cost	9,771	256	25,238	0	35,009	256	0.7%
Project ID	76,562	0	133,615	0	210,177	0	0.0%
Participant ID	76,550	12	133,615	0	210,165	12	0.0%
Participant role	76,562	0	133,615	0	210,177	0	0.0%
Participant legal name	76,561	1	133,615	0	210,176	1	0.0%
Participant country[498]	76,562	0	133,615	0	210,177	0	0.0%
Participant region	76,562	0	133,615	0	210,177	0	0.0%
Participant organisation type	74,271	2,291	133,615	0	207,886	2,291	1.1%
EC contribution per participant	71,748	4,814	133,569	46	205,317	4,860	2.4%
Project cost per participant	72,960	3,602	133,575	40	206,535	3,642	1.8%

In the eCorda database, the EC contribution per project shows some small differences between the data presented by project (project database) and the data presented by participant (participant database). The table below illustrates the differences, both in millions of euros and as shares of the EC contribution. It can be seen that the difference in EC contribution between the project and participant data is almost zero in FP7 and small in FP6. However, the differences can become significant when the data is aggregated.

[497] In FP6 these were called Priorities and in FP7 Work Programmes.
[498] The report uses ISO 2-digit codes for countries. See http://www.iso.org/iso/country_codes

Table B: Number of projects and EC contribution for the project data and participant data in eCorda

	Number of projects		EC contribution (MEUR)		Difference (Project – Participant) (MEUR)	Difference %
	Project Data	Participant Data	Project Data	Participant Data		
FP						
FP6	10,027	10,027	16,692.320	16,653.860	38.460	0.23%
FP7	25,238	25,238	44,917.330	44,917.200	0.130	0.00%
Total	35,265	35,265	61,609.650	61,571.060	38.600	0.06%
NT						
NT-FP6	908	908	1,702.740	1,695.500	7.250	0.43%
NT-FP7	2,636	2,636	4,660.840	4,660.750	0.090	0.00%
Total	3,544	3,544	6,363.580	6,356.250	7.340	0.12%

C1 Classification of projects

C1.1 Classification of nanotechnology projects

In order to identify the baseline set of nanotechnology-related projects for the NanoData work, a search was made for all FP projects that contained 'nano'[499] in the title or abstract of the project. 3,544 projects were selected in this way[500], of which 74% were FP7 projects and 26% were FP6 projects. Comparing the distribution of projects between FP6 and FP7 for nanotechnology and for the two FPs overall, it is found that the distributions are very similar the latter being 72% in FP7 and 28% in FP6. Nanotechnology projects make up 10% of Framework Programme projects, the share increasing slightly from FP6 (9.1%) to FP7 (10.4%).

The table below shows the distribution of total FP projects and of nanotechnology projects.

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

[500] Unlike the other sectors considered by the project (HT, EN, PH, MF), for ICT additional projects were identified by use of keywords such as graphene. These were judged to be too important in ICT to be omitted. This did, however, result in the total number of nanotechnology projects being different for ICT (4,143) and the other sectors (3,544).

Table C: Number and share of nanotechnology projects in FP6 and FP7

		Total	FP7	FP6
FP total	Number of FP projects	35,265	25,238	10,027
	Share of FP (total)	100%	71.6%	28.4%
Nanotechnology	Number of FP projects	3,544	2,636	908
	Share of FP	100%	74.4%	25.6%
Share of nanotechnology of total FP		10.0%	10.4%	9.1%

C1.2 Classification of projects by sector and sub-sector

The 3,544 projects relevant to nanotechnology were subjected to a search using the sector keywords to identify projects relevant to each sector. This search was undertaken using the keywords identified for each sector. The project details for the selected projects were reviewed manually, where possible, as a further check of the quality of the outputs of the keyword search process.

For example, using the method described above, 944 projects were categorised as being related to nanotechnology and health, approximately 27% of total nanotechnology projects. Using the keywords identified for each of the five health sub-sectors[501], a further classification could be made. In addition, nanotechnology projects relevant to health but not specifically to any of the five sub-sectors were categorised as Other. In this way, the breakdown of health nanotechnology projects was found to be: cancer 26% (CT); infectious diseases 7.8% (ID); cardiovascular diseases 5.2% (CV); neurodegenerative diseases 4.6% (ND); and diabetes (2.2%) (DB) with Other being 62% (OTH).

Where projects were classified as belonging to more than one sub-sector, a proportion of each such project was allocated to the sub-sector concerned. Thus a project relevant to cardiovascular disease and cancer would be allocated 50% to cardiovascular disease and 50% to cancer. The aim was to ensure an accurate analysis of the FP project data and to minimise double counting. The table that follows shows the number of project overlaps and the distributions of fractions of projects for the health sub-sectors.

[501] Cancer, cardiovascular disease, diabetes, infectious diseases and neurodegenerative diseases.

Table D: Distribution of projects with overlaps across health sub-sectors

	Total	CT	CV	ID	NE	DB	Other
Projects without overlaps	**883**	**196**	**23**	**48**	**24**	**11**	**581**
Projects with overlaps: fractions as allocated							
CT & ID	17	8.5		8.5			
CT & CV	12	6	6				
CT & ND	9	4.5			4.5		
CV & ID	5		2.5	2.5			
CV & ND	4		2		2		
CT & DB	4	2				2	
CV & DB	3		1.5			1.5	
ND & DB	2				1	1	
CT, ID & ND	1	0.33		0.33	0.33		
CT, ND & DB	1	0.33			0.33	0.33	
CT, CV & ID	1	0.33	0.33	0.33			
CT, CV, ID & ND	1	0.25	0.25	0.25	0.25		
ID & ND	1			0.5	0.5		
Sum of fractions	*61*	*22*	13	12	9	5	0
Total nanotechnology and health	**944**	**218**	**36**	**60**	**33**	**16**	**581**

C2 Harmonisation of data across FP6 and FP7

In order to have harmonised variables across both Framework Programmes, some names and coding of variables were required. These included the following:

i) Harmonising the participant types. The categories used in this report are presented in the table below. In the tables of top performers, if the same organisation appeared in FP6 and FP7, the FP7 code was used.

Table E: Harmonising participant type codes

Codes used	Description	FP6 Code	FP7 Code
HES	Higher or secondary education establishment	HES	HES
REC	Research organisations	REC	REC
PRC	Private commercial (excluding SMEs)	IND	PRC
SME	Small and medium-sized enterprises	SME	SME
OTH	Other including public bodies excluding research and education	OTH	OTH, PUB

ii) Introducing a classification of instruments in order to allow enhanced comparison between the varieties of instruments. The categorisation follows that of Arnold et. al (2012)[502].

Table F: Classification of instruments

Action	Instrument	FP
Research actions	ERC Grants	FP7
Collaborative RTD actions	Integrated Projects	FP6
	Specific Targeted Research Projects	FP6
	Large-scale Integrating Project	FP7
	Small or medium-scale focused research project	FP7
	Integrating Activities / e-Infrastructures	FP7
	Collaborative project (generic)	FP7
Actions for RTD knowledge transfer	Specific Actions to Promote Research Infrastructures	FP6
	Marie Curie Actions	FP6
	Coordination Actions	FP6
	Network of Excellence	FP6
	Coordinating Action	FP7
	Marie Curie Actions	FP7
	Research Infrastructure	FP7
	Collaborative project dedicated to international cooperation partner countries (SICA)	FP7
Actions for adoption and innovation	Co-operative Research Projects	FP6
	Collective Research Projects	FP6
	Joint Technology Initiatives	FP7
	Research for SMEs	FP7
Actions to support policymaking	Specific Support Actions	FP6
	Supporting Action	FP7

iii) Participant organisations identifiers

For the FP6 and FP7 participants the following organisation identifiers were used:

- FP7: CD_ORG_ID and
- FP6: Participant Identifying Code-PIC.

If these were not available, the programme participant identifiers were used. In order to improve the comparability of the FP6 and FP7 participant identifiers, some manual matching based on organisation legal name and address data was conducted for the NT participant sample. As a result, 5,945 unique nanotechnology participants were identified.

[502] In their work Arnold et. al. (2012) Understanding the Long Term Impact of the Framework Programme classifies the instruments of FP4, FP5 and FP6 into four categories that are used as guidance for our classification. For FP7 the classification is done by authors of this report.

C3 Treatment of decimals

As a general rule, the data in the tables and figures are produced by utilising the method of first summing the unrounded figures and then rounding the sum. Due to this process, some totals may not correspond with the sum of the separate figures (generally presented as limited to one decimal).

C4 Key terminology and abbreviations used

Table G: FP6 funding instrument types

Code	FP6 Type of instrument
STREP	Specific Targeted Research Projects
CA	Coordination Actions
SSA	Specific Support Actions
II	Specific Actions to Promote Research Infrastructures
IP	Integrated Projects
NOE	Networks of Excellence
MCA	Marie Curie Actions
CRAFT	Co-operative Research Projects
CLR	Collective Research Projects
I3	Specific Actions to Promote Research Infrastructures

Table H: FP7 funding instrument types

Code	FP7 Type of instrument
CP	Collaborative project
ERC	Support for frontier research (European Research Council)
MC	Support for training and career development of researchers (Marie Curie)
JTI/169	Activities under Article 169 or 171 European Treaty, Joint Technology Initiatives, Public Private Partnerships
CSA	Coordination and support action
BSG	Research for the benefit of specific groups
NOE	Network of Excellence

Table I: Organisation types

Code	Description
HES	Higher or secondary education est.
PCO	Private companies excluding SMEs
REC	Research organisations
SME	Small and medium-sized enterprises
OTH	Other (incl. public bodies and bodies with unknown organisation types)

Table J: Country codes EU28+[503].

NUTS0	Country		NUTS0	Country
AT	Austria		**LU**	Luxembourg
BE	Belgium		**LV**	Latvia
BG	Bulgaria		**MT**	Malta
CY	Cyprus		**NL**	Netherlands
CZ	Czech Republic		**PL**	Poland
DE	Germany		**PT**	Portugal
DK	Denmark		**RO**	Romania
EE	Estonia		**SE**	Sweden
ES	Spain		**SI**	Slovenia
FI	Finland		**SK**	Slovakia
FR	France		**UK[504]**	United Kingdom
EL[505]	Greece		**CH**	Switzerland
HU	Hungary		**IL**	Israel
HR	Croatia		**IS**	Iceland
IE	Ireland		**TR**	Turkey
IT	Italy		**NO**	Norway
LT	Lithuania		**ZK**	Macedonia

D Publications

Identification of publications relied on analysis of the data in the database at CWTS (the Centre for Science and Technology Studies, Leiden University, the Netherlands), data that is based on that in the Web of Science[506].

The CWTS database is organised and structured such that it allows (dynamic) field delineation and the collection of relevant publications. Hence it was possible to identify nanoscience and nanotechnology (NST) publications and, within those, to identify publications relevant to the sectors. More specifically, publications were sought within the NST group using the keywords. In addition, using the tools available at CWTS, related publications could be identified and included in the output.

Data available from the resource at CWTS included the journals in which the publications are found, the date of publication and the doi (digital object identifier). For licensing reasons, some of the data in the database at Leiden can be accessed by external parties only in aggregate form. For example, personal details of individual researchers cannot be accessed (e.g. address, email, phone number).

The report uses ISO 2-digit codes for countries. See http://www.iso.org/iso/country_codes

[503] Data was also analysed from countries outside of the EU28 namely Iceland (IS), Israel (IL), Norway (NO), Switzerland (CH) and Turkey (TR).

[504] GB is also used

[505] GR is also used

[506] http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html

E Patents

The patents analysed were collected from the database PATSTAT. That database includes patents from over 30 patent offices e.g. the European Patent Office, the US Patent Office and the Japanese Patent Office.

All patent offices worldwide tag nanotechnology-related patent applications using a special symbol of the International Patent Classification (IPC), namely B82Y. This special symbol is also part of the CPC (Co-operative Patent Classification). The core dataset of nano-related patents were selected using this special symbol (B82Y) from both the IPC and the CPC classifications.

All patent applications at the USPTO, the EPO and PCT (WIPO) classified as B82Y were identified in PATSTAT as well as the (simple) patent family to which they belong. From all these patent families, only patent applications at the USPTO, the EPO and PCT (WIPO) were collected. Such use of multiple patent offices helps to diminish the bias that might be caused by the so called 'home advantage' effect, i.e. the propensity of nationals to file the first patent application in their own country. By analysing across these three patent authorities a less biased overview of nanotechnology patents worldwide can be obtained.

As the patent information is being collected from more than one patent authority, and given that the same invention might be protected in more than one of these patents authorities, the (simple) patent families are used to avoid multiple counting of the same invention.

The identification of patents by sector from amongst the nanotechnology patents was based in most cases on the combination of two strategies. First, all patents including in their title and/or abstract at least one relevant keywords for a particular sector were retrieved. Second, to ensure that the patents retrieved in the first step are truly related to the sector, a number of representative IPC symbols of the sector were selected from PATSTAT[507]. For example, for the nanotechnology patents related to the health sector, the IPC symbols related to 'Pharmaceuticals' and 'Medical technology' were used. However, it was not possible to undertake this second step for all sectors as for some (e.g. manufacturing) there were no appropriate IPC symbols.

Organisations and/or individuals are listed in patent applications, these being applicants and/or inventors. This information is used in the identification of companies, universities and other research organisations active in patenting. The year of reference used is the year when the oldest priority of each patent family was applied (the closest date to the invention). The report uses ISO 2-digit codes[508] for countries.

F Products

Products were identified primarily through keyword, sector and sub-sector searches of reports and databases. This search strategy was based on a triangulation approach making use of complementing perspectives. For all perspectives the NanoData team made use of the sector specific lists of key words.

The first step was to use peer-reviewed and grey literature on products in the different sectors[509] as well as existing market reports[510]. The market reports were used to identify where nanotechnology is being applied already in products as there are many reports that appear to identify products but no product is for sale at a commercial level, being at the research stage or for very limited supply e.g. to the research community or for test purposes. These investigations were then complemented by querying web-based databases on nanotechnology products such as AZONANO[511], Nanowerk[512],

[507] PATSTAT also contains a table mapping 44 industrial sectors and the IPC classification. The linkage between technology areas and industrial sector is described in Schmoch et al (2003), "Linking Technology Areas to Industrial Sectors", final report to the European Commission, DG Research.
[508] http://www.iso.org/iso/country_codes
[509] E.g. Nanomedicine: Nanotechnology, Biology, and Medicine 9 (2013) 1–14, Hessen Nanotech (2008) Applications of Nanotechnologies in the Energy Sector.
[510] See BCC Research www.bbcresearch.com
[511] http://www.azonano.com/
[512] http://www.nanowerk.com/

the consumer products inventory of the Project on Emerging Nanotechnologies[513], the product database of understandingnano.com[514], the Nanoinformationsportal of the Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH[515], the Danish Inventory of Nanoproducts[516] and the nanowatch.de database[517]. Further sector-specific databases, such as the German database for medical practitioners and the database on European public assessment reports of the European Medicines Agency[518], were used for the identification and classification of nanotechnology related products in health, for example.

By querying databases on existing innovation policy projects, initiatives and industry platforms such as NANORA[519], the Nano-Map of the German Federal Ministry of Research[520], the database on photonic companies compiled by EPIC, the members directory of SEMI[521], and the Nano-Bio Manufacturing Consortium (USA)[522], additional enterprises active in nanotechnology sectors were identified.

A third perspective on products was developed by gathering additional information about the products from company websites identified in previous work, commercial databases and open sources of information on the web. The information was verified through additional searches (e.g. of product data sheets and company websites).

The information in the database was extensively verified. Where, for example, it was found that a product was identified but not verified, searches were made of sources including reports and company websites to check the information. Contact was also made, in some cases, directly with the company in order to ratify the existence on the market of the product. While some other databases actually state the level of known accuracy of their information (e.g. the entries in the Woodrow Wilson database are classified using a system that has categories from level 1 (extensively verified claim) to level 5 (not advertised by manufacturer – claims made only by third party)) others are not specific.

In NanoData, the aim is only to include products that can be verified.

G Other information

Several types of information are provided on the NanoData site as fixed text where data is limited or one-off. These include information on markets and wider economic data, as well as reports on environmental health and safety and information about regulation and standards.

Markets

The market data is based on available sources of information and sources of Frost & Sullivan and BCC Research, who gather their information through discussions with practitioners (e.g. company representatives) and open sources (e.g. commercial reports, web sites). The aim was to track, evaluate and measure the activities of major industry participants in the nanotechnology arena, looking at markets and usage of nanotechnology. The activities included the definition and specification of nano-materials and nano-enabled products, identification of current and upcoming products and applications, accumulating qualitative and quantitative data, identification and mapping of EU participants and last but not the least, identification and analysis of target markets.

A wide set of definitions, categorisations, data collection and forecasting methods were available. Data gathering was driven by experienced analysts and based on a data-rich portfolio of previous EU and OECD projects as well as on internal Frost & Sullivan databases and consortium members,

[513] http://www.nanotechproject.org/cpi/
[514] http://www.understandingnano.com/nanotechnology-product-suppliers.html
[515] http://nanoinformation.at/produkte.html
[516] http://nanodb.dk/
[517] http://www.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank/
[518] http://www.ema.europa.eu/
[519] http://www.nanora.eu/
[520] http://www.werkstofftechnologien.de/en/
[521] http://www.semi.org/en/Membership/MemberDirectory/
[522] http://www.nbmc.org/members-only/

and public database. European Patent Office[523], PRODCOM[524] and patentlens[525] databases could be used to provide in-depth information about a particular technology and to identify the key industry participants dominating the sector. Analysis of key value chains was undertaken and corroborated with other work-streams. The information thus acquired would be verified with the help of an array of primary interviews with leading technology researchers, industry experts and other active stakeholders.

The range of primary and secondary research processes would be followed by the application of innovation diffusion tools in order to forecast probable market scenario of the future. This would also include estimating the shape of the diffusion curve and prediction of market development of nano-enabled products.

Wider economic data

External information sources such as Eurostat, OECD and WHO data sources were used to put the nanotechnology data obtained in the project into context.

For example:

- A brief overview of the energy industry was based on Eurostat data.
- The health industry overview was based on Eurostat data supplemented by reports from industry organisations (both technical (e.g. the industry association for European pharmaceutical enterprises) and financial (e.g. the European Private Equity & Venture Capital Association))

While reports on industry as a whole were available, there were found to be very few reliable reports on nanotechnology and industry. Nanotechnology databases were also explored (e.g. those of Nanowerk and Nanora).

Environmental health and safety

For the sectors in which materials were the main focus, the tool used for the environmental health and safety evaluation was the "Stoffenmanager Nano" application[526]. In summary, Stoffenmanager Nano is a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios. In the absence of a comparable tool for consumer exposure, it was also used for this type of exposure. Stoffenmanager Nano combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. Stoffenmanager Nano does not consider dermal and oral routes of exposure.

In Stoffenmanager Nano, the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). Likewise, exposure bands are labelled 1-4 (1=low exposure, 4= highest exposure).

The hazard and exposure bands are combined to yield so called priority bands ranging from low priority (=4) to high priority (=1). A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures or to establish the risk involved with more precision.

See also Annex: *Human health and safety.*

Regulation and standards

International, European, national and regional data sources for regulation and standards include:

European documents:

- Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) - 1907/2006(EC);
- Regulation on Medical Devices - 2012/0266(COD); and

[523] https://www.epo.org/searching.html
[524] http://ec.europa.eu/eurostat/web/prodcom
[525] https://www.lens.org/lens/search?n=10&q=nanotechnology&p=0
[526] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

- European Commission Recommendation on the Definition of a Nanomaterial, as well as sectoral documents such as
- Nanomaterials in the Healthcare Sector: Occupational Risks & Prevention - E-fact 73; and
- Guidance on the Determination of Potential Health Effects of Nanomaterials Used in Medical Device.

National documents:
- Decree on the annual declaration on substances at nano-scale - 2012-232 (France);
- Royal Decree regarding the Placement on the Market of Substances manufactured at the Nano-scale (Belgium); and
- Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register – BEK nr 644 (Denmark).

H Concluding remarks

This Annex outlines the main methods for the selection of data for analysis, some data sources, the aggregation of data classes in order to enable analysis (mainly for the FP projects) and the ways in which data was analysed. References are made to some of the main quality control issues.

ANNEX 2: ICT KEYWORDS

Below is the list of keywords used in the extraction of data and the subsequent analyses.

Asterisks are used to indicate that part of a word is missing. For example, the search for "bio-comput*" would identify data related to "bio-computing" and "bio-computer". Thus one search term was used to cover each of the words with multiple possible endings. In addition, multiple spellings were included, not all of which are shown here (e.g. US spelling of aluminium (aluminium) and hyphenated words including MOS-FET, nano-ICT).

3-d integration
3-d stacking
Aluminium arsenide
Aluminum arsenide
Antimonide
Avalanche diode
Biocomput*
Bio-comput*
Black phosphorous
Black phosphorus
CBRAM
CMOS
CNTFET*
CNT-FET*
Complementary metal-oxide semiconductor*
Conductive bridging RAM
DNA comput*
DRAM
Dynamic random-access memor*
Electro-conductive coatings
Electronic* shield*
Electro-optical
Electrostatic discharge prevention
Electrostatic discharge protection
Electrostatic dissipative applications
Electrostatic Shield*
ESD
FDSOI
FET* Field effect transistor*
Fin FET
Floating gate memor*
Fluxtronic*
Gallium nitride electronic*
Gallium phosphide
Gate oxide*
Giant magnetoresistance
Giant magneto-resistance
GMR
GOI Germanium-on-insulator
Graphene
III-V
Indium gallium arsenide
Integrated circuit*
Interconnect
Low K dielectric coating*
Magnetic memor*
Magnetic tunnel junction*
Magnetoresistive RAM

Magnetoresistive random-access memor*
Memristor*
MEMS
Metal dichalcogenide*
Metal–oxide–semiconductor FET
Metal–oxide–semiconductor field-effect transistor
Microelectromechanical system*
Micro-electromechanical system*
Micro-electro-mechanical system*
Molecular electronic*
Molybdenum disulfide*
Molybdenum disulphide*
Molybdenum selenide*
Molybdenum telluride*
MOS FET
MOS field-effect transistor
MoS2
MoSe2
MOSFET
MoTe2
MRAM
MX2
Nano optomechanic*
Nanobiocomput*
Nano-biocomput*
Nanocomputer*
Nano-computer*
Nanocomputing
Nano-computing
Nanoelectromechanical system*
Nano-electronic memor*
Nanoelectronic*
NanoICT
Nano-ICT
Nanointerconnect*
Nano-interconnect*
Nanomechanical system*
Nano-mechanical system*
Nanooptomechanical system*
Nanophotonic*
Nanoresonator*
nano-resonator*
Nanoribbon heterojunction*
Nanowire electronic*
Nanowire MOS-FET
NEM*
NEMS
Network on chip
Network-on-chip
Neuromemristive
Neuromorphic
Neuro-morphic
NOMS
OFET*
OLED
Optical interconnect*
Organic FET*
Organic field effect transistor*
Organic LED
Organic light-emitting diode
Organic-FET*

Photonic crystal cavit*
PMC*
Programmable metallisation cell*
Quantum comput*
Quantum encryption
Quantum technolog*
Resistive RAM
RRAM
Self-sustaining diode*
Self-switching diode*
Semiconductor nano-device
Silicene
Silicon carbide electronic*
SOI Silicon-on-insulator
Spin torque
Spin transistor
Spin transport electronic*
Spin valve
Spin wave
Spinelectronic*
Spin-electronic*
Spintronic*
Spin-wave
SRAM
Stananine
STT MRAM
STT RAM
TMDC
Topological insulator*
Tungsten (IV) sulfide*
Tungsten (IV) sulphide*
Tungsten selenide*
Tungsten sulfide*
Tungsten sulphide*
Tunnel FET
Valleytronic*
Valley-tronic*
WS2
WSe2
WSe2
Zinc sulfide
Zinc sulphide
ZnS2

Notes:

1. The word 'graphene' had to be omitted from the search for publications as it resulted in many false positives.
2. The words electro-optical, graphene, III-V, iii-v, MoS2, MoSe2, nanoresonator*, nano-resonator*, PMC*, nanomechanical system* and nano-mechanical system* had to be omitted from the search for patents as they resulted in many false positives.

ANNEX 3: ABBREVIATIONS

Abbreviation	Definition
BEUC	Bureau Européen des Unions de Consommateurs
CAGR	Compound Annual Growth Rate
CBRAM	Conductive Bridge Random Access Memory
CBRNE	Chemical, Biological, Radiological, Nuclear and Explosive
CEN	European Standardisation Committee
CMC	Chemistry, Manufacturing and Controls
CMOS	Complementary Metal-oxide Semiconductor
CNT	Carbon Nanotubes
COD	Co-decision Procedure
DFG	Deutsche Forschungsgemeinschaft
d-MRI	Diffusion Magnetic Resonance Imaging
DRAM	Dynamic Random-Access Memory
EC	European Commission
EEB	European Environmental Bureau
EFSA	European Food Safety Authority
EGE	European Group on Ethics Roundtables
EoL	End of Life
EPA	Environmental Protection Agency
EPR	Enhanced Permeation and Retention
ESD	Electrostatic Discharge
ETUC	European Trade Union Confederation
EU	European Union
Eurofound	European Foundation for the Improvement of Living and Working Conditions
FDSOI	Fully-depleted Silicon on Insulator
FET	Field Effect Transistor
f-MRI	Functional Magnetic Resonance
FP7	Seventh European Framework Programme
GMR	Giant Magnetoresistance
GOI	Germanium-on-insulator
ICT	Information and Communication Technologies
IPC	International Patent Classification
IPR	Intellectual Property Rights
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
MAPP	Manual of Policies and Procedures
MEMS	Micro-electromechanical System
MNBS	Micro- and Nano-Bio Systems
MOSFET	Metal Oxide Semiconductor field-effect transistor
MR	Magnetic Resonance
MRAM	Magnetoresistive Random Access Memory
MRI	Magnetic resonance imaging
MRS (MRSI)	Magnetic Resonance Spectroscopy (imaging)

Abbreviation	Definition
MWCNT	Multi-walled Carbon Nanotubes
MX2	Metal Dichalcogenides
NACE	Nomenclature Statistique des Activites Economiques dans la Communauté Européenne
NEMS	Nano-Electromechanical System
NGO	Non-Governmental Organisation
NIR	Near Infrared
NIR-II	Near-Infrared-ii Imaging
NOC	Network on Chip
NOMS	Nano-Optomechanical System
NP	Nanoparticles
NST	Nanoscience and Nanotechnology
NT	Nanotechnology
OFET*	Organic Field Effect Transistor
OLED	Organic Light-Emitting Diode
OSHA	European Agency for Safety and Health at Work
OSH-professional	Occupational Safety and Health Professional
PATSTAT	European Patent Office Worldwide Patent Statistical Database
PMC	Programmable Metallisation Cell
ppm	Parts Per Million
QD	Quantum Dot
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RRAM	Resistive RAM
SME	Small or Medium Sized Enterprise
SNAP	Strategic Nanotechnology Action Plan
SOI	Silicon-On-Insulator
SRAM	Static Random Access Memory
STOA	Science and Technology Options Assessment
STT MRAM	Spin Transfer Torque Magneto-Resistive Random Access Memory
STT RAM	Spin Transfer Torque Random Access Memory
SWCNT	Single Walled Carbon Nanotubes
TMDC	Transition Metal Dichalcogenide
TT	Technology Transfer
US	United States
US EPA	US Environmental Protection Agency
US NIOSH	US National Institute for Occupational Safety and Health
USA	United States of America
UV/Vis/IR	Ultraviolet / Visible / Infra-red
VC	Venture Capital
WEEE	Waste Electrical and Electronic Equipment

ANNEX 4: TERMINOLOGY

Word/phrase	Definition/explanation
Carbon Nanotubes	Allotropes of carbon with a cylindrical nanostructure.
Dendrimers	Nanostructured synthetic molecules having evenly spread branching structure originating out of a central core.
Liposomes	An artificially-prepared vesicle composed of a lipid bilayer
Nanobiosensors	Biosensor at nano-scale: measurement system for detection of an analyte that combines a biological component with a physiochemical detector
Nano-biotechnology	Intersection of nanotechnology and biology, the ways that nanotechnology is used to create devices to study biological systems, this is different from bionanotechnology
Nanocapsule	Nano-scale shells made of non-toxic polymer
Nanocarrier	Nano-object or objects, which are at a larger scale but which carry nanoscale payloads able to transport a diagnostic or therapeutic agent either on its surface, within its bulk structure or within an internal cavity
Nano-coatings	Applying a coating of nano-scale structures to a surface.
Nanocrystal	Nano-object with a crystalline structure
Nanodiagnostics	Application of nanotechnology in molecular diagnostics
Nanoemulsion	Nanodispersion with a liquid matrix and at least one or more liquid nano-objects
Nano-enabled	Products, systems, devices integrating, using, enabled by nanotechnology
Nano-fibres	Nano-object with two external dimensions in the nanoscale and the third dimension significantly larger
Nano-indentation	Variety of indentation hardness tests applied to small volumes. For testing the mechanical properties of materials (hardness).
Nanomaterials	Materials the single units of which is sized (in at least one dimension) between 1 and 1000 nanometres (10^{-9} meter) but is usually 1—100 nm (the usual definition of nano-scale).
Nanomedicine	Medical application of nanotechnology
Nanometres	One billionth of a metre
Nano-needles	Conical or tubular needles in the nanometre size range, made from silicon or boron-nitride with a central bore of sufficient size to allow the passage of large molecules
Nanoparticle	Small object that behaves as a whole unit with respect to its transport and properties, between 1 and 100 nanometres in size.
Nanopolymers	Nanostructured polymers
Nanoproducts	Any product containing nanoparticles
Nanorod	One morphology of nano-scale objects, produced by direct chemical synthesis.
Nano-scale	Refers to structures with a length scale applicable to nanotechnology, usually cited as 1–100 nanometres, also called nanoscopic scale
Nanoscience	The study of the fundamental and functional properties of matter on the nano-scale.
Nanosensor (proteomic, gold)	Any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world
Nanoshells (plasmon)	This is also called nanoshell plasmon, is a type of spherical nanoparticle consisting of a dielectric core, which is covered by a thin metallic shell (usually gold).

Word/phrase	Definition/explanation
Nano-specific	Refers to a system or response that is sensitive to nanomaterials
Nanostructures	An object of intermediate size between microscopic and molecular structures
Nanosuspensions	Submicron colloidal dispersions of nanosized drug particles stabilised by surfactants. Nanosuspensions consist of the poorly water-soluble drug without any matrix material suspended in dispersion
Nanotechnologies / Nanotechnology	Manipulation of matter with at least one dimension sized from 1 to 100 nanometres
Nanotechnology-Based Platforms	Suite of technologies using nanomaterials, structures and objects
Nanotube	Hollow nano-fibre
Quantum Dots	A nanocrystal made of semiconductor materials that are small enough to exhibit quantum mechanical properties

ANNEX 5: ADDITIONAL INFORMATION ON MEMBER STATE POLICIES AND PROGRAMMES

In addition to actions at the level of the whole of the European Union, many countries have developed strategies and action plans and funded programmes and projects. Some of these are identified and outlined below, by country.

The aim in this section is to give a flavour for the policies and programmes that are or have been in place for nanotechnology at Member State level, in the wider context of national strategies for science, technology, research and development. As it focusses on targeted initiatives for nanotechnology, not all EU28 countries are included.

This section has been prepared from existing data sources (e.g. Member State government and agency reports and web sites, European Commission sources (such as ERAWATCH/RIO[527]), evaluation reports). While efforts have been made to use the most up-to-date sources, it cannot be guaranteed that all information is current.

AUSTRIA

In Austria, the two main ministries involved in the funding of research and development (R&D) are the Federal Ministry of Science and Research (BMWF)[528] and the Federal Ministry for Transport, Innovation and Technology (BMVIT)[529]. The largest share of direct support for R&D is channelled through three funding agencies: The Austrian Science Fund (FWF)[530] that focuses on funding academic research; the Austrian Research Promotion Agency (FFG)[531] specialising in funding applied industrial research and the co-operation between the higher educational sector and industry; and the Austria Economic Service (AWS)[532] that is mainly active in support programmes for SMEs.

In 2004, the Federal Ministry for Transport, Innovation and Technology launched the "Austrian NANO Initiative" and in 2010, the "**Austrian Nanotechnology Action Plan**"[533] was adopted by the Federal Government. The NANO initiative was a response to regional activities in the Austrian Bundesländer (such as NanoNet Styria [for more information, see later in this Annex]) that sought to identify existing competences and to formulate potential themes for large-scale co-operative projects.

An important motivation in the establishment of such a national research programme was the expectation that its creation would strengthen the national research community in specific fields thereby better linking them to international communities. At that time, most Austrian peer countries (Germany, Switzerland, UK, and Finland), as well as the European Framework Programmes, were using the label nanotechnology for framing focused research programmes.

The NANO initiative aimed to address the following issues: What would be the best way for Austria to harness the opportunities in nanotechnology (for instance, in environmental and energy technology and new resource-saving products or for small- or medium-sized enterprises)? How could Austria contribute to ensuring the safety for its citizens of nanotechnology applications?

NANO had the following objectives: to increase networking among actors to achieve critical mass; to open up ways to exploit the benefits of nanotechnology for industry and society; and to ensure proper support for qualified personnel. To achieve these objectives, it had two programme action lines:

1. National co-operative RTD Projects (Research and Technology Development in Project Clusters (RPCs) and
2. Transnational co-operative RTD Projects (Research and Technology Development in Transnational Projects).

527 https://rio.jrc.ec.europa.eu/
528 http://www.en.bmwfw.gv.at/
529 https://www.bmvit.gv.at/en/
530 https://www.fwf.ac.at/en/
531 https://www.ffg.at/en
532 http://www.awsg.at/
533 https://www.bmlfuw.gv.at/dam/jcr:00058164-0320-4544-b6a4-320325dcfd86/Austrian%20Nanotechnology%20Action%20Plan.pdf

A key aspect of the **Nanotechnology Action Plan** to implement the NANO initiative was to strengthen communication and the dissemination of information to specific target groups, particularly the interested public. Information on the fundamentals, opportunities and risks of nanotechnology was provided to the public through an information portal for nanotechnology. A primary objective was to engage the public in the process of drawing up and implementing a Nanotechnology Action Plan[534], which underwent public consultation via the Internet in Autumn 2009, as did the Implementation Report in November 2012. The feedback received was published online and taken into account in the follow up to the Action Plan and Implementation Plan respectively.

One of the central measures of the Austrian Nanotechnology Action Plan was the establishment of a programme for the environment, health and safety (EHS). NANO EHS was established to provide targeted funding for environment- and health-related research into assessing the risks of synthetic nanomaterials.

NANO was implemented from 2004 to 2011 by the Austrian Research Promotion Agency (FFG)[535] and, in total, nine large-scale co-operative projects were funded across a wide array of sectors such as photonics, nanomedicine, and nanomaterials. Since 2012, support for nanotechnology R&D has been provided through the thematic programmes of FFG.

In addition to the above governmental actions, an Austrian network was created, **BioNanoNet**[536]**,** combining a wide range of expertise in numerous disciplines of medical and pharmaceutical research in nanomedicine and nanotoxicology. The BioNanoNet Association is also the owner of BioNanoNet Forschungs GmbH. Working across both biotechnology and nanotechnology, and visible at international levels, BioNanoNet addresses the scientific areas of:

- Nanotoxicology,
- Sensor technology
- Health and safety, including (nano-) medicine and nanosafety.

The BioNanoNet coordinates **EURO-NanoTOX**[537], which is an open virtual centre and national platform. EURO-NanoTOX is co-funded by the Federal Ministry of Science and Research (BMWF). It elaborates strategies to conduct standardised toxicological in-vitro as well as in-vivo methods on nanostructured materials. Its main focus is on human nanotoxicology and human risk assessment.

Regional Nanotechnology initiatives:

Wirtschaftsstrategie Steiermark 2020 (2011)[538]**:** Styria's Economic Strategy 2020 is a successor to the State Government's previous economic strategy 2006. The 2006 strategy identified so-called economic and technological strong-points ("Stärkefelder") of the region, on which innovation policy activities were focused: material sciences; mechanical engineering/automotive and transport technologies; chemical and process engineering; human technology; information and communication technologies; environmental technologies; energy; building services engineering (including timber construction); nanotechnology; computer simulation and mathematical modelling. The 2011 strategy bundles activities in these fields under three major leading themes: i) mobility, ii) eco-technology, and iii) health technology. The central aim is to focus on future activities and to establish Styria as a "European benchmark for the structural change towards a knowledge based production-society".

BELGIUM

Since its two regions play a central role in Belgian policy making, the main nanotechnology activity in the country is carried by the regional government of Flanders, with a number of institutions working in the area of nanotechnology.

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[534] http://www.sozialministerium.at/cms/site/attachments/6/1/7/CH2120/CMS1371046721712/umsetzungsbericht_2012_en.pdf
[535] https://www.ffg.at/en
[536] http://www.bionanonet.at/about-bionanonet
[537] http://www.bionanonet.at/about-nanotoxicology?lang=english
[538] http://www.wirtschaft.steiermark.at/cms/beitrag/10430090/12858597

Strategische onderzoekscentra[539] (SOC's) is a strategy of the Region of Flanders which gives institutional funding to four Strategic Research Centres that collaborate with the academic and business worlds. Each of the institutes have their own specific focus.

- Imec[540] is a leading European independent research centre in micro- and nanoelectronics, ***nanotechnology,*** design methods and technologies for ICT systems. It carries out research that runs three to ten years ahead of industrial needs. The world's top integrated device manufacturers, equipment and material suppliers, system houses and electronic design automation (EDA) vendors participate in the research conducted there. Work at Imec has a strong connection to nanotechnology given its use in electronics and as the next generation technology for electronics and ICT.
- VIB[541], the Flanders Institute for Biotechnology, is an autonomous entrepreneurial research institute that conducts strategic basic research in life sciences, including molecular biology, cell biology, developmental biology, structural biology, genetics, biochemistry, microbiology, genomics and proteomics. It is considered to be a leading European centre. Much of its work is at the ***nanoscale***.
- VITO[542], the Flemish Institute for Technological Research, is an independent contract research and consulting centre. It converts the latest scientific knowledge and innovative technologies into practical applications, both for public authorities and industry. The research centre operates in the fields of energy, environmental and material technology, in industrial product and process technologies and in remote sensing, with ***nanotechnology*** applications.
- iMinds[543] is an independent research institute that stimulates innovation in information & communication technology (ICT) and broadband. This research is interdisciplinary and demand-driven, and takes place in close collaboration with businesses and governments, both local and international. Its aim is to provide solutions to complex problems and thus help meet society's future challenges.

In 2003, the Regional Government of Wallonia launched a nanotechnology programme to support research projects in that field which led to the creation of **NanoWal[544]**, a structure to favour interactions between actors in nanotechnology field. Nanowal became a non-profit organisation in 2009.

The Czech Republic

In 2005, the Academy of Sciences of the Czech Republic approved the programme "**Nanotechnology for the Society**" with the objective of achieving progress in the development of research and utilisation of nanotechnologies and nanomaterials within Czech society[545]. It included four different sub-programmes in the areas of: nanoparticles, nanofibres and nanocomposite materials; nanobiology and nanomedicine; nano-macro interface; and new phenomena and materials for nanoelectronics, with specific priorities in all of them. The programme was planned to end in 2012.

Other general programmes with a less specific mention to nanotechnology came from the Grant Agency of the Czech Republic, the Ministry of Education, Youth and Sports and the Ministry of Industry and Trade.

In the National Research, Development and Innovation Policy document of the Czech Republic in 2009-2015[546], nanotechnology is addressed under the **Materials Research** priority, where it is set as an area to be supported by national budget in order to increase the global competitiveness of the Czech economy through products with high added-value.

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[539] http://www.ewi-vlaanderen.be/wat-doet-ewi/excellerend-onderzoek/strategische-onderzoekscentra
[540] http://www2.imec.be/be_en/home.html
[541] http://www.vib.be/en/Pages/default.aspx
[542] https://vito.be/en
[543] https://www.iminds.be/en
[544] www.nano.be/
[545] http://www.csnmt.cz/getfile.php?type=file&IDfile=24
[546] http://www.vyzkum.cz/FrontClanek.aspx?idsekce=1020

DENMARK

In Denmark, the Ministry of Higher Education and Science[547] has the main responsibility for research and innovation policy.

In the period from 2001 to 2004, steering groups set up by the Danish government carried out a Technology Foresight pilot programme. The aim of the programme was to carry out eight foresight studies in the three-year period, and to identify issues of strategic importance for science, technology, education, regulation and innovation policy in these areas. The foresight studies included bio- and health care technologies, and ICT (pervasive computing, future green technologies, hygiene and nanotechnology, especially nanomedicine[548]). The last phase of the foresight programme was closely linked to the establishment of the Danish National Advanced Technology Foundation[549] for the development of generic technologies of future importance such as ICT, biotechnology and nanotechnology.

The Action Plan "Strategy for Public-Private Partnership on Innovation", launched in 2003, focused on how to improve co-operation between education, research and trade/ business. The goal was for more enterprises, especially SMEs, to have faster and easier access to knowledge. In 2004, the Ministry of Science, Technology and innovation issued **the Technology Foresight on Danish Nanoscience and Nanotechnology – Action Plan[550]** as a basis for Danish policy on research, education and innovation in the area. The vision was to raise awareness of and promote the utilisation of nanotechnology in Denmark.

In 2003, on foot of the above developments, the Ministry of Science, Technology and innovation published a call for the establishment of high-tech public-private networks in bio, nano and information technology. The goal was to create stable collaboration patterns between companies and knowledge institutions to increase knowledge transfer to, and use in, private industry. The funding was to be used to finance networking. In the first round (in 2004) the Ministry provided seven networks with a budget of EUR 3.7 million (around EUR 0.5 million each). Amongst the networks was NaNet which, (together with Nano Øresund) became one of the two most important Danish nanotechnology networks. NaNet's mission was to create platforms for the exchange of information on nanotechnology, and to facilitate its utilisation on all levels of society, from research and education to industrial application and development.

Between 2005 and 2010, EUR 116 million was allocated to strategic research centres, research alliances and research projects, EUR 62 million being for nanotechnology, biotechnology and ICT. Among the strategic research centres funded under the programme is a Centre for Nano-vaccines[551].

Since 2009, the Danish National Advanced Technology Foundation has channelled funding for projects in high-tech sectors, such as nanotechnology, biotechnology and ICT.

Support for nanotechnology research has been managed through a number of sources. The Danish Council for Strategic Research, part of the Danish Agency for Science, Technology and Innovation is one of these, although the council itself did not authorise funds for research, dependent instead on the Programme Commission, which covers Nanoscience, Biotechnology and IT (NABIIT). The Strategic Research Programme for the Interdisciplinary Applications of NABIIT technologies supported the establishment of networks and research initiatives. Research support also came from the Danish National Research Foundation, the Danish Ministry of the Interior and Health's inter-ministerial working group on Nanotechnology and Human Health, and the Danish National Advanced Technology Foundation. Latterly, also under the Danish Council for Strategic Research, the Programme Commission on Strategic Growth Technologies has had annual calls of total annual value approximately EUR 10 million for research projects on nanotechnology, biotechnology and information- and communication technology. In 2013, The Danish government and five political parties decided to revise the research and innovation system, agreeing to merge the Danish National Advanced Technology Foundation, the Danish Council for Strategic Research and the Danish Council for Technology and Innovation into a new innovation foundation. Thus, the new organisation

[547] http://ufm.dk/en
[548] Danish Nano-science and Nano-technology for 2025, Foresight Brief No. 032
[549] http://www.tekno.dk/about-dbt-foundation/?lang=en
[550] http://ufm.dk/en/publications/2004/technology-foresight-on-danish-nanoscience-and-nanotechnology
[551] http://www.nano-vaccine.org/

Innovation Fund Denmark[552] (IFD), has been the responsible body since 2014.

FINLAND

The main focus areas of public research and development (R&D) funding in Finland are energy and the environment, health and well-being, the information and communications industry, the forest cluster, and metal products and mechanical engineering. Nanotechnology is treated as a technology to be applied across all these focus areas. Finland spends approximately 3.5 % of its gross national product on (R&D). Exploitation of research results being seen as even more important than the amount of investment, the Finnish innovation environment seeks to promote the exploitation of scientific and technological results in Finnish companies.

The main research policy decisions are drawn up in the Science and Technology Policy Council of Finland chaired by the Prime Minister. The principle instruments in the implementation of the policy are the funding organisations working under the ministries. Tekes, the Finnish Funding Agency for Technology and Innovation operates under the remit of the Ministry of Trade and Industry while the Academy of Finland is governed by the Ministry of Education. Nearly 80% of all public research funding is channelled through these two organisations.

The **first Finnish nanotechnology programme** was financed jointly by Tekes and the Academy of Finland in 1997–1999[553]. Its objective was to build know-how, multi-disciplinary infrastructure and linkages between fundamental and applied research. The programme also established a new form of co-operation using joint funding between Tekes and the Academy of Finland. The total value of the programme was EUR 7 million (Tekes EUR 4m, the Academy of Finland EUR 3 m).

FinNano, the Finnish nanoscience and nanotechnology programme, was established in 2005. The programme was co-ordinated jointly by Tekes and the Academy of Finland and covered the whole innovation chain from basic research to commercial products. The aim of the programme was to strengthen Finnish nanotechnology research in selected focus areas and to accelerate the commercial development of nanotechnology in Finland. The key objective was to boost internationally recognised high-level research and competitive business based on nanotechnology.

In addition to FinNano, the Ministry of Education provided funding to develop nanoscience education and infrastructure in Finnish universities and the Nanotechnology Cluster Programme was initiated in 2007 with the Centre of Expertise Programme. In total, Finnish public funding for nanotechnology during 2005–2010 was approximately EUR 235m.

In practice, the FinNano programme was executed in two parts: Tekes' FinNano – Nanotechnology Programme (2005–2009) and the Academy of Finland's FinNano – Nanoscience Programme (2006–2010). The Programme had a total value of approximately EUR 70m, including EUR 25m in research funding and EUR 20m in corporate financing from Tekes. The original programme plan defined three main focus areas:

1) Innovative nanostructure materials;
2) Nanosensors and nanoactuators; and
3) New nanoelectronics solutions.

In 2007, the aims of the programme were redefined as being for:

- Society: Renewal of industry clusters and production, environment and safety;
- Applications: Electronics, forest cluster, chemical sector, health and well-being; and
- Technologies: Nanostructured and functional materials, coatings and devices; Measurement methods, production and scalability.

According to a programme's interim evaluation in 2008, the main successes of FinNano were to activate companies in research and product development, to map all the existing nanotechnology infrastructure and to create cross-cutting networks of nanotechnology professionals.

In 2011, the final report on FinNano was published, showing the results of the Programme[554].

[552] http://innovationsfonden.dk/en; In 2015, IFD had an annual budget of DKK 1.6 billion, but their budget is expected to decrease to DKK 1.47 billion in 2016. The total budget for innovation funds areas was over DKK 2 billion in 2010, so a significant loss of funding took place during the last 5 years. http://innovationsfonden.dk/da/nyhed/innovationsfonden-investerer-ogsaa-i-forskernes-gode-ideer
[553] http://www.tekes.fi/globalassets/julkaisut/research_and_technology.pdf
[554] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf

According to that report and an independent evaluation by Gaia Consulting Ltd., all the Finnish nanotechnology programmes succeeded and fulfilled their objectives, which ranged from capturing knowledge in nanoscience and technology to boosting Finnish nano research and business. The next steps in the development of nanotechnology for industry in Finland were recommended to be achieved by other means. These included measures to enhance technology transfer, encouragement of entrepreneurship, and seed funding and basic research funding based on problems and not in disciplines.

In more recent years, Finland has therefore stopped identifying nanotechnology as a separate area for funding, opting to fund it under general R&D funding programmes and actions to enhance technology transfer and commercialisation by industry in Finland.

FRANCE

In 1999, the "**French Research Network in Micro and Nano Technologies**" (RMNT) was created for the purpose of strengthening and reorganising micro- and nano research and aligning it with the private sector.

In 2003, a **network of major technology centres** was created, linking together the facilities at the following organisations:

- *CEA-LETI*[555] in Grenoble (centred in Minatec);
- The *Laboratoire d'Analyses et d'Architectures des Systemes*[556] (LAAS) in Toulouse ;
- The *Laboratoire de Photonique et de Nanostructures*[557] (LPN) in Marcoussis ;
- *The Institut d'Électronique Fondamentale*[558] *(IEF) Orsay,* in Minerve; and
- The *L'Institut d'Electronique, de Microélectronique et de Nanotechnologie* [559] (IEMN) in Lille.

The creation of this network was supported by a total subsidy of EUR 100 million for the period 2003 to 2006.

Launched in 2003 to fund fundamental research, France's national N**anosciences Programme** was co-ordinated by the Ministry of Research in co-operation with the CNRS (National Scientific Research Centre), the CEA (French Atomic Energy Commission) and the DGA (General Delegation for Weaponry).

In 2005, the French National Research Agency (ANR) was established to assume responsibility for the funding and organisation of all national R&D projects, in order to improve co-ordination. Today, national nano research is funded within the national programme for nanosciences and nanotechnologies (**PNANO**[560]) under the ANR. The budget of the ANR for 2005 was EUR 539m, EUR 35.3m of which was dedicated to PNANO. The ANR has funded research projects in nanosciences and nanotechnologies mostly through the following research programmes:

- Non-thematic programmes (called "programmes blancs")
- Nanotechnologies and Nanosystems programmes P2N.
- Additional programmes, which are more specific to a given topic, such as those on hydrogen storage and fuel cells or on home photovoltaics.

A EUR 35 billion economic stimulus package **Investissements d'Avenir**[561] (Investments for the Future) was launched at the end of 2009. Within that context and since 2011, nano-bio-technology has been one of the priority areas for funding under the ANR, with a particular focus on health and environmental research. The package aims to support scientific research, accelerate its transfer to a pilot stage and to consolidate knowledge about toxicology and nanomaterials, the programme is funding therapies, imaging, diagnostics and medical devices base on nanotechnology and biotechnology.

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555 http://www-leti.cea.fr/en/
556 https://www.laas.fr/public/
557 http://www.lpn.cnrs.fr/fr/Commun/
558 http://www.ief.u-psud.fr/
559 http://exploit.iemn.univ-lille1.fr/
560 http://www.agence-nationale-recherche.fr/suivi-bilan/historique-des-appels-a-projets/appel-detail1/programme-national-en-nanosciences-et-nanotechnologies-pnano-2005/
561 http://www.gouvernement.fr/investissements-d-avenir-cgi

GERMANY

As far back as 1998, the Federal Ministry of Education and Research (BMBF) increased collaborative project funding for nanotechnology. In addition, an infrastructure plan was put in place in the form of the establishment of six competence centre networks. The measures were implemented two years before the USA began its national nanotechnology initiative and four years before the European Union's comparable measures under the Sixth Framework Programme.

In 2004, the German Innovation Initiative for Nanotechnology - "**Nanotechnology Conquers Markets**[562]" was launched and presented to the public. On the basis of the White Paper presented at the nanoDe congress in 2002 and intensive discussions with representatives from business and science, the BMBF's new approach to nanotechnology funding was based on Germany's highly-developed and globally competitive basic research in sciences and technology and primarily aimed to open up the application potential of nanotechnology through research collaborations (leading-edge innovations) that strategically target the value-added chain. The main elements of the strategy were to open up potential markets and boost employment prospects in the field of nanotechnology. Five leading-edge innovation programmes were funded initially:

- NanoMobil, for the automotive sector;
- NanoLux, for the optics industry;
- NanoforLife, for pharmaceuticals and medical technology;
- NanoFab, for electronics; and
- NanoChance, a BMBF funding measure for targeted support of R&D -intensive small and medium-sized enterprises.

Existing policy actions were re-organised under the umbrella of the **High-Tech Strategy**[563] in 2006. This was done through the **Nano Initiative—Action Plan 2010**[564], a cross-departmental initiative by seven departments of the Federal Government that started in 2007 and was headed by the BMBF. Tying in with BMBF's 2004 Innovation Initiative for Nanotechnology, the action plan aimed to integrate nanotechnology funding in the various policy fields into a national nanotechnology strategy. The Action Plan's main goals were (1) to speed up the use of the results of nanotechnological research for innovations; (2) to introduce nanotechnology to more sectors and companies; (3) to eliminate obstacles to innovation by means of early consultation in all policy areas; and (4) to enable an intensive dialogue with the public. The focus was on the opportunities offered by nanotechnology, but possible risks were also taken into account. The total funding for the years 2007 to 2009 was EUR 640 million.

In 2011, the German Ministry for Education and Research (BMBF) published the **Action Plan Nanotechnology 2015**[565], outlining the strategy for responsible development, innovation and public dialogue for the period 2010-2015. The plan included proposals for developing nanotechnology in five main areas (climate/energy, health/food and agriculture, mobility, communication and security). In parallel, a new funding instrument was launched - **Innovation Alliances** - to provide funding for strategic co-operation between industry and public research in key technology areas that demand a large amount of resources and a long time horizon, but promise considerable innovation and economic impacts. Public funds and funding from the industry is combined in a typical proportion of 1:5 (public: private). Innovation was supported with special emphasis on SMEs and development of value chains. Risk assessment was incorporated as well as an improvement of boundary conditions such as educating the workforce, and addressing issues of legislation, norms and standards. The public dialogue on nanotechnology was intensified, including information and dialogue with citizens as well as stakeholders and NGOs.

Innovation alliances were launched as a successor to the leading edge innovation programmes. They were planned as an instrument of public support to ground-breaking industrial innovation, providing support funding for strategic co-operation between industry and public research in high-potential technology areas that require high levels of funding and long lead times. Through a public-private partnership, the Federal Government provided funding for R&D and other innovation-related

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[562] http://d-nb.info/97392179x/34

[563] http://www.research-in-germany.org/en/research-landscape/r-and-d-policy-framework/high-tech-strategy.html

[564] http://www.cleaner-production.de/fileadmin/assets/pdfs/Nano_initiative_action_plan_2010.pdf

[565] http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf

activities for specific, long-term co-operative R&D projects. R&D activities could range from fundamental research to prototype development. Public funds were complemented by private money from industry, typically at a proportion of 1:5 (public: private). Each innovation alliance was set up through an industry initiative, organised as a long-term co-operative research project and involving several industry partners as well as public research organisations.

An Innovation Alliance that followed this policy approach was on "Molecular Imaging for Medical Engineering" (nanotechnology) and was formed by Bayer Schering Pharma AG, Boehringer Ingelheim Pharma GmbH & Co. KG, Carl Zeiss AG, Karl Storz & GmbH Co. KG and Siemens AG. The alliance's goal was creating new diagnostic agents and imaging procedures for clinics and the development of pharmaceuticals.

In addition to policies and programmes to support R&D and commercialisation, Germany took action to address concerns about the environmental and safety costs of the nanotechnology. These are particularly important to look at when trying to develop and label commercial nanotechnology products for the market. In response to these issues, governments have increasingly included the concept of responsible development in their nanotechnology activities. Responsible development aims to stimulate the growth of nanotechnology applications in diverse sectors of the economy, while addressing the potential risks and the ethical and societal challenges the technology might raise. Germany has dedicated policies for the responsible development of nanotechnology. The report "Responsible Handling of Nanotechnologies" ("Verantwortlicher Umgang mit Nanotechnologien") launched by the Nano-Commission of the German Federal Government in December 2010 showed that the nanotechnology sector is continuing to develop dynamically.

Regional initiatives in Germany that make specific mention of nanotechnology include:

- Innovation Strategy of Nordrhein-Westfalen (2006): This strategy was a government statement dated 26 June 2006. It presented a short analysis of the importance of innovations for North Rhine-Westphalia, and in the following elaborated the overall strategy and the measures employed and purposes targeted. The government strategy aimed to generate new potential for growth by reinforcing strengths, sharpening profiles, promoting excellence and pooling forces. Thus, the funding of research and technology was focused on four priority areas with high potential both related to innovation, employment and growth: (i) *nanotechnology,* microtechnology and new materials; (ii) biotechnology; (iii) energy- and environmental research; and (iv) medical research, medical engineering.
- Cluster Offensive Bayern (2007)[566]: The Bavarian cluster policy was initialised in 2007 and focused on 19 branches/technologies with high importance for the future of Bavaria. These were organised into five fields:
  - materials engineering (including *nanotechnologies*, materials engineering, chemical industries);
  - mobility (including automotive, rail, logistics, aerospace and satellite navigation);
  - life sciences and environment (including biotechnology, medical technologies, energy technologies, environmental technologies, forestry and food);
  - IT and electronics (ICT, high-performance electronics, mechatronics and automation); and
  - service and media (financial services, media).

After a positive evaluation in 2010, the State Government announced some changes in the future organisation of the overall initiative: A major change is that the (nonetheless successful) clusters high-performance electronics, logistics, biotechnology and medical technologies would be restructured into networks, while future funding would be focused on the other clusters, where funding so far was most successful in generating additionality.

- Research Strategy of Thuringia (2008): Main objectives of Thuringia's research policy were to strengthen regional universities and non-university research institutes and regional companies in their research and development efforts to achieve scientific excellence, to initiate knowledge and technology transfer as well as innovation. The document described outstanding research areas of the state and measures to strengthen and relate the regional research landscape to target fields in the regional economy: micro and nano technologies, microelectronics; information and communication technologies; media and communication; health research and medical technology; microbiology and biotechnology; optical technologies, photonics;

566 https://www.cluster-bayern.de/en/

materials and production technologies; environmental and energy technologies, infrastructure; and cultural and social change. Main fields of activity of regional research policy were (i) to support competitiveness, (ii) to strengthen networks, (iii) to support young researchers, and (iv) to invest in infrastructure.

IRELAND

Following the establishment of Science Foundation Ireland (SFI) in 2000, public funding was made available to support many public research initiatives including the **Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN)[567]**. Since its foundation in 2003, CRANN has become a research institute of international standing with 17 Principal Investigators (PIs) across multiple disciplines including physics, chemistry, medicine, engineering and pharmacology, and a total of 250 researchers. CRANN was funded predominately by Science Foundation Ireland (SFI), in partnership with two universities (Trinity College Dublin and University College Cork) and industry, and was formed to harness the cross-disciplinary nanoscience research of individual PIs to deliver world leading research outputs and to enable CRANN researchers to address key industry challenges.

In addition, in December 2009, the **Competence Centre in Applied Nanotechnology (CCAN)** was launched. It was an industry-led, collaborative, applied research centre enabling its member companies and research providers to work together to develop nanotechnology enabled products and solutions for the ICT and biomedical industries (i.e. diagnostics, drug delivery, and regenerative medicine). It was co-hosted by CRANN and Tyndall National Institute at University College Cork. With a growing membership, the founding industry members were Aerogen, Analog Devices, Audit Diagnostics, Creganna-Tactx, Intel, Medtronic, Proxy Biomedical and Seagate. CCAN ran until mid-2015.

Ireland has developed its reputation in nanoscience with its researchers recently ranked sixth globally for the quality of their research. Active collaborations between industry and academia exists and are beginning to deliver significant economic benefits to Ireland. Three of the largest industries in Ireland are directly impacted by nanoscience research in perhaps – medical devices, pharmaceuticals and ICT.

The industry ministry, the Department for Jobs, Enterprise and Innovation (formerly the Department of Enterprise, Trade and Employment) plays a pivotal role in industrial innovation policy with its agencies, Enterprise Ireland (EI) (responsible for supporting Irish companies); Science Foundation Ireland (SFI) (funding basic and applied research); and IDA Ireland (in charge of overseas inward investments).

Apart from the establishment of research infrastructures, policy priorities were also being addressed in the Irish national innovation system. In 2004, the Irish Council for Science, Technology and Innovation, with its Secretariat provided by Forfás, launched **its ICSTI Statement on Nanotechnology**. The Statement assessed Ireland's capabilities in the field of nanotechnology, mapped out specific areas of opportunity for the Irish economy and presented a sustainable vision and strategy for the promotion, development and commercialisation of nanotechnology in Ireland. Among the key application areas that were identified were also pharmaceutical and medical technologies.

In 2010, Forfás[568] itself launched a report on **'Ireland's Nanotechnology Commercialisation Framework 2010 – 2014'**. The report presented a national framework to position Ireland as a knowledge and innovation centre for certain niche areas of nanotechnology. It highlighted that Ireland's nanotechnology players should focus on three main technology areas (advanced materials, "More than Moore" and nanobiotechnology) and four application areas (next generation electronics, medical devices & diagnostics, environmental applications, and industrial process improvements).

The BioNano Laboratory in CRANN (mentioned above) is dedicated to interdisciplinary research at the interface between the physical and life sciences including nanotechnology and diagnostics, nanotoxicology and nanomedicine. The group investigates molecular, cellular and physiological interactions using novel biophysical tools such as cell actuators, and magnetic and ultrasound fields. Members of the BioNano Laboratory are also members of the **Integrated Nanoscience Platform**

[567] http://www.crann.tcd.ie/

[568] Forfás ceased to exist in 2015 and was, in part, subsumed under the Department of Jobs, Enterprise and Innovation.

for Ireland (INSPIRE)[569], a consortium of all Irish third level institutions with international leading research capability in nanoscience and nanotechnology. Furthermore, CRANN is also part of the Molecular Medicine Institute which is a not for profit company established by an extended network of Irish Universities and their associated academic hospitals. The BioNano Laboratory aims to facilitate and accelerate the translation of biomedical nanotechnology research into improved nanoscale diagnostics and nanomedicine.

In October 2013, a new Science Foundation Ireland funded research centre, **Advanced Materials and BioEngineering Research (AMBER)[570]** was launched. AMBER is jointly hosted in TCD by CRANN and the Trinity Centre for BioEngineering, and works in collaboration with the Royal College of Surgeons in Ireland and UCC. The centre provides a partnership between leading researchers in material science and industry to develop new materials and devices for a range of sectors, particularly the ICT, medical devices and industrial technology sectors.

THE NETHERLANDS

In the Netherlands, nanotechnology was established as a distinct field of scientific research in the early years of the 21st century. A foresight study (Ten Wolde 1998) conducted by the Dutch Study Centre for Technology Trends (STT) between 1996 and 1998 laid the foundation of a national research agenda. The study showed the importance of nanotechnology for electronics, materials, molecular engineering and instrumentation, and recommended to pay due attention to nanosafety issues and set up research in that area.

The Netherlands hosts three dedicated nanotechnology research centres: The University of Twente (with the **Mesa+** research centre in microsystems technology and nanomaterials[571]), Delft University of Technology (with the **Else Kooi Laboratory**[572], previously called Dimes research centre on nanoelectronics) and the University of Groningen (with **BioMaDe[573]** focused on bio-nanotechnology). The early 2000s, these formed the core of **NanoNed** - the Nanotechnology R&D initiative in the Netherlands[574]. NanoNed was initiated after three years of preparatory work in 2004 by nine industrial and scientific partners including Philips and TNO. It clustered the Dutch expertise on nanotechnology and enabling technology into a national network. The total budget of the NanoNed programme amounted to EUR 235 million, funded by the Dutch Ministry for Economic Affairs. The NanoNed programme was organised into eleven independent programmes or flagships. Each of those was based on regional R&D strength and industrial relevance. The flagships were Advanced NanoProbing, BioNanoSystems, Bottom-up Nano-Electronics, Chemistry and Physics of Individual Molecules, Nano Electronic Materials, NanoFabrication, Nanofluidics, NanoInstrumentation, NanoPhotonics, Nano-Spintronics and Quantum Computing.

In 2006, the Cabinet vision on Nanotechnology "**From Small to Great**" was published. The content of the document mirrored the outline of the European Commission's 2005 Action Plan, with sections on business and research opportunities; societal, ethical, and legal issues; public engagement; and risk assessment.

In 2008, the Dutch Government published its **Nanotechnology Action Plan[575]**. The plan, prepared by the Interdepartmental Working Grou #p on Nanotechnology (ION) and building on the 2006 vision document, incorporated the most up-to-date scientific findings, and reflected information and agreements from European Union and other international initiatives. Four generic themes were defined on the basis of the central theme impact on society and risk analysis, i.e.: bio-nano-technology, beyond Moore, nanomaterials, and nano production (including instrumentation and characterisation). In addition, four application areas were singled out: clean water, energy, food and "nanomedicine".

The Dutch systematic approach to nanotechnology strategy resulted in the development of stable

[569] http://www.crann.tcd.ie/Research/Academic-Partners/testt.aspx
[570] http://ambercentre.ie/
[571] https://www.utwente.nl/mesaplus/
[572] http://ekl.tudelft.nl/EKL/Home.php
[573] http://www.biomade.nl/
[574] However, four other universities, and TNO, the Netherlands Organisation for Applied Scientific Research, are also represented.
[575] http://www.rritrends.res-agora.eu/uploads/27/8079721-bijlage%281%29.pdf

research groups, centres, department and laboratories. On the national level, **NanoLab NL**[576] formed a consortium that built, maintained and provided a coherent and accessible infrastructure for nanotechnology research. NanoLab drew on government funding, which was first spent on upgrading existing infrastructure. Only when the existing infrastructure was fully used and a well-characterised additional need was identified and additional investment made. As a consequence, the Dutch nanotechnology research infrastructure was heavily used by research groups and the local industry. The partners in this enterprise considered themselves often as competitors but co-operate and co-ordinate their actions because of the substantial government funding.

In 2011, the **NanoNextNL**[577] national research programme on nanotechnology was started as a continuation of NanoNed and MicroNed (the Netherlands Microtechnology program). NanoNextNL is based on a Strategic Research Agenda that was asked for by the government in both the cabinet and the action plan. Risk evaluation and Technology Assessment form part of this research programme. 15% of the budget is dedicated to risk-related research, as was demanded by government in the action plan. It is planned that NanoNextNL programme will finish in 2016 but anticipated that many aspects of it will be continued under an industry umbrella. Since 2011, the research agenda for nanotechnology is also part of the **Top sector policy of the Netherlands**[578], which aims to enhance the knowledge economy by stimulating nine top sectors (leading economic sectors).

The Top sector policy is implemented via innovation contracts, in which agreements are laid down between business leaders, researchers and government, jointly focusing the available resources for knowledge and innovation towards the leading economic sectors. Support programmes that aim to support the development and deployment of nanotechnology, are mostly project based. The formats for such supports range from small business oriented measures to financing large research project which involve co-operation between private and public research performers.

POLAND

In 2000, the Polish State Committee for Scientific Research (KBN) started a targeted research project in the topic of nanotechnology called "**Metallic, Ceramic and Organic Nanomaterials: Processing – Structure – Properties – Applications**" with two aims:

- stimulating research on nanomaterials in Poland and promoting collaboration between researchers in this field; and
- making a landscape of the status of nanotechnology in Poland.

The project involved 15 scientific institutions working on 26 research tasks.

In the Polish National Development Plan for the years 2007-2013, launched by the State Committee for Scientific Research in Warsaw in 2004, nanotechnology was foreseen as an area that should contribute to achieving a significant competitive potential in the European Arena.

During 2006, the Ministry of Science of Higher Education established the Interdisciplinary Committee for Nanoscience and Nanotechnology. This Committee analysed the nanotechnology situation and capabilities in Poland and proposed the basic fields that should be strategically supported and launched in 2007 the "**Strategy for the Reinforcement of Polish Research and Development Area in the Field of Nanosciences and Nanotechnologies**"[579]. The areas to be supported were nanoscale phenomena and processes, nanostructures, nanomaterials and nanoscale devices on the one side and nano-analytics/nano-metrology and manufacturing processes and devices for nanotechnology on the other. The priority of the strategy of nanosciences and nanotechnologies was the development, co-ordination and management of the national system of research, education and industry in this field in the short-, medium-, and long-term perspective. Other main objectives to be achieved by 2013 were the development of high added-value nanotechnology products, the creation and commercialisation of manufacturing devices for the production of nanomaterials, the development of the education system in the field of nanotechnology, educating about 20-30 doctors yearly in the specialisation of nanotechnology, building specialist laboratories, establishing co-operation networks of research and industrial units, financial institutions, etc. and integrating

576 http://www.nanolabnl.nl/
577 http://www.nanonextnl.nl/
578 http://topsectoren.nl/english
579 www.bioin.or.kr/fileDown.do?seq=5186

dispersed activity of research units in a joint programme of nanotechnology development.

In 2014, the Government approved the **National Smart Specialisation Strategy** as an integral part of the Enterprise development Programme, setting "Multifunctional materials and composites with advanced properties, including nano-processes and nano-products" as a horizontal smart specialisation area in Poland.

PORTUGAL

In 2005, the Portuguese and Spanish Governments decided to jointly create the **International Nanotechnology Laboratory (INL)**[580] in Braga, Portugal, which was partly funded under the European Regional Development Fund (ERDF). The decision of Portugal and Spain to create an international research laboratory was announced by the head of Government of Spain and the Prime Minister of Portugal at the end of the XXI Portugal-Spain Summit that took place in Évora, Portugal.

The International Nanotechnology Laboratory (INL) was installed in Braga, Portugal, its Director is the Swedish Professor Lars Montelius, and it has over 90 employees.

INL concentrates on nanotechnology, and considers applications to several other areas, following a truly interdisciplinary approach. The Laboratory has been conceived to:

- Assure world class research excellence in all areas of activity;
- Develop partnerships with the industry and foster the transfer of knowledge in economic values and jobs;
- Train researchers and contribute to the development of a skilled workforce for the nanotechnology industry; and
- Survey, prevent and mitigate nanotechnology risks.

Among its research areas nanomedicine, nanoelectronics, nanomachines & nanomanipulation and environment monitoring, security and food quality control can be found.

Further information on the policies and programmes of Spain is given below.

SPAIN

The Minister of Economy and Competitiveness is responsible for the design of the national innovation strategy in Spain. An Inter-ministerial Commission on Science and Technology (CICYT) has the role of co-ordinating the actions of the different bodies involved in innovation policy in a complex governance structure. The regions of Catalonia, the Basque Country and Valencia are especially active in S&T policy.

The 2004-2007 R&D plan was the first Spanish national R&D plan containing a specific cross-programme action regarding nanoscience and nanotechnology. The **Strategic Action (SANSNT)** was designed for the overall enhancement of Spanish industry competitiveness through the implementation of deep changes in several industrial sectors by generating new knowledge and applications based on the convergence of new technologies, where nanotechnology plays a central role. The SANSNT included seven thematic lines among which the first one is "***Nanotechnologies*** applied in materials and new materials within the field of health". Also included are systems biology, synthetic biology and *nanobiotechnology*. The Strategic Action encompassed the development of activities within the six Instrumental Lines of Action (human resources; projects; institutional strengthening; infrastructures; knowledge use; and articulation and internationalisation of the system).

Nanoscience and nanotechnology were included as a **Strategic Action** of both the 2004-2007 National Plan for Research, Development and Innovation (R+D+I) and the funding set aside within this Plan for the Industrial Sector (PROFIT Programme), with the aim of promoting the development of industrial projects (carried out by companies) with nanotechnology-focused objectives.

During the 2004-2007 periods, around 40 projects were funded as a result of this Strategic Action, receiving a total of EUR 2 million in subsidies and EUR 8.5 million in associated investments. All the projects were coordinated by industrial companies, although universities and technological centres were involved in the development of many of them either on a collaborative basis, or were subcontracted by the company carrying out the project.

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[580] http://inl.int/

In 2005, the Government of Spain launched the strategic programme **INGENIO 2010**[581] to align Spain with the strategy of the European Union to reach a 3% of the GDP invested in R&D by year 2010, thereby reducing the gap between Spain and other countries. Its general objective was to achieve a gradual focus of Spanish resources on strategic actions to meet the challenges faced by the Spanish Science and Technology System. This was to be achieved by continuing the existing policies, agendas and successful programmes, as well as by implementing new actions needed to finish meeting the challenges identified for the national science, technology and engineering system.

In order to enhance critical mass and research excellence, the goals of the INGENIO 2010 Programme, within the **CONSOLIDER programme** (launched by the Ministry of Education and Science, through the General Secretariat of Scientific Policy, to promote high quality research and to reach critical mass and research excellence), included creating Centros de Investigación Biomédica en Red (Biomedical Research Networking Centres, CIBER) by setting up consortia, with their own legal personality, without physical proximity, which were designed to conduct single-topic research on a specific broadly-defined disease or health problem. CIBER were formed through the association of research groups linked to the national health system to help form the scientific basis of the programmes and policies of the national health system in the priorities areas of the National R+D+I Plan. Among the centres that have been created within this programme is the Biomedical Research Networking centre in Bioengineering, Biomaterials and ***Nanomedicine*** (CIBER-BBN), founded in 2006. The ***Nanobiomed consortium***, which researches the use of nanoparticles for drug delivery, was also founded with CONSOLIDER funds.

Between 2008 and 2011 the **National Strategy of Nanoscience and nanotechnology, new materials and new industrial products**[582] was implemented by the Ministry of Economy and Competitiveness. This policy measure was part of the National Plan for R+D+I 2008-2011[583] and its objective was to enhance the competitiveness of Spanish industry by promoting knowledge about and stimulating the development of new applications based on nanoscience, nanotechnology, material science and technology, and process technologies. Six themes were targeted: Nanotechnologies applied to materials and new materials in health sector, nanotechnologies for information and telecommunications, nanotechnologies in relation to industry and climate, smart materials with tailored properties based on knowledge as materials and performance coatings for new products and processes, advances in technology and materials processing, development and validation of new industrial models and strategies/new technologies for manufacturing design and process/network production, and exploitation of convergent technologies. The measure covered different lines such as supporting investments, projects, institutional strengthening, infrastructure and utilisation of knowledge, supporting first market operations for innovative products and access to early stage/development funding, system articulation and internationalisation and targeted public research organisations, SMEs and other companies.

Both in the last Spanish Strategy of Science, Technology and Innovation 2013-2020[584] and in the State Plan of Scientific and Technical Research and Innovation 2013-2016[585] (both dependent on the Ministry of Economy and Competitiveness), nanotechnology is considered a sector to be boosted when referring to Key Enabling Technologies (KETs), but there is not a strategic plan such as in previous periods.

Regional initiatives in Spain include:

- Estrategia Nanobasque (2008)[586]: In order to promote the implementation of micro and nanotechnologies in the Basque companies, the Basque Government designed a strategy called NanoBasque in 2007. On December 3 2008, the Department of Industry, Trade and Tourism of the Basque Government launched the nanoBasque Strategy in the framework of the Basque Science, Technology and Innovation Plan 2010. The nanoBasque Strategy was an initiative designed to develop a new economy sector enabled by nanotechnology. It was created with the purpose of covering three main areas of action, namely: company, knowledge and society. One

581 http://www.ingenio2010.es/
582 http://www.idi.mineco.gob.es
583 Ibid
584 http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_Strategy_Science_Technology.pdf
585 http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_RDTI_Plan_2013-2016.pdf
586 http://www.nanobasque.eu/aNBW/web/en/strategy/index.jsp

of the objectives was to create a new model of relations to involve both national and international companies, scientific, technological, political and social agent. The expected result were targeting the efficiency and the integration of the ecosystem of innovation that was clearly aimed at the market, based on the co-operation between all parties. The launch of the nanoBasque Strategy was accompanied by the creation of a dynamic support agency, the nanoBasque Agency, with the mission of coordinating and managing the development of the Strategy. The nanoBasque Strategy strived to boost Basque the presence of companies and research agents on international nanotechnology initiatives and markets. EUR 550 million were expected to be mobilised in the 2009-2015 period, with a proportion of public funding of 52% on the total.

- Within the nanoBasque strategy and using CONSOLIDER funds, the Cooperative Research Center NanoGUNE was created with the mission of performing world-class nanoscience research for the competitive growth of the Basque Country, thereby combining basic research with the objective of boosting nanotechnology-based market opportunities and contributing to the creation of an enabling framework to remove existing barriers between the academic and business worlds.
- The Andalusian Centre for Nanomedicine and Biotechnology, BIONAND, is a mixed centre part owned by the Regional Ministry of Health and Social Welfare, the Regional Ministry of Finance, Innovation, Science and Employment and the University of Malaga. BIONAND has been co-financed, with a contribution of 70% of the total cost, by the European Regional Development Fund (ERDF) together with the Ministry of Economy and Competitiveness in the frame of The Spanish National Plan for Scientific Research, Development and Technological Innovation 2008-2011 (record number, IMBS10-1C-247, quantity. EUR 4.9m). The three main research areas are nanodiagnostics, therapeutic nanosystems, and nanobiotechnology.
- IMDEA-Nanociencia is a private non-profit Foundation created by the regional Government of the Community of Madrid in November 2006 to shorten the distance between the research and society in the Madrid region and provide new capacity for research, technological development and innovation in the field of nanoscience, nanotechnology and molecular design. Researchers at IMDEA Nanoscience are developing distinct diagnostic tools, including nucleic acid-based and nanoparticle-based sensors for detection of biological targets of medical interest, and magnetic nanoparticles to be used in medical imaging as high-sensitive contrast agents.

THE UNITED KINGDOM (UK)

The main player in UK policy measures related to nanotechnology as a key enabling technology (KET) is the Department for Business, Innovation and Skills (BIS) and its agency, the Technology Strategy Board, now called Innovate UK[587]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[588] and identified future potential growth sectors. Both institutions have also developed measures facilitating the knowledge exchange and technology adoption, such as: commercialisation opportunities and Knowledge Transfer Partnerships, Knowledge Transfer Networks, Technology and Innovation Centres, and Small Businesses Research Initiative.

The main interest of the UK government for nanotechnology started in 2002, when they published the **Taylor Report**[589] which recognised that investment in nanotechnology was increasing rapidly worldwide. Following the Taylor Report, an announcement was made by Lord Sainsbury of GBP 90m of funding for the Micro and Nano Technology Manufacturing Initiative. This funding was committed between 2003 and 2007. **Micro- and Nano-technology Manufacturing Initiative** (MNT Initiative) were joint investments by the Government, the Regional Development Agencies (RDAs) and the devolved administrations of Wales and Scotland. The Initiative was launched to help the industry build on the expertise of the UK science base and win a share of this developing market, harnessing the commercial opportunities offered by nanotechnology.

Approximately one third of this investment went to Collaborative R&D MNT Projects, and two thirds to capital infrastructure. Generally built on existing university or business expertise, the twenty-four facilities were targeted at addressing a broad range of key application areas where micro/nano scale activity was considered key to future UK industry capability and where the UK had some strength.

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587 https://www.gov.uk/government/organisations/innovate-uk
588 https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative
589 http://webarchive.nationalarchives.gov.uk/20130221185318/http://www.innovateuk.org/_assets/pdf/taylor%20report.pdf

Micro/nano technologies were included within relevant broader collaborative R&D competitions, principally in the materials, medicine and electronics areas. In 2007 the **Nanotechnology Knowledge Transfer Network (NanoKTN)[590]** was created with the objective of supporting the exploitation and commercialisation of MNT through informing, linking and facilitating innovation and collaborations between users and suppliers of nanotechnology in order to build a strong MNT community in the UK. The centres were grouped into four main themes: nano-metrology; nanomaterials (including health and safety); nanomedicine; and nanofabrication. Between its creation and 2014 the NanoKTN secured about £82million for UK industry, mainly focussed on SMEs, providing a good return investment on the initial input of £3million. In 2014, NanoKTN was merged with another 15 KTN in the new organisation KTN Ltd.

In 2006, the Engineering and Physical Sciences Research Council issued its **Report of the Nanotechnology Strategy Group[591]** as an active response to the EPSRC 2005 Nanotechnology Theme Day Report that found that there were flaws in the structure for nanotechnology R&D in the UK. The report proposed, in conjunction with researchers and users, to identify a series of "grand challenges" in nano-science and nano-engineering, focused initially on areas such as energy, environmental remediation, the digital economy and healthcare, where an interdisciplinary, stage-gate approach spanning basic research through to application will be an integral part of the challenge of enabling nanotechnology to make an impact. The "grand challenges" were to be addressed via interdisciplinary consortia spanning the EPSRC research spectrum, and including collaboration with sister Research Councils (e.g. BBSRC).

In December 2007, the Research Councils announced a Cross-Council programme "**Nanoscience through Engineering to Application[592]**", with the objective of providing an additional GBP 50 million in areas where the UK nanotechnology research base could make a significant impact on issues of societal importance such as healthcare. These societal or economic Grand Challenges wanted to be addressed in a series of calls for large-scale integrated projects. They were led by the Engineering and Physical Sciences Research Council, in collaboration with stakeholders including other Research Councils, industry, the Technology Strategy Board (TSB) and the Nanotechnology Research Coordination Group.

Government announced its intention to develop a UK Strategy for nanotechnologies in its 2009 response to the Royal Commission on Environmental Pollution's report, Novel materials in the Environment: The case of Nanotechnology.

The **Nanoscale Technologies Strategy 2009-2012[593]** was launched in October 2009 by the TSB and targeted the ways by which nanotechnologies could address major challenges facing society such as environmental change, ageing and growing populations, and global means of communication and information sharing. Its objective was to provide the framework for future applied research predominantly through activity inspired by the needs of wider technologies and challenge-led calls.

In 2010, the Ministerial Group on Nanotechnologies, the Nanotechnology Research Co-ordination Group (NRCG), and the Nanotechnology Issues Dialogue Group (NIDG) issued the UK **Nanotechnologies Strategy - Small Technologies, Great Opportunities[594]**. This Strategy defined how Government will take action to ensure that everyone in the UK could safely benefit from the societal and economic opportunities that these technologies offer, whilst addressing the challenges that they might present.

In 2012 the Department for Environment, Food and Rural Affairs (DEFRA) launched the **Nanotechnology Strategy Forum (NSF)**[595] to facilitate discussion and engagement between Government and stakeholders in matters referred to the responsible advancement of the UK's nanotechnologies industries. The NSF is an advisory body formed by *ad hoc* expert with a membership drawn from industry, regulators, academia and NGOs (non-governmental organisations and it is jointly chaired by the Minister of State for Universities and Science (BIS) and the

[590] https://connect.innovateuk.org/web/nanoktn
[591] https://www.epsrc.ac.uk/newsevents/pubs/report-of-the-nanotechnology-strategy-group/
[592] https://www.epsrc.ac.uk/newsevents/pubs/nanotechnology-programme/
[593] http://www.nibec.ulster.ac.uk/uploads/documents/nanoscaletechnologiesstrategy.pdf
[594] http://www.steptoe.com/assets/htmldocuments/UK_Nanotechnologies%20Strategy_Small%20Technologies%20Great%20Opportunities_March%202010.pdf
[595] https://www.gov.uk/government/groups/nanotechnology-strategy-forum

Parliamentary Under-Secretary for DEFRA and is supported by a small secretariat based in DEFRA.

The UK **Enabling Technologies Strategy 2012-2015**[596] also addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.

[596] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015

ANNEX 6: PRODUCTS FOR NANOTECHNOLOGY AND ICT

This Annex is divided largely into the same categories as used in the main body of the report:

1. Data storage
2. Printed electronics
3. Low-k dielectric coatings and other improvement applications
4. Digital imagers and sensors
5. Optical components (e.g. switches and optical amplifiers (op amps))
6. Components
7. Novel technologies

1 DATA STORAGE

Product Name	Description	Producer
Metal Nano Dot (MND) Memory	The metal nano-dot (MND) memory is a non-volatile memory. Nanoparticles, in the form of rods of diameter 2 nm are suspended in a solid matrix in an insulator.	Asahi Glass
NANO CUBIC Technology	NANO CUBIC technology is an ultra-thin layer coating that results in higher resolution for recording digital data, ultra-low noise and high signal-to-noise ratios that are ideal for magneto-resistive (MR) heads. It can increase the capacity of data cartridge and digital videotape to one-terabyte (native = uncompressed) capacities, and floppy disc capacities to three gigabytes native.	FUJI Film
Intel® StrataFlash® Cellular Memory	The Intel® StrataFlash® Cellular Memory (M18) is a 90 nm NOR MLC (multi-level cell) device. This fifth generation of Intel StrataFlash memory delivers more value and improved performance to cellular developers, and enables highly reliable, yet cost-effective, cellular solutions. Offering faster read and write speeds, increased density and better power consumption, the M18 delivers the unique combination of memory features cellular designers need for today's cellular applications-high performance, high density, and low-power operation. The M18 gives wireless products the capacity to do more while consuming less power.	Intel
3DXPOINT	Micron and Intel 3D XPoint™ technology, a new category of non-volatile memory that addresses the need for high-performance, high-endurance, and high-capacity memory and storage. 3D XPoint technology is up to 1,000 times faster and has up to 1,000 times greater endurance than NAND, but is 10 times denser than conventional memory. For memory and storage applications.	Micron Technology Inc.
Phase-Change Memory (PCM)	Phase-change memory (PCM) has the potential to allow developers to stack multiple layers of PCM arrays in a single die, thereby greatly increasing the density of the non-volatile memory medium.	
NRAM™ non-volatile random access memory	Nantero, Inc. is building a high density non-volatile random access memory chip, which can replace DRAM (dynamic RAM), SRAM	Nantero, Inc.

Product Name	Description	Producer
	(static RAM), flash memory, and ultimately hard disc storage, i.e. a universal memory chip suitable for countless existing and new applications in the field of electronics. Nantero's design for NRAM™ involves the use of suspended nanotube junctions as memory bits, with the "up" position representing bit zero and the "down" position representing bit one. Bits are switched between states through the application of electrical fields. Nantero is a nanotechnology company using carbon nanotubes for the development of next-generation semiconductor devices. These devices include memory, logic, and other semiconductor products. In the field of memory, Nantero is developing NRAM™, a high-density non-volatile Random Access Memory.	
Flash Memory 90 nm technology	Samsung is the industry's first manufacturer to apply 90-nanometre process technology to a Flash memory device, to make ultra-high-capacity non-volatile memory technology. The 2Gb device 0.05 μm^2 design rule is half the minimum cell size found in other NAND Flash memory chips. The ultra-high capacity device can make for an affordable 256 MByte USB Flash drive, expediting the replacement of the floppy drive and zip drive combination. Suitable for existing fabrication lines, no need for additional facilities investments. The 90-nanometer process technology greatly reduces manufacturing costs. The 2Gbit Flash memory utilises a novel SSA-STi (Sacrificial Self Align Shallow Trench isolation) to improve cell data storage reliability, challenging at sub-100nm process.	Samsung

2 PRINTED ELECTRONICS

Product Name	Description	Producer
NINK®-Ag silver conductive ink	The NINK®-Ag series of conductive silver inks are for piezoelectric inkjet printing on various substrates and are made up of surface modified nano-silver. Fine-pitch conductive lines can be placed on various substrates, such as olycarbonate, polyester, polyimide, and ceramics. The sintering temperature of the nano-sized silver particles (around 150°C) is lower than for micro-sized silver particles.	ABC Nanotech Co
CNT-based aerosol ink	CNT-based aerosol inks are formulated for compatibility with Optomec's Aerosol Jet® printer. The materials are designed for transparent conductive, conductive trace, sensor and interconnect applications. These surfactant-free CNT inks are designed for low-temperature application on a wide range of substrates including paper, printed circuit boards, ceramic, glass, and silicon. The use of	Brewer Science

Product Name	Description	Producer
	the inks with Optomec Aerosol Jet® technology is ideal for quick prototyping of devices with direct transfer to large-scale production systems.	
Innovalight	Ink that contains silicon nanoparticles suspended in a chemical mix. When applied to silicon solar cells during the manufacturing process, the ink boosts the cells' absorption of sunlight at lower wavelengths, generating more electricity	DuPont
DYAG50 conductive silver printing ink	Dyesol's DYAG50 Conductive Silver Ink helps to achieve exceptionally high conductivity at low cure temperatures when printing on a variety of substrates including glass and polyesters (PET/PEN) and ITO/FTO coated substrates.	Dyesol
AgCite™Silver Nano-Particle Inks	AgCite™ family of inks sinters at low temperatures and is suited to a broad range of substrates including paper, polymers, glass and ITO. With unparalleled conductivity, less ink is needed for the same application requirement, bringing about major cost-savings.	Nano Dimension Ltd.
Nink	NanoLab produces two types of ink, Nink-1000 (multiwall carbon nanotube ink) and Nink-1100 (single wall carbon nanotube ink). NanoLab formulated Nink to be printable using HP's DeskjetTM series printers.	NanoLab
NanoGold	Conductive ink	NanoMas Technologies
NanoSilver	Conductive ink	
Metalon™ Inks: silver	Metalon silver inks are formulated for range of applications. Off-the-shelf inks for inkjet, screen, flexo, gravure, and spray/aerosol are available. The inks can be processed using traditional thermal methods as well as using the PulseForge tools. In some cases, a short (1-3 minute) drying time is suggested prior to processing with a PulseForge tool. Processing conditions are currently being developed which would remove the need for even a brief dry cycle.	Novacentrix
PChem nano silver flexo	The technology is based on patented silver nanoparticles. The conductive inks derived from these stabilised silver nanoparticles gives superior conductivity and ultrafine resolution in various printed electronic applications including simple consumer devices, as transparent electrodes in solar and lighting products, and sensors in medical and automotive products.	PChem Associates
Z TACH™	Z TACH™ anisotropic conductive adhesive is applied as a paste without any pressure and then cured either with heat at low temperature (70˚C to 150˚C) or with UV in a magnetic field. This results in the self-assembly of conductive columns at regular intervals throughout the adhesive thickness (Z-Axis).	SunRay Scientific

Product Name	Description	Producer
	The columns create electrical and thermal interconnection in the Z-Axis, while maintaining electrical insulation in the X-Y plane. After formation, the columns maintain their structure due to immobilisation within a now rigid polymer matrix.	
UTDAg conductive silver nanoinks	UTDAg silver nanoink is general-use ink for aerosol or ink-jet printing on variety of substrates. The ink is based on silver nanoparticles with average size around 10 nm and dispersed in a liquid. Since they are surface stabilised, UTDAg inks are highly soluble in non-polar organic solvents and stable under atmospheric conditions at room temperature.	UT Dots Inc.
Siren™	Graphene printed electronics-based anti-theft retail package product	Vorbeck Materials

3 Low-k dielectric coatings and other improvement applications

Product Name	Description	Producer
Graphistrength® thermoplastic masterbatches	Graphistrength® thermoplastic masterbatches contain multi-wall carbon nanotubes dispersed in a polymer matrix in a high concentration. They are particularly suited to applications where stringent requirements, in terms of cleanliness, permanent electrostatic dissipation, and perfect surface finish, are in place, such as semi-conductors and components sensitive to ESD (electrostatic discharge), housings of electronic devices, etc.	Arkema
Chip on heatsink	Integrating the thermal printed circuit board (PCB) into a heat sink ensures the shortest thermal path from the heat source, an optimal thermal management solution for high power devices such as LEDs, IGBT transistors or MOSFETs. Electrical insulation of a conventional aluminium heat sink is provided by application of a dielectric ceramic layer directly on its surface.	Cambridge Nanotherm
Nanotherm flexible circuit board	Flexible circuit board substrates for LEDs and electronics, the aluminium foil is ideal for many applications, including as a thermally conductive electric insulation barrier in power electronics, or as the substrate for flexible printed circuit board LED lighting applications, or for use in energy harvesting applications as a super-thin thermally conductive substrate. The foil is nano-ceramic aluminium, a sheet of aluminium where the top surface has been converted to nano-ceramic – a material which is extremely thermally conductive, but which stops electricity transfer.	
Nanotherm LC	A metal clad printed circuit board, Nanotherm-	

Product Name	Description	Producer
	LC is fabricated from a sheet of nano-ceramic aluminium, a sheet of aluminium where the top surface has been converted to nano-ceramic – a material which is extremely thermally conductive, but which stops electricity transfer.	
NANOTIM APS	NANOTIM is a silicone-based thermal interface material made from a silicone fluid with thermally conductive material and metal oxide fillers. TTM can offer various type of thermal interface material such as high-conductivity phase change material, thermal grease, and silicone pad with adhesive etc. NANOTIM APS is a nano-powder thermal interface material.	CoolTTM
NANOTIM PCM (phase change material)	Phase change material (PCM): PCM25 is designed to solve heat problems from electronic components such as high-end CPUs, GPUs, FB-Dimm and custom ASICS chips. PCM25 is a wax-based phase change material made from a paraffin wax with thermally-conductive material and metal oxide fillers. The product offers high thermal conductivity, virtually no wide operating bleed or evaporation over temperature range.	
NANOTIM SPS (silicon thermal pad)	The NANOTIM SPS (silicon thermal pad) series comprises thermal interface materials specially designed for heatsink applications, with excellent thermal conductivity cushioning and gap-filling properties. It is also suitable for mounting a heat spreader onto a power converter and motor control PCB.	
NANOTIM TGS (thermal grease)	The NANOTIM TGS (thermal grease) series are thermal interface materials with nano-dispersion technology to mix the silicon fluid and high performance nano-powder, which can help the thermal dissipating of electric components. They are used as a thermal interface material between a heat source and a heat sink.	
NANOTIM TSS	NANOTIM is a silicone-based thermal interface material made from a silicone fluid with thermally conductive material and metal oxide fillers. TTM can offer various type of thermal interface material such as high-conductivity phase change material, thermal grease, and silicone pad with adhesive etc. TTS is a nano-powder thermal interface material - thermal spreading sheet.	
SiLK™	SiLK™ semiconductor dielectric resin: SiLK resin formulations are specialty polymer solutions manufactured by Dow for the microelectronics industry. For example, SiLK™ I 1070 is designed for easy integration and extendibility, and its formulations offer a robust feature set. High thermal stability and fracture toughness means SilK™ I 1070 is compatible with standard IC processing tools	Dow Chemical

Product Name	Description	Producer
	in today's fabrications.	
Neushield	NeuShield® utilises POSS® dispersion technology (POSS, polyhedral oligomeric silsesquioxane - a nano-structural chemical) to achieve high loading levels of gadolinium atoms within low density polyethylene. The product is suitable for shielding semiconductors against radiation induced memory loss. NeuShield® chip caps and hot-melt adhesive glue sticks are very easily applied to chips and connectors. NeuShield® adhesive tape is designed for simple application to housings, structures and cables.	Hybrid Plastics
Nanoglass	NANOGLASS© is a family of inorganic porous oxide-like low-k dielectric materials. Higher processor speeds, lower power requirements, and less thermal problems than conventional dense dielectrics, can be achieved using NANOGLASS©.	Nanopore Inc.
Prolimatech PK1 thermal compound paste	Used to provide good heat transfer from a CPU to the heat sink base, Prolimatech PK-1 is a thermal compound that is easy to spread and is reliable throughout the year. It requires no burn-in time, has a long lifespan with low dry-out, and is not electrically conductive. The nanoparticles help to fill in microscopic imperfections in the surfaces between the heat sink and contact surface, providing good thermal dissipation.	Prolima Tech
Prolimatech PK-2 nano-aluminium thermal compound paste	Used to provide good heat transfer from a CPU to the heat sink base, Prolimatech PK-2 thermal compound is a high performance thermal bonding agent specially designed for easy application. PK-2's core feature is its low viscosity, allowing for one to quickly and easily apply the thinnest coat of thermal compound possible.	
Prolimatech PK3 thermal compound paste	Used to provide good heat transfer from a CPU to the heat sink base, PK-3 thermal compound is made up of specially designed nano-particles. The nano-particles work by filling in any small air gaps caused by microscopic imperfections and allowing for peak transfer of heat away from the components.	
Zano® Al-10	Zano® is a series of specialty zinc oxides that combine excellent broad-band UVA/UVB absorption properties with high levels of transparency in a wide range of applications. Zano® also offers good anti-microbial properties, which makes it a good additive to, among others, plastics and textiles. Zano® Al-10 is a microfine, aluminium-doped zinc oxide with a typical aluminium content of 1wt% and is used for electronics applications.	Umicore Zinc Chemicals

4 DIGITAL IMAGERS AND SENSORS

Product Name	Description	Producer
DIC100TH (weld inspection system)	DIC100TH (Dynamic Imaging Camera). The digital x-ray imaging device provides the full benefit of a direct conversion x-ray sensor using custom charge integration CMOS. Fast frame read-out with extremely low noise level, matches the requirements for low-contrast/high sensitivity applications and specifically this product is a unique solution for inspecting welds in heat exchangers, namely tube to tube-sheet welds. The sensor is connected to the computer via an industry-standard CameraLink connection. A PCI frame grabber is shipped with the sensor.	Ajat Oy
PID350	In nuclear medicine (PET, SPECT) as well as bone densitometry, the PID350 technology family offers energy dispersive imaging with high position resolution.	
SCAN300FL	The SCAN300FL digital x-ray imaging device provides the full benefit of a direct conversion x-ray sensor using custom charge integration CMOS. Fast frame read-out, with extremely low noise level, matches the requirements for low-contrast/high sensitivity scanning applications. The sensor is also well suited for high SNR applications using integrated digital frame accumulation techniques. The very high efficiency Cd(Zn)Te-CMOS sensor technology provides excellent image quality with x-ray energies up to 300 kVp, but can also operate on low energies starting from 10 kVp. The sensor is connected to the computer via an industry standard CameraLink connection. A PCI frame grabber shipped with the sensor employs large memory buffers on board to establish a high reliability data transfer link. SCAN300FL incorporates an active Peltier element for controlling the temperature within +-0.1 degrees for maximal performance. The system also includes specialised calibration software for high performance imaging.	
SCAN5000TDI	Using the SCAN5000TDI sensor family, a cost effective and highly performing scanning linear array can be implemented with active area of 450mm that can scan-image the chest or other body parts at 40cm/sec with 0.1mm line width (i.e. 4000lines/sec TDI output). Since this is a linear rather than a full format array, the cost of such sensor is highly competitive against flat panels, while CdTe/CdZnTe offers exquisite image quality, sensitivity and contrast.	
Graphene-based photodetector	The worldwide fastest graphene-based photodetectors with a potential of a maximum data rate of 50 Gbit/s.	AMO GmbH
Low-Power 100 Gb/s Optical Engine	Kotura's silicon photonics platform supports optical engines using Wave Division Multiplexing (WDM), in which different signals can share the same path. As the only silicon photonics provider	Kotura (Mellanox Technologies)

Product Name	Description	Producer
	to offer WDM, Kotura's optical engine provides distinct advantages, including reducing the cost of fibre and associated connectors within the interconnect fabric for 4x25 GHz solutions by a factor of four, as well as readily expanding from four channels to eight, 16 or even 40 channels over a single strand of optical fibre. Additionally, Kotura's silicon photonics platform also supports optical engines using parallel fibre channels.	
WDM filters	Wavelength-division multiplexing (WDM) filters for fibre-optic communications.	NanoOpto Corp (part of API Nanotronics)
APD TO/ROSA	Small and hermetic germanium-on-silicon avalanche photodiodes in TO-can/ROSA (receiver optical sub-assembly) packages for the easy and suitable installation in data communications and telecommunication systems.	SiFotonics Technologies Co., Ltd.
Ge/Si APD	These Ge/Si avalanche photodiodes use a separate absorption, charge and multiplication (SACM) structure to achieve excellent absorption efficiency, high gain and low noise factor. They are based on the high responsivity of germanium to near-infrared light and the low k-factor of Si as multiplication layer. The APDs have lower temperature dependence (compared with traditional InP or InAlAs materials) owing to incorporating Si as the avalanche material, and can operating over a wide temperature range from -40°C to 85°C.	
Ge/Si PIN PD	Germanium-on-silicon technology is the new driving technology to manufacture near-infrared (0.8um to 1.6um) photodiodes instead of InGaAs material for the fields of telecommunications, metro networks and FTTHs. Superiority in mass production and uniformity, owing to compatibility with CMOS manufacturing process. SiFotonics Ge/Si PIN photodiodes have been optimised for best performance, including high responsivity, fast response, low capacitance and low bias voltage. The product portfolio covers speeds from 10 Gb/s to 25 Gb/s. All SiFotonics Ge/Si PD devices can be customised, including optimal wavelength, data rate, array size and array pitch.	
Transceiver integrated circuits	SiFotonics has developed a series IC integrating laser/VSCEL driver, limiting amplifier (LA) and MCU (microcontroller) into a tiny 5mm x 5mm QFN32 package for active optical cable (AOC) applications. It can be used not only for traditional SFP+ (enhanced small form-factor pluggable transceivers), passive optical network (PON) SFP+ but also suitable to be used in AOC which require a small size package.	
SNAP225 digital x-ray imaging device	The SNAP225 is a compact digital x-ray imaging device, a frame mode direct conversion x-ray sensor combined with asymmetric active area using charge integration CMOS. This unique sensor combines three functionalities in one and is intended for integration into dental panoramic,	Ajat OY

Product Name	Description	Producer
	cephalometric and local 3D/CT systems. These functionalities are achieved using reconstruction and image processing software.	

5 Optical components (e.g. switches and optical amplifiers (op amps))

Product Name	Description	Producer
Semiconductor optical amplifiers	Semiconductor optical amplifiers (booster optical amplifiers) are amplifiers which use a semiconductor to provide the gain medium. They have a similar structure to Fabry–Perot laser diodes but with anti-reflection design elements at the end faces. Recent designs include anti-reflective coatings and tilted waveguide and window regions which can reduce end face reflection to less than 0.001%. Since this creates a loss of power from the cavity which is greater than the gain, it prevents the amplifier from acting as a laser.	Innolume
APS4300	Optical Module for 1+1 unidirectional protection	LYNX Photonic Networks
APS4300B-HP	A high-power optical module for 1+1 unidirectional protection	
APS4301	Optical module for 1:1 fibre link protection	
APS4301-D	Dual 1:1 protection switching module for bidirectional fibre links	
APS4305	Optical module for 1+1 fibre link protection.	
APS4305-E	Optical module for 1+2 fibre link protection.	
APS4310	Optical module for single-ended bi-directional protection. For fibre link, equipment and dual homing protection applications.	
APS4325-B	Dual bi-directional fibre-links protection module with embedded by-pass switching.	
LightLEADER 3002-U	Optical bypass protection switch for 2 circuits.	
LightLEADER 3201/3202/3212	Optical add-on protection system for WDM bi-directional fibre links.	
LightLEADER 4000	LightLEADER 4000 platform modular platform supporting a large variety of optical fibre monitoring, protection switching and intrusion detection applications.	
LightLEADER 4301-i	Protection and by-pass system for intermediate network sites.	
LightLEADER 4301-i	Protection and by-pass system for intermediate network sites.	
Nano-optic isolator	SubWave Optical Isolator, a family of high-performance, nano-structure-enabled optical isolators which can reduce cost and device size for data communications and telecommunications transceivers and transponders. The SubWave optical isolator can either be used in standard transceiver designs,	NanoOpto Corp (part of API Nanotronics)

Product Name	Description	Producer
	or as the basis for more compact new architectures. The SubWave optical isolator uses a proprietary nano-structure-based design to directly integrate a required polarisation function on the surface of a garnet Faraday rotator, thereby creating thinner isolator cores – as thin as 0.5mm or less, a reduction of over 30% compared to traditional isolator designs – and so enabling physically smaller isolators – on the order of 0.5mm x 0.5mm, depending on the application. This nano-lithography based manufacturing methodology is being used by NanoOpto to produce surface mount, cylindrical mount and magnet-less isolators.	
Polarising beam splitters/combiners	The devices are used to combine light from two input beams into a single output beam (PBC mode) or to separate the orthogonal polarisation components of an input signal into two output beams (PBS mode). These advanced optical devices are optimised for operation at either 1310 nm or 1550 nm. PBS/C are nanofabricated directly on thin glass substrates using proprietary processes, resulting in a product with a small form factors and great shape and size versatility. The NanoOpto devices can be produced with thicknesses ranging from 0.2 mm to 1.6 mm and sizes from 0.5mmX0.5mm to 15mmX15mm. The operating range is -40 to 80°C. PBS/C have applications in telecom, scientific equipment such as Raman amplifiers, polarisation division Mux/DeMux, polarisation switches, variable optical attenuators, and general fibre networks.	
Waveplates, retarders and trim retarders	SubWave AQWP650+, an achromatic quarter waveplate for high performance, robust, DVD/CD read/write combination drives with applications for entertainment, mobile systems and computing. This novel wideband achromatic waveplate improves performance, increases compactness, improves reliability, reduces assembly costs, and simplifies the design of DVD/CD read/write combination drives. The SubWave AQWP650+ uses a proprietary nano-structure-based design to provide true zero order performance across a broad wavelength range. It provides 90(degree) (i.e., quarter wave) +/-4(degree) of phase retardance uniformly across a 630 to 805nm wavelength range, encompassing the 650nm and 785nm wavelengths used for DVD/CD read/write operations. This device is constructed using only dielectric materials and exhibits stable optical performance and physical robustness over a broad operating temperature range.	

6 Components

Product Name	Description	Producer
AO3160	The AO3160 is fabricated using an advanced high voltage MOSFET process that is designed to deliver high levels of performance and robustness in popular AC-DC applications.	Alpha & Omega Semiconductor
AMD Athlon 64 X2 Dual-Core Processor	Using its Automated Precision Manufacturing (APM) system, AMD has taken the critical step from its 130 nanometres (nm) Silicon On Insulator (SOI) process to a 90nm SOI. Lithography is the printing process used to manufacture processors. 90nm here corresponds to the International Technology Roadmap for Semiconductors' (ITRS) definition of the minimum metal pitch – the smallest metal lines – used being 90nm. These tiny proportions allow AMD to etch onto a silicon die complex circuits of millions upon millions of transistors, which allow for more-powerful-but-smaller processors. AMD uses a combination of 248nm and 193nm lithography tools, along with resolution enhancement techniques, to etch sub-50nm transistor gates – the smaller transistors switch faster and draw less power.	AMD
OMAP 5 Processors	28 nm CMOS low-power process with highest levels of processor performance and lowest power consumption	
N Channel	This new generation MOSFET has been designed to minimise the on-state resistance (RDS(on)) while maintaining switching performance, making it ideal for high efficiency power management applications.	Diodes Incorporate
650 V E-HEMT transistors	Gallium Nitride (GaN) devices offer five key characteristics: high dielectric strength, high operating temperature, high current density, high speed switching and low on-resistance. These characteristics are due to the properties of GaN, which, compared to silicon, offers ten times higher electrical breakdown characteristics, three times the bandgap, and exceptional carrier mobility.	GAN Systems
GS66508T-EVBHB	The EVB is a fully functional half bridge power stage consisting of two 650V GaN E-HEMTs (top side cooled GS66508T, 30A/55mΩ), gate drive power supply, half bridge gate drivers and heatsink.	
IBM® PowerPC® 970FX/970MP Processors	Processors made using a 90 nm manufacturing process.	IBM
P-Channel & Small Signal MOSFET	HEXFET® power MOSFETs includes P-channel devices in surface mount and leaded packages and form factors that can address almost any board layout and thermal design challenge.	Infineon
Intel® Core™ Duo Processor	The Intel® Core™ Duo (dual core) processor and the Intel® Core™ Solo (single core) processor are built on Intel's next generation 65 nanometre process technology with copper interconnect.	Intel

Product Name	Description	Producer
Netspeed Gemini	High-performance, scalable, coherent on-chip network IP solution. It supports all three levels of coherent traffic – cache coherent, I/O coherent & non-coherent traffic – in a single on-chip network. NetSpeed Gemini provides full cache coherency for small and large SoC designs, delivers high performance and significant time-to-market advantages to SoC designers for a wide range of markets from mobile, networking to high-performance computing.	Netspeed Systems
Netspeed Orion	High-performance, scalable, coherent on-chip network IP solution. NetSpeed Orion represents a new way of designing and optimising sysem-on-chip interconnects.	
i.MX6DL: i.MX 6DualLite Processors	The i.MX 6 series of applications processors combines scalable platforms with broad levels of integration and power-efficient processing capabilities particularly suited to multimedia applications.	NXP
i.MX6Q: i.MX 6Quad Processors – High-Performance, 3D Graphics, HD Video, ARM Cortex-A9 Core	The i.MX 6 series of applications processors combines scalable platforms with broad levels of integration and power-efficient processing capabilities particularly suited to multimedia applications.	
i.MX6S: i.MX 6Solo Processors – Single-Core, Multimedia, 3D Graphics, ARM Cortex-A9 Core	The i.MX 6 series of applications processors combines scalable platforms with broad levels of integration and power-efficient processing capabilities particularly suited to multimedia applications.	NXP
AMD Phenom™ II Processors	Process technology based on 45 nanometre, SOI (silicon-on-insulator) technology	Pall Corporation
DTMOS Series (VDSS of 600V / U-MOS Series VDSS of 12V to 250V)	Extensive portfolio of low-VDSS and mid/high-VDSS MOSFETs in various circuit configurations and packages, featuring high speed, high performance, low loss, low on-resistance, small packaging, etc. Its main products include the mid- to high-voltage DTMOS Series with a VDSS of 600V or so and the low-voltage U-MOS Series with a VDSS of 12V to 250V.	Toshiba

7 Novel technologies

Product Name	Description	Producer
Organic Field Effect Transistor (OFET) Materials	Organic field effect transistors (OFETs) are the basic building blocks for flexible integrated circuits and displays. To make OFETs, materials ranging from conductors (for electrodes), semiconductors (for active channel materials), to insulators (for gate dielectric layers) are needed.	Aldrich
D-Wave 2X	With 1000+ qubits and many other technological advancements, the D-Wave 2X	D-Wave Systems

Product Name	Description	Producer
	will enable customers to run much larger, more complex problems on the system. In addition to scaling beyond 1000 qubits, the new system incorporates other major technological and scientific advancements. These include an operating temperature below 15 milli-Kelvin, near absolute zero and 180 times colder than interstellar space. With over 128,000 Josephson tunnel junctions, the new processors are believed to be the most complex superconductor integrated circuits ever successfully used in production systems. Increased control circuitry precision and a 50% reduction in noise also contribute to faster performance and enhanced reliability.	
D-Wave One	"The world's first commercially-available quantum computer" operating on a 128-qubit chipset using quantum annealing (a general method for finding the global minimum of a function by a process using quantum fluctuations) to solve optimisation problems.	
Magnetic Sensors	NVE is a leader in spintronic Giant Magnetoresistance (GMR) sensors. NVE sensors are smaller, more sensitive, and more precise than conventional sensors such as Hall effect or AMR. NVE developed the first commercial GMR sensors in 1995. The product line includes analogue sensors, digital sensors, angle sensors, gear tooth sensors, current sensors, medical sensors, and sensor evaluation kits for precision gear tooth and encoder applications, as well as sensors with custom magnetic, electronic and packaging specifications.	NVE
OFET Semiconducting Small Molecules	A collection of small semiconducting molecules for thin film organic field effect transistors (OFETs).	Ossila

ANNEX 7: HUMAN HEALTH AND SAFETY

INTRODUCTION

The basis for the evaluation is the "Stoffenmanager Nano" application developed by TNO (Van Duuren-Stuurman, et al. 2012). In short, Stoffenmanager Nano is a risk-banding tool developed for employers and employees to prioritize health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios. This tool combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. "Stoffenmanager Nano" does not contemplate the dermal and oral routes of exposure. The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in production facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries (ECHA 2012). The dermal route may be the main route of exposure for some substances or exposure situations, and cause local effects on the skin or systemic effects after absorption into the body (ECHA 2012). However, nanoparticles as such are very unlikely to penetrate the skin (Watkinson, et al. 2013), and consequently nano-specific systemic toxicity via the dermal route is improbable. Therefore, when evaluating nano-risks for the respiratory route, the most important aspects of occupational safety are covered.

Currently version 1 of Stoffenmanager Nano is being updated with recent data and insights. The hazard of six metal oxide nanoparticles has been reassessed and their hazard bands have been updated. This revision, which follows the hazard assessment methods established by van Duuren-Stuurman et al. (2012), but makes use of more recent toxicity data, has been published in a TNO-report (Le Feber, et al. 2014). Hazard bands for the nanoparticles, as listed in the table *Hazard bands for selected nanoparticles,* are taken by preference from this report and, if not available in that report, from van Duuren-Stuurman et al. (2012). If a nanoparticle in the list has not been evaluated in either publication, data were collected from public literature to derive its hazard band.

HAZARD ASSESSMENT OF NANOPARTICLES NOT ASSESSED IN STOFFENMANAGER NANO

INTRODUCTION

In "Stoffenmanager Nano" the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). Not for all nanomaterials of importance for the ICT sector which are listed in the table, hazard banding has been performed within the context of Stoffenmanager Nano. For those nanoparticles toxicity data have been collected and hazard bands are derived according to the methodology described for "Stoffenmanager Nano" in van Duuren-Stuurman et al. (2012). In essence, it applies the toxicity classification rules of EU Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures. The method is summarized in the figure.

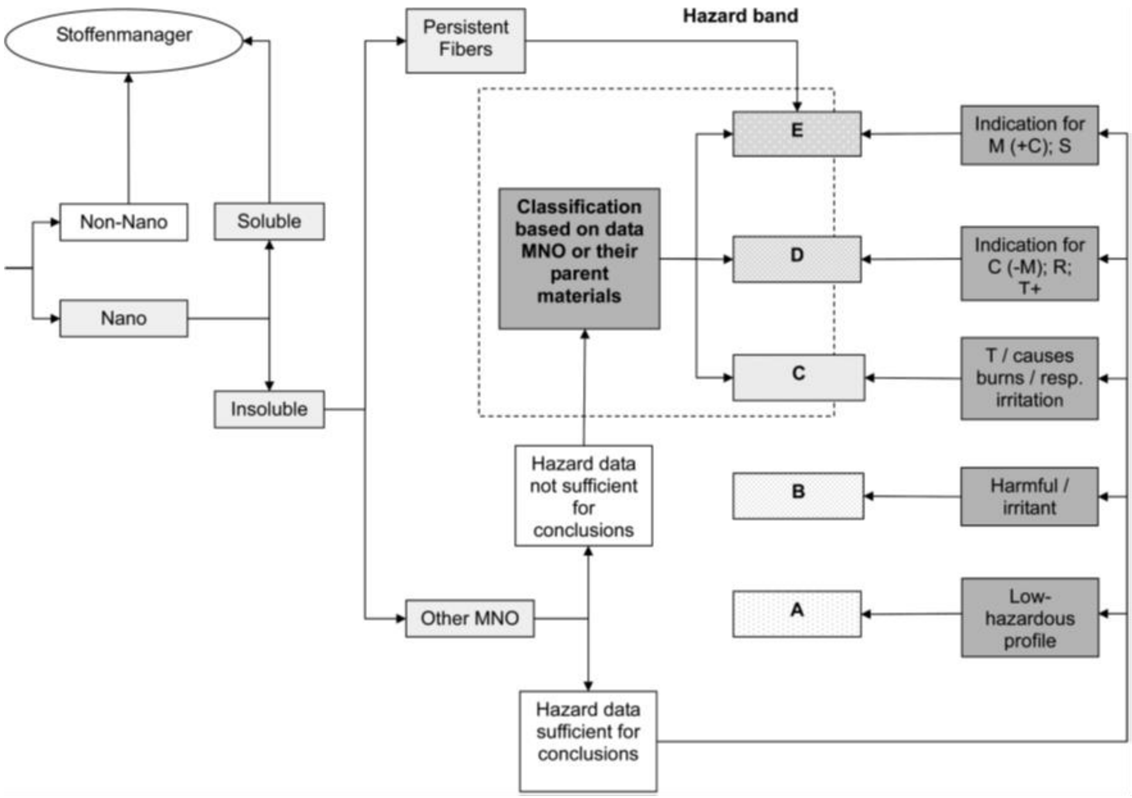

Figure 1: The stepwise approach of hazard banding of Stoffenmanager Nano (Van Duuren-Stuurman, et al. 2012)

C = carcinogenic, +C = and carcinogenic, M = mutagenic, -M = and not mutagenic, MNO = manufactured nanoparticle, R = reprotoxic, resp. = respiratory, T = toxic, T+ = very toxic

Stoffenmanager refers to the non-nano version of Stoffenmanager as described by Marquart et al. (2008).

GALLIUM ARSENIDE (GAAS)

No toxicity studies on nano-GaAs were encountered in public literature. According to data from the REACH dossier of GaAs[597], (powdered) GaAs has limited solubility in water (based on released As^{3+} ions). GaAs is marketed as an article made from very pure (99.9999%) crystalline bulk material, predominantly in the shape of wafers (Bomhard, et al. 2013), implying an even lower water solubility. Therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent material are used. GaAs is classified as carcinogenic, but not mutagenic (based on sufficient evidence) by the EU[598]. It should be noted that the classification for carcinogenicity was based on inhalation studies with micronised powdered GaAs, and that the relevance of these studies for human exposure to crystalline GaAs is questioned (Bomhard, et al. 2013). Based on the classification of the bulk material, nanoGaAs is attributed hazard band D.

GALLIUM NITRIDE

No relevant toxicity studies on nano-gallium nitride were encountered in public literature. Gallium nitride wafers are virtually insoluble in water, even in dilute acid (Jewett, et al. 2012), and therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent

[597] See http://apps.echa.europa.eu/registered/data/dossiers/DISS-9eb10650-da4f-6514-e044-00144f67d031/DISS-9eb10650-da4f-6514-e044-00144f67d031_DISS-9eb10650-da4f-6514-e044-00144f67d031.html

[598] See http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/cl-inventory/view-notification-summary/104548

material are used. Gallium nitride is not classified for any toxicity by the EU[599]. However, this absence of classification was based on lacking data. Besides the gallium ions, which are not considered relevant for gallium nitride since it is insoluble in water (Foster, et al. 2013), only one structurally similar compound was found using the on-line ChemID database: gallium phosphide, which was characterised as being 80% similar with gallium nitride. Also on this compound no relevant toxicity data were found, meaning read-across could not be employed. Therefore, no hazard banding can be derived.

GRAPHENE

Graphene is composed of sp^2-hybridised carbon atoms arranged in a two-dimensional structure. The various forms of graphene include few-layer graphene, reduced graphene oxide, graphene nanosheets and graphene oxide (GO) (Seabra, et al. 2014).

The UK government body, the Medicines and Healthcare Products Regulatory Agency (MHRA), and the US Food and Drug Administration (FDA) are now reviewing all forms of graphene and functionalised graphene oxide (GO) because of their poor solubility, high agglomeration, long-term retention, and relatively long circulation time in the blood (Begum et al. 2011 cited in Nezakati, et al. 2014).

Currently, limited information about the in vitro and in vivo toxicity of graphene is available (Seabra, et al. 2014). The toxicity profiles of graphene and graphene oxide (GO) nanoparticles remain difficult to separate, since their characterisation, bulk and chemical composition are very similar at the nanometre length scale (Nezakati, et al. 2014).

In vitro graphene has been demonstrated to be cytotoxic, be it overall to a lesser degree than carbon nanotubes (Seabra, et al. 2014). However, the reliability of this conclusion can be doubted since Seabra et al. stated that graphene showed an inverse dose-relationship, being more cytotoxic than carbon nanotubes at low concentrations. The only elaborate comparative study reported by Seabra et al., refers to genotoxicity towards human fibroblast cells. GO proved to be the most potent genotoxic agent compared to iron oxide (Fe_30_4), titanium dioxide ($Ti0_2$), silicon dioxide ($Si0_2$), zinc oxide (ZnO), indium (In), tin (Sn), core—shell zinc sulphate-coated cadmium selenide (CdSe (3) ZnS), and carbon nanotubes.

Intratracheal instillation of 50 µg GO in mice caused severe pulmonary distress after inhalation causing excessive inflammation, while the amount of non-functionalised graphene instilled did not (Duch et al. 2011). Single intravenous (i.v.) injection of graphene oxide into mice at a dose of 10 mg/kg bw accumulated in the lung resulting in pulmonary oedema and granuloma formation, with NOAEL of 1 mg/kg bw (Zhang, et al. 2011). Furthermore, surface functionalised graphene (PEGylated) appears to be far less toxic: no toxic effects after single i.v. injection of 20 mg/kg bw (Yang, et al. 2011). In mice, PEGylated GO materials showed no uptake via oral administration, indicating limited intestinal absorption of the material, with almost complete excretion. In contrast, upon i.p. injection in mice, PEGylated GO was found to accumulate in the liver and spleen (Yang, et al. 2013 (cited in Seabra, et al. 2014)).

The toxicity of graphene is dependent on the graphene surface (the chemical structure or the nature of the functionalised coatings), size, number of layers, cell type, administration route (for in vivo experiments), dose, time of exposure, and synthesis methods (Seabra, et al. 2014). Generalisations are therefore hard to make, but graphene nanostructures are not fibre-shaped and theoretically may be assumed to be safer than carbon nanotubes (Seabra, et al. 2014).

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

MOLYBDENUM DISULPHIDE

No relevant toxicity studies on nano-molybdenum disulphide were encountered in public literature. It is insoluble in water and therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent material are used. Molybdenum disulphide is not classified for

[599] See http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/cl-inventory/view-notification-summary/5411.

any toxicity by the EU[600]. Based on this absence of classification, the nanoforms should be assigned hazard band C, the lowest category a nanoparticle can be assigned just based on toxicity data for its non-nano parent compound (Van Duuren-Stuurman, et al. 2012).

TUNGSTEN SELENIDE

No relevant toxicity studies on nano-tungsten selenide were encountered in public literature. Tungsten selenide is also not classified for any toxicity by the EU[601]. However, this absence of classification was based on lacking data. Also on the top 5 similar compounds retrieved by ChemID (rhenium selenide, tantalum selenide, tungsten telluride, manganese selenide and molybdenum selenide, similarity ranging from 85 to 95%) no relevant toxicity data were found, meaning read-across could not be employed. Therefore, no hazard banding can be derived.

Overview of hazard bands of nanoparticles in the manufacturing sector

The table *Hazard bands for selected nanoparticles* presents an overview of selected nanoparticles of the manufacturing sector and their hazard bands, either taken from le Feber et al. (2014) or van Duuren et al. (2012), or derived in this report.

Table 1: Hazard bands for selected nanoparticles

Nanoparticles	Hazard Band	Hazard Band Source
Gallium Arsenide	D	This report
Gallium Nitride	n/a	no data
Graphene	E	This report
Molybdenum Disulphide	C	This report
Silicon Dioxide (silica), Synthetic Amorphous	C	le Feber et al. (2014)
Silicon Dioxide (silica), Crystalline	E	van Duuren et al. (2012)
Silver	D	le Feber et al. (2014)
Tungsten Selenide	n/a	no data

EXPOSURE ASSESSMENT

For the materials, manufacturing is a crucial phase regarding health and safety, due to relatively high potentials for exposure of employees. However, the production phase was earlier described in the sector "manufacturing" and will not be evaluated in this sector report.

Most of the engineered nanomaterials are present in the products as part of a matrix. Some of the identified substances for evaluation may not necessarily be engineered nanomaterials. During the manufacture of ICT products engineered nanomaterials may be used and are applied mainly as coatings. For the majority of these coatings, only a low percentage of engineered nanomaterials are present. The production phase of ICT products on industrial scale consists mainly of automatic processes, with employees only engaged in product quality control or system engineering. In addition, most processes are performed in cleanrooms and/or under well-controlled conditions, as dust is a major threat to the quality of the products. Nevertheless, spray scenarios for coating normally result in high exposure concentrations, so potential exposure cannot be neglected. In the situation of a manual process without proper exposure control measures (e.g. local exhaust ventilation, cleanroom), employees may be exposed to relatively higher concentrations. Lastly, during the end-of-life phase several metals may be present in the ICT product, which can be worthwhile to recycle. Recycling of these metals may involve, for example, shredding of ICT

[600] See http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/cl-inventory/view-notification-summary/37514.

[601] http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/cl-inventory/view-notification-summary/1552.

products, and engineered nanomaterials possibly present can become airborne. However, as the shredded products only will contain a small amount of engineered nanomaterials, potential exposure to engineered nanomaterials during this process will be relatively low.

In conclusion, the use of ICT products results in exposure band 1 (consumers and workers), whereas during the production of ICT products exposure band 2 (workers) is believed to be realistic. Furthermore, during the end-of-life phase an exposure band 1 (workers) is realistic.

RISK ASSESSMENT

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table *Priority bands in the Stoffenmanager*. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures or to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 2: Priority bands in the Stoffenmanager

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Risks based on the hazard and exposure banding applied to the sector are listed in the table *Priority bands ICT sector*. Since exposure does not vary between ICT sector categories, and the nanoparticles may, in principle, be applied in any of these categories, they are not separately listed in this table.

Table 3: Priority bands ICT sector

		Exposure Band	
		Production Phase	Use and End-of-life Phase
Nanoparticle	Hazard Band	2	1
Gallium Arsenide	D	2	2
Gallium Nitride	n/a	n/a	n/a
Graphene	E	1	1
Molybdenum Disulphide	C	2	3
Silicon Dioxide (silica), Synthetic Amorphous	C	2	3
Silicon Dioxide (silica), Crystalline	E	1	1
Silver	D	2	2
Tungsten Selenide	n/a	n/a	n/a

The highest priority is for graphene and crystalline silica during the production, use and end-of-life phases, while gallium arsenide and nanosilver have intermediate priority in those phases. Molybdenum disulphide and amorphous silica also have intermediate priority in the production phase, but low priority during use and end-of-life phase in view of a lesser potential of exposure in those phases. For gallium nitride and tungsten selenide no adequate data were available to perform hazard and exposure banding.

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