European Commission

NanoData Landscape Compilation

Transport

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EXECUTIVE SUMMARY

Background

This report offers a snapshot of the status of the environment for nanotechnology in the context of transport. Transport is defined here as a sector based on vehicles for transporting people and/or goods via the air, rail, road, water and space[1], and is here divided into two main areas, vehicles and infrastructure. The industry generates about 5% of European employment and 7% of European GDP[2]. However, transport is also responsible for the emission of nearly 25% of greenhouse gases in the EU[3].

Role of nanotechnology

Nanotechnology is being deployed currently, and has significant future potential, as a means to improve the performance of vehicles, for example: to reduce the weight of vehicles (through lightweight nano-composites), improve road handling (via the use of nanomaterials in tyres and sensors), to monitor engine systems and optimise their parameters (through active feedback systems), as catalysts in fuels, to reduce maintenance (by protecting vehicles from dirt and wear) and with wide application potential in autonomous vehicles. Organic light-emitting diodes (LEDs) are also expected to grow in use for flexible, high-resolution and low-energy consumption displays and vehicle lighting. Energy-related applications of nanotechnology in transport include batteries, hydrogen fuel cells and solar cells for next-generation vehicles. Many transport nanotechnology developments initially took place in the aerospace industry, gradually filtering down to road vehicles, or in the area of competitive, high-performance vehicles (bicycles and cars) for racing.

Nanotechnology is also being used to improve the infrastructure for transport, through improvements in roads, bridges and tunnels as well as in better traffic monitoring and management systems. In asphalt, nanomaterials are being considered as a means to reduce the costs of repair and maintenance by improving thermal performance, water-proofing and anti-corrosive properties.

The nanomaterials being used (or explored) for transport applications include, for example, carbon nanotubes (for increased strength, reduced weight and water-repellence); oxide nanoparticles (as fuel additives to improve combustion and reduce soot emissions); nanoclays (in asphalt binders); nanoparticles in paints and films (for vehicle bodies); and thin films and nanopolymer coatings (for concrete, timber or steel infrastructure).

Policies

National policies to address different aspects of transport range from research and development to enterprise (for employment and competitiveness), environment and health (where emissions are concerned), mobility (and equal access), etc. The main focus in this report is on the European policies and programmes that link directly to the development and exploitation of nanotechnology i.e. actions for research, development, innovation, demonstration and deployment of technology. These include the European Framework Programmes (most recently FP6 and FP7, and now Horizon 2020), European strategies for transport and for clean and efficient vehicles, European Technology Platforms (such as ACARE) and Joint Technology Initiatives (such as Clean Sky and the FHC Fuel Cells and Hydrogen initiative). Contractual public-private partnerships also exist for transport, e.g. the European Green Vehicles Initiative. Other relevant policies relate to energy efficiency (e.g. the EU 2020 Energy Strategy) and emissions (e.g. via the targets on emissions and the EU Emissions Trading System). Many actions are underway to develop green vehicles, not least KIC[4] InnoEnergy and Climate KIC, supported by the European Institute of Innovation and Technology (EIT).

Most European research, development and innovation is funded in Member States, much through national public funding. Transport-related nanotechnology policies and programmes at national and regional levels, while few, have included Germany's 2011 *Action Plan for Nanotechnology 2015,* one of its five focus areas being mobility, and uses of nanotechnology including 'cost-effective, resource saving mobility', 'electric mobility' and 'nanomaterials for intelligent streets'.

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[1] For further details about the definition of the transport sector see the NACE European Nomenclature of Economic Activities: http://ec.europa.eu/eurostat/statistics-explained/index.php/NACE_background

[2] Gross domestic product

[3] https://ec.europa.eu/clima/policies/transport_en

[4] Knowledge and Innovation Community.

EU R&D projects

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

There were 200 nanotechnology transport projects in FP6 and FP7 together, over 5% of all nanotechnology projects. They received EUR 586 million (9.2% of total nanotechnology funding), EUR 171 million in FP6 and EUR 415 million in FP7. The largest amount of transport-related nanotechnology funding was allocated under the NMP programme for both FP6 (33 projects with 72% of funding, EUR 124 million) and FP7 (39 projects with 41% of funding, EUR 168 million). In FP7, the Transport priority also received 14% of the funding and Space 6% (the same proportion as for Aeronautics and Space in FP6).

Throughout FP6 and FP7, the same six countries (DE, UK, FR, IT, ES and NL) received the highest proportions of nanotechnology transport funding as for nanotechnology and for FP funding overall. Together they have been allocated over half of the total funding for nanotechnology and transport.

Higher education establishments received over 30% of funding in FP6 and FP7 for nanotechnology and transport, slightly more than research organisations at around 29% of funding, with little change between FP6 and FP7. The proportion allocated to large companies increased from 14 to 21%, the equivalent reduction being seen in the category Other. SMEs saw little change at around 18% of transport nanotechnology funding.

In terms of individual organisations in the EU28, Germany was well ahead with almost 19% of funding going to organisations such as Fraunhofer Gesellschaft, Airbus GmbH, Infineon and Max-Planck. It was followed by the United Kingdom, France and Italy (all with just over 11% of funding) with organisations including the CNRS (FR), Centro Richerche Fiat (IT), CEA (FR), the Universities of Cambridge, Birmingham and Surrey (UK), Politechnico de Torino (IT), CNR (IT) and Thales (FR).

Looking at companies alone, Airbus (DE), Thales (FR) and Infineon (DE) were the top three, Airbus having seven projects (EUR 7.85 million of funding), Thales four projects (EUR 3.7 million) and Infineon six projects (EUR 3.7 million).

Publications

Publication data for nanotechnology and transport revealed that, of 1.8 million publications globally related to nanoscience and nanotechnology between 2000 and 2014, almost 17,000 were related to transport and nanotechnology, close to 1% of total output.

The strongest publishing countries in 2014 were the US and China with three to four times the output of the next strongest, Germany and the United Kingdom. Of the top EU 28 countries, following the top two (DE, UK) were France and Spain. The top publishing organisations were led by China and the US in the top four places, followed (in terms of EU28 and EFTA) by organisations in the United Kingdom (2), Switzerland and Finland as well as Greece, Germany and Italy. The United Kingdom had four organisations and Finland had two in the top ten for publishing by organisations in the EU28 and EFTA countries.

Specifically, the EU28 organisations performing best in nanotechnology and transport include the University of Birmingham (UK), UMIST (UK), the Finnish Meteorological Institute (FI), the University of Helsinki (FI) and Aristotle University Thessaloniki (GR/EL). However, there has been no normalisation of data to take into account factors influencing publication output such as the number of researchers/technicians/students or the research budgets. The companies with the most nanotechnology and transport publications globally in 2014 were the Ford Motor Company and Aerodyne Research.

Patenting

Between 1992 and 2011, the number of transport patent families identified among the nanotechnology patents was 317, 0.7 % of all nanotechnology patent families. The prevalence of countries such as Germany and France continues as patenting patterns in the EU28 are reviewed (although patenting is greatly dominated by the US and its research-performing organisations (151 patent families[5]), followed by Japan (53). The United Kingdom, Sweden, the Netherlands, Spain, Italy and Belgium all feature also but at some distance. In Asia, the lead country for applicants, Japan (53), is followed by Korea (19), China (8) and India (4).

Overall the numbers of patent families and patents granted are small[6] so it is not appropriate to analyse the data in depth. However, it can be seen that organisations in the EU such as the CNRS (FR), CSIC (ES), Tecnalia (ES), Leibniz (DE), the French Institute of Petroleum (FR), and Fraunhofer (DE) are all undertaking patenting activities. The EU companies identified include Saab (SE), Michelin (FR), Siemens (DE), ASML (NL) and Philips (NL), although the leaders are from the US and Japan (e.g. Goodyear, Nissan and Boeing).

Products and markets for transport through nanotechnology

Global sales of nanotechnology products in the transport sector in 2013 were estimated to be under USD 8 million and are forecast to grow to USD almost 14 million by 2019, largely based on the growth in existing products and market areas.[7]

The main areas where nanotechnology is applied in the field of transport include: nanotubes and particles (e.g. for use in capacitors and batteries), nanoporous materials (e.g. for use in fuel cells), thin films and coatings (for multiple transport applications), and nano-composites (e.g. for vehicle parts). Of the 385 products using nanotechnology that have been identified as being commercially available for transport applications, approximately 20% are coatings (anti-scratch and anti-stick), 16% cleaning agents, 10% lubricants, 9% batteries and 9% hydrophobic/oleophobic nano-composites. While nanodevices (i.e. sensors) are not yet seen as a large market specific to transport, the market is expected to increase by 2019 to about four times its size in 2013, while sales of nano-composites are projected to almost triple in relative share. Carbon nanotubes are currently forecast to play only a marginal role in terms of shares of sales.

Regulation and standards

European regulations for nanotechnology are well-advanced with both definitions and many regulatory documents. The use of nanomaterials is not incorporated in transport regulations, with the relevant authorities relying on the application of regulations for chemicals to the case of nanotechnology. Nanomaterials must comply with the overarching regulatory framework known as REACH[8]. However, the EU is also reviewing the definition of a nanomaterial and this may have future implications for transport, as for other sectors.

A number of technical committees of the International Organisation for Standardisation (ISO) cover areas linked to transportation, e.g. rubber compounding ingredients (including carbon black), but, in general, neither ISO not its European equivalent, the European Committee for Standardisation (CEN), has developed specific standards for nanotechnology and transport although both have technical committees working on nanotechnology.

Human health and safety

From a hazard assessment of nanomaterials commonly used in transport[9], it was found that the highest potential risk arises in the construction phase due to high expected exposure, for all the materials examined except calcium carbonate. In the use phase, aluminium (oxide), calcium carbonate, cerium oxide, magnesium hydroxide and titanium dioxide have low risk priority, nanoclay intermediate priority, and carbon nanotubes and cobalt oxide the highest risk priority. In the use phase, all nanomaterials are contained in a solid matrix, with exposure being negligible and health risks low. In the end-of-life phase, risk management/evaluation of transport materials containing carbon nanotubes and cobalt oxide should receive the highest priority, while the materials containing the remainder of the listed nanomaterials should receive intermediate priority.

[5] At the European Patent Office, US Patent and Trademark Office or World Intellectual Property Office

[6] In part, this is because there are some patents relevant to transport that are not categorised in the IPC codes as being for transport as their applications are generic e.g. some coatings and paints.

[7] BCC Research

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

[9] Aluminium, aluminium oxide, calcium carbonate, carbon nanotubes, cerium oxide, cobalt oxide, magnesium hydroxide, nanoclays and titanium dioxide.

1 BACKGROUND

Nanotechnology is being applied to the transport sector to improve performance and safety and to reduce cost and environmental impact. Transport is defined here as an energy-consuming sector based on vehicles whose purpose is transporting people and/or goods via the air, rail, road, water and space[10]. The sector can be divided into two main areas, vehicles and infrastructure.

Vehicles used for the transportation of people and/or goods include

- cars (automobiles), buses, trucks, lorries;
- trains;
- ships, boats and barges;
- aircraft (aeroplanes and helicopters) and spacecraft; and
- motorcycles, mopeds and bicycles.

Vehicles whose primary purpose is not transportation (such as bulldozers) are excluded.

Transport infrastructure[11] includes roads, rail (for trains), railway stations, bus stations, airports, tunnels and aqueducts, bridges, waterways and canals, trucking terminals, refuelling depots (including fuel docks and fuel stations) and seaports.

This report is a Landscape Compilation of facts and figures related to nanotechnology and transport as defined above. It offers a snapshot of the status at the start of 2016 of the environment for nanotechnology in the context of transport. It reports on past and current policies and programmes for nanotechnology (in particular, but not exclusively, those relating to transport); the outputs of research (including projects, publications and patents) and how those outputs are used in the application of nanotechnology to transport (e.g. in products and markets). Being a landscaping of nanotechnology, it does not provide detailed analysis of data trends or draw policy conclusions.

The outline of this report is as follows:

- Introduction to transport and the role of nanotechnology;
- Policies and programmes to support nanotechnology and transport;
- Research projects, mainly within the EU Framework Programmes, on nanotechnology and transport;
- Publications in nanotechnology and transport;
- Patenting in nanotechnology and transport;
- Industry, nanotechnology and transport;
- Products and markets for nanotechnology and transport; and
- The wider environment for nanotechnology and transport (regulation, environmental health and safety, communication and public attitudes).

The next section introduces transport and the role of nanotechnology.

[10] For further details about the definition of the transport sector see the NACE European Nomenclature of Economic Activities
http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE)

[11] Fulmer, Jeffrey (2009). "What in the world is infrastructure?" PEI Infrastructure Investor (July/August): 30–32

2 INTRODUCTION TO TRANSPORT AND THE ROLE OF NANOTECHNOLOGY

The aim of the application of nanotechnology to transport is make improvements in the sector in terms of durability, economy, sustainability, environmental impact and safety[12]. The areas in which nanotechnology contributes to improved performance in the transport sector can be divided into vehicles and infrastructure.

The transport industry has been estimated as being responsible for generating 7% of European GDP and 5% of employment[13]. The mobility of people and the flow of goods to, from and within Europe must be cost-effective, safe and environmentally sustainable. Currently[14], the sector is responsible for the emission of approximately 25% of EU green-house gases (GHG) (the largest proportion from road transport at almost 72% of transport GHG emissions) and 20% of CO_2 emissions come from road transport in the EU. In 2012, transport in the EU was about 94% dependent on oil, 86% of which was imported from outside the EU15. A 2014 report by the Intergovernmental Panel on Climate Change (IPCC)[16] predicted that transportation growth will result in an increase in energy use and carbon emissions by 80% over 2002 levels by 2030.

Nanotechnology in the transport sector could enhance the performance of vehicles and infrastructure through the following current or future applications, for example:

- Nanomaterials (e.g. in components);
- Nano-coatings (e.g. to protect from dirt and wear);
- Nanotechnology in lighting and displays (e.g. organic LEDs[17] (OLEDs);
- Nanosensors;
- Nano-fluids and additives (e.g. in fuels);
- Nano-filters (e.g. in exhaust systems);
- Nanotechnology for energy usage and storage (e.g. lithium ion batteries).

Nanotechnology draws on other sectors for applications to transport, sectors such as manufacturing, photonics, ICT and energy. For example, the uses of ICT in the transport sector (now and in the future) include:

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

The market for automated driving support systems (e.g. collision warning, drowsiness monitoring and night vision) is expected to reach USD 7.6 billion, representing an almost 30% compound annual growth rate in 2012 to 2017, and sales of human machine interfaces (HMI) and navigation systems are expected to grow annually by almost 10% to reach USD 5.2 billion over the same period[18]. Other estimates expect markets of

- Over USD 13 billion for automotive human machine interfaces by 2017[19];
- Over ten million 'eCockpits' or HMI systems for cars to be shipped in 2020[20];
- Over EUR 120 billion by 2021[21] for 'connected car' technologies[22].

[12] http://repository.up.ac.za/bitstream/handle/2263/6352/Steyn.pdf?sequence=1
[13] ERTRAC, the European Road Transport Research Advisory Council http://www.ertrac.org/index.php?page=ertrac-research-agenda-and-plans
[14] http://ec.europa.eu/clima/policies/transport/index_en.htm
[15] http://ec.europa.eu/transport/themes/urban/studies/doc/2015-07-alter-fuels-transport-syst-in-eu.pdf
[16] https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf
[17] Light-emitting diodes
[18] Strategic Research Agenda of EPoSS, http://www.smart-systems-integration.org/
[19] http://www.strategyr.com/PressMCP-6712.asp
[20] https://www.yanoresearch.com/press/pdf/1147.pdf
[21] http://www.strategyand.pwc.com/reports/connected-car-2015-study
[22] 'Connected car' technologies i.e. cars with access to the internet that enables automated links to smartphones, tracking devised, traffic lights, other vehicles and potentially home appliances.

Nanotechnology is not only applied in automated driving and navigation systems. Paints and coatings were estimated to account for over 40% of the entire nanotechnology market in the automotive industry in 2015[23]. Examples of applications of nanotechnology in both vehicles and infrastructure are presented in the table below.

Table 2-1: Applications of nanotechnology to transport: vehicles and infrastructure

Nanotechnology	Vehicles	Infrastructure
Nanomaterials	Bodies	Nano-modified asphalt
	Tyres	
	Engine components	Nano-modified cement
Nano-coatings	Anti-fouling	Anti-glare coatings on surfaces
	Anti-glare coating for windows	
	De-icing coating	
	Protective coating for textiles	Anti-graffiti coating for walls (e.g. on tunnels)
	Anti-corrosion coating	
Nano-enabled OLED[24]	Lighting panels	
	Displays on dashboard	
Nano-sensors	Monitoring soot emission	Monitoring condition infrastructure
	Monitoring condition vehicle components	Intelligent transportation systems
	Monitoring	
Nano-fluids and lubricants	Coolants	
	Lubricants	
	Fuel additives	
	Cleaners	
Nano-filters	Diesel particulate filters	Air filtration systems (e.g. in tunnels)
	Air filters	
Nano-enhanced energy storage	Lithium-ion batteries in electric vehicles (EV)	
	Supercapacitors	
	Hydrogen storage (fuel cell electric vehicles)	
	Solar capture (photovoltaics)	

2.1 Nanotechnology in vehicles

Nanotechnology can have an impact on many different parts of a vehicle including the structure and interior of the vehicle, the engine and the fuel systems, external surfaces and lighting.

2.1.1 Structure and interior of the vehicle

In the quest to improve vehicle performance and appearance, the vehicle manufacturing industry requires materials that are lighter, stronger, more durable and are more resistant to extreme conditions than conventional and currently used materials. One option is to modify existing materials, through nanotechnology. For example, the addition of carbon nanotubes to materials such as metals, polymers, plastics, carbon fibre and glass fibre can increase their strength and/or reduce

[23] www.nanomagazine.co.uk Nano Issue 4: Editorial on Nanotechnology and Transportation
[24] Organic light-emitting diodes

their weight. Lightweight materials created in this way are being used as structural materials for vehicles ranging from bicycles (e.g. for competitions such as the Tour de France) to aircraft[25], with graphene, in particular, often being used in lightweight bicycles. Carbon fibre components are now having carbon nanotubes added to them, one product being nano-enhanced carbon fibre wheels that are more energy efficient and safe[26].

Nanotechnology is also contributing to the sustainability and resource efficiency of tyres. The use of carbon black results in tyres that are more environmentally-friendly and wear-resistant than conventional tyres and gives them a longer life-cycle[27].

Not only is nanotechnology being applied in improving the materials used in transport, it can also have an impact on the manufacturing process itself. The application of nanotechnology in photonics can enhance the laser techniques used in the manufacturing process, especially in the automotive industry.

However, the greatest progress in new nanomaterials and manufacturing techniques has been made over the years, and is still being made, in aerospace. In the EU-funded project SARISTU[28] (Smart Intelligent Aircraft Structures), different (nano)materials have been integrated into components (for example, the wings) in order to reduce weight and save energy. There are also several modifications that have the goal of keeping the air resistance to a minimum. An essential element for this is a resin containing carbon nanotubes that retains its elasticity at the extremely cold temperatures experienced at altitude[29], as seen, for example in a drag-minimising connecting element between the flaps and the wings. Aerospace engineers at MIT have also developed a carbon nanotube (CNT) film that can significantly reduce the energy required in the manufacture of aircraft and other industrial composites. The heated CNT film stimulates the composite to solidify in the same manner as in a conventional furnace but at a fraction of the energy cost[30].

2.1.2 External surface coatings

Nanotechnology coatings for vehicles can have multiple functions including: self-healing, self-cleaning, super-hardening, de-icing, glare-resistance and anti-corrosion. Coatings can be used on different types of materials, varying from coating for super-hardening of composite structures to glare-resistance coatings on glass or polymer windows and windscreens. There are already many different nano-coating products on the market for consumers, in particular for the automotive industry. Nano-coatings can also be used to protect systems, such as displays, from environmental damage (such as from light) or damage caused by the user [31].

Nanotechnology already has a significant impact in anti-fouling applications. Paints containing multi-walled carbon nanotube (MWNT) can reduce bio-fouling of the hulls of ships by reducing the ability of algae and barnacles to attach to the surface[32]. Superhydrophobic coatings can also be used for anti-fouling applications. These kinds of surfaces are usually created by a chemical modification, which leads to an increase in the contact angle of a water drop[33] and makes it harder for the water to attach itself to the surface. Adding carbon nanotube composite materials to epoxy and silicone resins creates superhydrophobic surfaces making the surface water-repelling. Paints and anti-fouling coatings modified with nanoparticles are not only more effective in protecting the hulls from bio-fouling relative to conventional anti-fouling, they are also generally stronger and less subject to corrosion, thereby reducing the costs associated with maintenance, repainting and repair.

Other application areas of nano coatings are textiles used in public vehicles. A nano-coating spray for textiles in rental cars or trains can make the seats liquid-repellent, self-/easy-cleaning, stain-

[25] http://articles.sae.org/7240/
[26] http://www.kurzweilai.net/worlds-first-nano-enhanced-carbon-fibre-downhill-bike-rim
[27] http://www.keepeek.com/Digital-Asset-Management/oecd/science-and-technology/nanotechnology-and-tyres_9789264209152-en#page15
[28] http://www.saristu.eu/
[29] http://cordis.europa.eu/news/rcn/36614_en.html
[30] http://www.nanowerk.com/nanotechnology-news/newsid=39745.php
[31] http://www.nanowerk.com/nanotechnology-in-displays.php
[32] http://mechanosynthesis.mit.edu/journals/076_devolder_13_sciencereview.pdf
[33] https://www.thevespiary.org/rhodium/Rhodium/Vespiary/talk/files/3900-Transformation-of-a-Simple-Plastic-into-a-Superhydrophobic-Surface6d99.pdf?topic=1698.0

resistant, antistatic and anti-microbial and any dirt that accumulates can more easily be removed[34]. In general, these coatings are based on superhydrophobic characteristics.

In the aircraft industry, de-icing coatings using nanotechnology are widely used. To prevent ice formation on their outer surfaces, including wings and control surfaces, aircraft are subject to treatment by energy-intensive heaters and frequent de-icing prior to departure. Most ice-repellent coating and anti-icing surfaces are not sufficient in preventing ice-formation in high-humidity conditions. Developments are being made in nano-structured surfaces, which can be infused with repellent and anti-icing liquid[35]. Carbon nanotube-based coatings can also be sprayed on aeroplane wings[36], reducing ice adhesion and removing moisture[37]. The same materials can also be used on other infrastructure subject to extreme weather conditions, for example to reduce ice formation on railways in colder regions.

2.1.3 Engine components and performance

Nano-modified materials incorporated in engine components can make engines lighter and less subject to corrosion. The use of multi-walled carbon nanotubes (MWCNTs) in nano-composite cams (in combination with steel pushers) in high-pressure gasoline pumps, is an application showing promise in reducing friction losses and wear[38].

Making use of heat-transferring properties optimised at nanoscale can improve the performance, emissions from and durability of an engine [39]. In recent years, nanotechnology has contributed in the development of thermoelectric (TE)[40] materials used for improving energy harvesting and energy efficiency of generators[41]. Thermoelectric materials have been in use for decades by NASA in spacecraft by NASA. For cars, one-third of all the energy in the fuel burned can be classified as waste energy. The waste heat released by the engine can be converted in energy by means of the thermoelectric effect, increasing the overall energy efficiency of the vehicle and, according to major automotive companies, such as BMW, GM and Ford in 2012, could improve mileage by 5%. Carbon nanotubes and metal nanowire arrays have the right heat-transferring properties to be suitable as thermal interface materials. Currently, research projects are aiming to prove a large volume/commercially viable production; improvement of the thermoelectric materials and TEG efficiency and evaluation of prototypes in vehicles[42].

2.1.4 Coatings for fuel systems

Carbon nanotube coatings can be used to protect fuel systems components in vehicles for electrostatic discharge (ESD) and electromagnetic interference (EMI)[43]. ESD is problematic, because when electrostatic potential builds up, arcing can occur, which can pierce a hole in the fuel system through which fuel and vapours can escape. Protecting fuel systems from EMI implies preventing the electronics in aircraft from the damage created by lightning.

Due to the heat-transferring properties of nanotubes, nano-coatings can also be applicable for heat transfer in heater, engines and gasoline tanks. As electronic cars have less energy available for the heating of the interior, Fraunhofer[44] has developed a film-based panel heater, which is more energy efficient than conventional heaters and therefore more effective for these type of vehicles [45]. A thin film can be coated with a thin layer of conductive carbon nanotubes. The natural resistance created

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[34] http://articles.sae.org/13156/
[35] http://www.aizenberglab.seas.harvard.edu/papers/Kim2012.ACSNano.pdf
[36] http://www.nanowerk.com/nanotechnology-news/newsid=39745.php
[37] http://www.geglobalresearch.com/innovation/ge-scientists-demonstrate-promising-anti-icing-nano-surfaces
[38] http://ac.els-cdn.com/S1359836814001735/1-s2.0-S1359836814001735-main.pdf?_tid=c61606ce-d0a0-11e5-9501-00000aacb35e&acdnat=1455182644_23036e62cf2b0c79791c546d306b2f4f
[39] http://www.researchandmarkets.com/research/34c985/nanotechnology_in
[40] The thermoelectric effect is the conversion of temperature difference to electric voltage and vice versa.
[41] http://www.npl.co.uk/upload/pdf/nanostructured_cuenat.pdf
[42] http://energy.gov/sites/prod/files/2014/03/f13/ace00e_fairbanks_2013_o.pdf
[43] http://www.businesswire.com/news/home/20110617005245/en/Research-Markets-Nanotechnology-Automotive-Transportation-Industry-Applications
[44] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.
[45] http://www.greencarcongress.com/2015/09/20150902-fraunhofer.html

when electricity flows through the film generates the heat. The carbon nanotube thin-film heater is therefore more effective than conventional heaters.

2.1.5 Lighting and displays

Organic light-emitting diodes (OLEDs) for automotive applications are still in development and a large potential market is envisaged. They have several application possibilities in the transport sector, including vehicle displays. Developments in OLED technology are increasing the potential for extremely high-resolution, low-energy thin and flexible displays. For example, graphene, added as a transparent conductor, makes for materials that are very thin and flexible[46]. The large manufacturer BMW committed to using an OLED display screen on the dashboard in 2012[47] and, in 2014, it realised its plan to develop OLED vehicle lights[48].

Currently, OLEDs are not yet suitable for all types of automotive lighting. For example, headlights require a brightness level that cannot yet be achieved with OLEDs but brake lights are more suited to their use in terms of the required light output[49]. OLEDs are also suitable for lighting inside vehicles[50]. Applying nanomaterials and techniques to the transparent electrodes in organic LEDs makes the lights more efficient[51]. OLEDs have a longer lifetime than regular LEDs and the flexibility of the material lends itself to distinctive and custom designs.

2.1.6 Energy applications

On-board batteries, ultracapacitors (or supercapacitors), hydrogen fuel cells and solar cells (potentially on the roof of vehicles) are examples of energy conversion and storage systems, both in electric vehicles (including hybrid electric vehicles (HEVs) and plug-in hybrid vehicles) and in more conventional vehicles.

Nano-sized materials, in particular carbon nanotubes, have properties that are beneficial in improving storage capacity[52]. Ongoing research in these areas will have implications for the performance as well as the design of the vehicles. Expectations are that, in the future, more vehicles will make use of these alternative power sources.

Improvements in the performance of catalysts through nanotechnology can enhance the potential energy efficiency of vehicles. To optimise catalytic performance, the surface area of the catalytic particle needs to be increased to improve the capacity of the chemical reactants to adsorb, react with and desorb on it[53]. An increase in the surface area can only be accomplished by decreasing the size of the particle: this is where nanotechnology plays a role.

More detail follows on the application of nanotechnology to batteries and supercapacitors; hydrogen (storage); and photovoltaic applications.

Batteries and supercapacitors

Nanotechnology is seen as an enabler of next generation lithium-ion batteries and supercapacitors, creating a significant improvement in capacitance[54], reducing weight and cost and increasing the running times of lithium-ion batteries in electric vehicles[55]. Nanoparticles coated onto electrolytes increase the surface area over which current can flow without using any more material, leading to overall weight reduction. European battery manufacturers are also working towards the use of

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[46] http://www.nanowerk.com/news/newsid=15236.php
[47] https://www.plusplasticelectronics.com/lighting/bmw-commits-to-developing-oled-vehicle-lights-by-2
[48] https://www.plusplasticelectronics.com/lighting/bmw-commits-to-developing-oled-vehicle-lights-by-2
[49] https://books.google.nl/books?id=dcjECQAAQBAJ&printsec=frontcover&dq=OLED+fundamentals:+materials,+devices+and+processing&hl=nl&sa=X&redir_esc=y#v=onepage&q=automotive&f=false
[50] http://www.sae.org/mags/aei/7240
[51] http://www.researchandmarkets.com/research/34c985/nanotechnology_in
[52] http://www.sciencedirect.com/science/article/pii/S1319610311000305
[53] http://ac.els-cdn.com/S1319610311000305/1-s2.0-S1319610311000305-main.pdf?_tid=6d656ac2-d0ac-11e5-ab6e-00000aab0f6b&acdnat=1455187649_407cbbe6887071bf8cdc2825e234ddcf
[54] http://www.lockheedmartin.com/content/dam/lockheed/data/corporate/documents/nano/energy.pdf
[55] The aim of the NECOBAUT FP7 project (New Concept of Metal-Air Battery for Automotive Application based on Advanced Nanomaterials) is to develop a new concept of battery for automotive applications based on a new metal/air technology that overcomes the energy density limitation of the Li-ion battery used at present for electrical vehicles. http://www.necobaut.eu/summary/summary.php

carbon nanotechnologies in new types of additives, aiming to improve the conductivity of active materials in lead-based batteries[56].

The first demonstrations of supercapacitors based on nano-structured carbon thin-films have been achieved[57]. Supercapacitors are commonly used in commercial power storage applications such as light-rail, electric vehicles and power grids. Carbon nanotubes (CNTs) can be used to improve their performance in terms of capacitance, charge and discharge rates, lifetime and cost.

Hydrogen (storage)

Hydrogen is considered to be an ideal energy carrier because it has the highest energy per mass of any fuel and its conversion to energy is non-polluting. Hydrogen can be used as a fuel by direct burning (as in aerospace) or it can be used to produce electricity via hydrogen fuel cells. The latter application makes hydrogen suitable for use in electric vehicles. Nanotechnology has been applied to build longer-lasting, lighter and more efficient fuel cells. By 2020, the US Fuel Cell Technologies Office (FCTO) aims to develop on-board automotive hydrogen storage systems meeting customer requirements with respect to range, passenger and cargo space, refuelling time and overall vehicle performance[58].

The storage of hydrogen in liquids requires extreme low temperatures, because hydrogen is flammable, and hydrogen stored in gaseous form requires large-volume systems. Fuel-cell-powered vehicles with on-board hydrogen storage have recently reached the market, having addressed the issue of the distance that can be driven following charging[59]. While refuelling can be achieved quickly (in approximately five minutes), the issue is where to find a refuelling station, a problem common to all vehicles using new or non-standard fuels. In addition, although some vehicle manufacturers have now demonstrated progress with some vehicles travelling more than 300 miles on a single fill, this driving range must be achievable across different vehicle models and without compromising space, performance or cost in order to be competitive with current vehicles[60].

The absorbing capacity of carbon nanotubes is being researched as a means to increase the hydrogen storage capacity of fuel cells[61], using carbon nanotubes in the membranes of fuel cells to increase their performance. In addition, safe tanks to hold the hydrogen fuel and lightweight nanomaterials that can hold and release the hydrogen when necessary can also play a role in this development[62].

In addition, nanotechnology can be used for the production of hydrogen. Some nanomaterials are very effective in the decomposition of water molecules into hydrogen and oxygen through photocatalysis (e.g. nanoscale titanium dioxide).

Photovoltaic applications

Transparent organic solar cells (photovoltaics) are being incorporated in a light-capturing car roof in which the light is absorbed and energy generated for use in the vehicle[63]. This joint concept vehicle of Daimler and BASF, called 'smart forvision', is the first prototype of its kind. In general, nanotechnology can be used to make solar cells more efficient by maximising the light entering the solar cell, through anti-reflective coatings; by minimising light escaping the solar cell, through nanostructured photonic waveguides; and by improving light absorption, through integrated plasmonic components [64].

Nanotechnology can also be used to make solar cells more flexible, thinner and cheaper. Silicon is the main raw material for most photovoltaics (PV) and, by making the solar cells thinner, material

[56] http://www.eurobat.org/sites/default/files/rev_of_battery_executive_web_1.pdf
[57] http://www.sciencedirect.com/science/article/pii/S0008622313002303
[58] http://energy.gov/eere/fuelcells/hydrogen-storage
[59] http://worldwide.hyundai.com/WW/Showroom/Eco/ix35-Fuel-Cell/PIP/index.html
[60] https://www.hydrogen.energy.gov/storage.html
[61] http://ac.els-cdn.com/S1319610311000305/1-s2.0-S1319610311000305-main.pdf?_tid=6d656ac2-d0ac-11e5-ab6e-00000aab0f6b&acdnat=1455187649_407cbbe6887071bf8cdc2825e234ddcf
[62] http://www.understandingnano.com/fuel-cells.html
[63] https://media.daimler.com/dcmedia/0-921-1653624-1-1420787-1-0-1-0-0-0-0-1549054-0-1-0-0-0-0-0.html
[64] see NanoData Energy Landscape Compilation report, this project.

costs can be reduced. Increased flexibility enables a variety of shapes to be created, as well as making possible cheaper production techniques, such as printing.

2.1.7 Filters

Diesel particulate filters (DPFs) are used to remove soot from the exhaust gases of a diesel engine. There are two types of technologies: fuel additive systems and coated DPFs. The first is used in conjunction with a diesel catalyst, fuel additives acting as an aid to the catalyst regeneration process. The additives enable the regeneration process to take place at a lower temperature. Fuel additives used to facilitate DPFs are usually known as fuel borne catalysts[65]. Coated DPFs or "non-additive" DPFs, use a catalysing coating to aid the regeneration process, without needing a catalytic converter. The coating also lowers the temperature of the regeneration process[66]. The application of a nano catalyst in DPFs can also foster an increase in efficiency. New nano-coated filters are being developed that are more efficient in the regeneration of soot than conventional filters coated with precious metals[67].

Air filters used in aeroplane cabins now mostly use nanotechnology-based filters. These filters enable mechanical filtration, in which nanoscale pores trap particles. The filters can also remove odours. Besides aircraft, nanotechnology-based air filters are widely used in cars, buses and other vehicles.

2.1.8 Sensors

Nanotechnology can also have major impacts on the operations of infrastructure or vehicles through sensor applications. Physical nano-sensors use the properties of nanotubes and nanoribbons to measure magnitudes such as mass, pressure, force or displacement [68] [69]. Sensors can be used for monitoring and controlling the engine and other vehicle components. Damage detection is an important feature for both vehicles and infrastructure. Sensors can also be used to electronically control fuel injection and to detect damage, or to alert the operator when an engine component needs cleaning (for example, a diesel particulate filter). Sensors are also used to monitor soot emissions.

Sensors are also gaining ground in their use in autonomous vehicles. Coupled with actuators, they are used for navigation and guidance; driving and safety; and performance management, as outlined below[70].

Navigation and guidance applications are the most familiar to most drivers, with global positioning satellites (GPS) enabling location accuracy of a few metres in most cases. These GPS systems are small but sophisticated, using systems-on-a-chip or multi-chip systems coupled to a power supply and an antenna. As such electronic components become smaller and smaller, they are increasingly reliant on nanotechnology for their production and operation (e.g. their manufacture through photolithography). In autonomous driving systems, these GPS systems are being linked to inertial measurement units (IMUs), which monitor the motion of the vehicle and enable it to be guided and tracked even where a GPS signal is blocked (from being in a tunnel or underground, for example). Currently using micro-electro-mechanical systems (MEMS), nanotechnology may enable improved precision in navigation and guidance of vehicles.

Autonomous vehicles can use cameras as one component of their driving and safety systems but these tend to be very limited (due to the need for many cameras to counter the effects of lighting and shadows and the lack of accurate depth perception). The main unit on an autonomous vehicle may use pulses of laser light travelling at high speed to enable a three dimensional judgement of distance. These LIDAR systems (light detection and ranging) are supplemented with radar systems to judge shorter distances (such as bumper-to-bumper spacing in traffic congestion).

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65 https://www.dieselnet.com/tech/dpf_fbc.php
66 http://www.bmcatalysts.co.uk/diesel-particulate-filters/
67 http://www.elringklinger.de/sites/default/files/brochures/downloads/2012_ek_cleancoat_e.pdf
68 http://www.ijcaonline.org/volume14/number2/pxc3872349.pdf
69 http://www.aicit.org/JCIT/ppl/JCIT2553PPL.pdf
70 Adapted from: 'The Autonomous Car: A Diverse Array of Sensors Drives Navigation, Driving, and Performance', Bill Schweber for Mouser Electronics
http://eu.mouser.com/applications/autonomous-car-sensors-drive-performance/

Nanotechnology is inherently part of such detection systems using lasers and radar, for pulse generation and measurement and for component manufacture.

Sensors in autonomous vehicles are similar to those used in standard vehicles, monitoring aspects such as power usage and controlling fuel injection as well as indicating when a component needs to be cleaned or replaced. The main difference is in the actuation part where the vehicle may have greater control of the responses to the signals it is monitoring. As before, a significant part of the nanotechnology is in the electronics but nanotechnology is also used as the sensing material, e.g. detecting emissions, heat and pressure.

2.1.9 Fluids and additives

Developments in nano-fluids (fluids containing nanoparticles) are expected to have major impacts on the transport sector. Nanotechnology is already widely applied in cleaners, such as automotive shampoos, car polish and waxes.

Some nano-fluids have superior heat-transferring properties compared to traditional fluids. Coolants using nanotechnology, some of which are already on the market, are used to remove the excess heat produced by the vehicle engine. The improvements in cooling resulting from the use of nanomaterials can make it possible to decrease the size of the system required for engine cooling.

Nanotechnology-based fuel additives can help to reduce soot emissions, as they promote more complete combustion, thereby leading to improved air quality as well as savings in fuel costs.

The size of an additive particle has a significant impact on the performance of fuel additives for the quality of exhaust emissions. A few examples of nano-additives are: cerium oxide nanoparticles; aluminium nanoparticles; magnesium-aluminium and cobalt oxide nanoparticles. Cerium oxide nanoparticles have the ability to catalyse combustion reactions. They can also be used to remove soot (which clogs up the DPF) and thereby improve the performance of the filters. Magnesium-aluminium and cobalt oxide nanoparticles are especially useful in the reduction of NOx[71] emissions for biodiesel fuels[72].

Nano-additives can also be used in lubricants to improve engine performance by decreasing friction and wear. Research has shown that, for example, the use of graphite nanoparticles additives improves the lubrication properties of conventional lubricants[73].

The paragraphs that follow consider the role of nanotechnology in transport infrastructure.

2.2 Nanotechnology in infrastructure

Nanotechnology can enable the construction and maintenance of a more durable, economical, safe and sustainable infrastructure through the use of lighter structures; stronger structural composites (bridges, tunnels); low maintenance coatings; improved pipe joining materials and techniques; reduced thermal transfer rates of fire retardant materials and insulation; and increased sound absorption[74]. Nanotechnology is considered below in terms of its use in materials; coatings; and sensors.

2.2.1 Materials

Materials used for the construction of infrastructure such as roads (e.g. cement and asphalt) can be nano-modified to increase their strength. Research into ways to improve asphalt for roads has increased in recent years in response to the growing costs of repairing and reconstructing the layers on the road. Previously, many types of materials have been used to modify asphalt, including rubbers, polymers, sulphur, metal complexes, fibres and chemical agents[75]. Nanotechnology is now being considered for inclusion in asphalt mixtures with a view to improving the performance of the road with respect to temperature-sensitivity, water-proofing, corrosion protection and moisture

[71] Nitrous oxide
[72] http://www.azonano.com/article.aspx?ArticleID=3085#Cerium_Oxide_Nanoparticles
[73] A study on the tribological characteristics of graphite nano lubricants: http://link.springer.com/article/10.1007/s12541-009-0013-4
[74] https://www.researchgate.net/profile/Shashi_Rana2/publication/228915597_Significance_of_Nanotechnology_in_Construction_Engineering/links/00b4952dddc79c2408000000.pdf
[75] http://www.jmst.org/fileup/PDF/2012-1425.pdf

resistance. A mixture of nanoclays and asphalt binder, or a combination of nanoclays with rubber modified asphalt, can be used to improve the mechanical properties of asphalt binder. The use of nanoclay-modified binder for roads decreases high-temperature rutting, low-temperature cracking and stripping in the presence of moisture. It also increases the service life time of the road in comparison to the traditional asphalt modification method[76]. In addition to the use of nanoclays, other nanoparticles can be used such as carbon nanotubes (CNT) and nanoparticles of silica, alumina, magnesium, calcium and/or titanium dioxide (TiO_2).

2.2.2 Coatings

Nano-coatings can be used for the protection and strengthening of transport infrastructures. Nano-modified polymer coatings are good alternatives to organic polymer and polymer-modified cement coatings. Protective coatings can be applied to concrete, timber, steel or brick structures in, for example, tunnels or bridges[77]. Nano-composite coating can also be self-cleaning (for example, for graffiti, to make it disappear from walls during rain), anti-reflecting, anti-corrosion and self-repairing. Coating on infrastructures can also absorb sound and light. Photocatalytic coating on, for example, concrete walls next to roads and motorways, can be used to transform environmental pollution and neutralise it.

2.2.3 Sensors

Intelligent transportation systems based on sensors can continually monitor the condition and performance of roads, bridges, tunnels and rails over time[78]. Permanent structural monitor systems have already been successfully deployed on bridges, dams and pipelines.

Developments in nanoelectromechanical sensors (NEMS) are enabling the monitoring of the chemical properties of infrastructure, such as roads and bridges, warning of wear or potential failure of such transport infrastructure and using sensors embedded directly in the material of the structure. [79]

Researchers have also developed self-sensing nanotechnology composite materials for traffic monitoring, using piezo-resistive multi-walled carbon nanotubes as an admixture in cement[80]. Wireless sensors offer infrastructure owners a lower-cost option for instrumentation, thereby allowing more infrastructure to be economically monitored.

Nanoscale sensors and devices can also be used for the monitoring and the communication of disturbances in the transportation of people or goods; for collision avoidance in automobiles; for maintaining lane position and the adjustment of travel routes to circumnavigate congestion[81]. Sensors can also be used in detectors for chemical and biological weapons at airports and train stations.[82] Other application areas of nano sensors are automatic toll collection and congestion charging.

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

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[76] http://www.me.mtu.edu/~gmodegar/papers/Const_Build_Mat_2011_1072.pdf

[77] http://www.academia.edu/3658791/Nano-Composite_Coatings_for_Transportation_Infrastructures-_Demonstration_Projects-India

[78] http://www.nano.gov/you/nanotechnology-benefits

[79] https://books.google.nl/books?id=TfTCAgAAQBAJ&pg=PA324&lpg=PA324&dq=piezoresistive+multi-walled+carbon+nanotubes+sensor+infrastructure&source=bl&ots=ny3qGOntpN&sig=HAu1cIAUaVtJDd-SUEwwu9zgbac&hl=nl&sa=X&ved=0ahUKEwjS_saCwvLKAhXD-g4KHSi6Bw0Q6AEIMDAC#v=onepage&q=nano&f=false

[80] http://www.nanowerk.com/spotlight/spotid=13009.php

[81] Ibid

[82] http://www.ijcaonline.org/volume14/number2/pxc3872349.pdf

3 EU POLICIES AND PROGRAMMES FOR NANOTECHNOLOGY AND TRANSPORT

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 Connecting Europe Facility[83], the Third Health Programme[84], Life[85], Erasmus+[86] and COSME[87].

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) [88]. Within FP6 funding, over 70% of transport nanotechnology projects were funded under NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) and 16% under Information Society.

Nanotechnology funding in FP6 was followed up with targeted funding in the Seventh Framework Programme (FP7, 2007-2013). The largest part of funding for transport and nanotechnology under the Co-operation Programme was under NMP - "Nanosciences, Nanotechnologies, Materials and new Production Technologies (NMP)" - (40.5%), followed by Joint Technology Initiatives (15.0%), ICT (14.1%), Transport (13.6%) and Space (5.6%).

Transport nanotechnology 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[89]) for investigator-driven, bottom-up research ideas in science, engineering and interdisciplinary research, awarded through open competition, with 4.3% (EUR 17.9 million) of transport nanotechnology funding;
- The Marie Curie Actions[90]: 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 3.6% (EUR 14.8 million) of transport nanotechnology funding; and
- The Capacities Programme[91]: 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;

[83] Improving trans-European infrastructure for transport, energy and telecommunications.
[84] Preventing diseases, protecting EU citizens from cross-border health threats, contributing to innovative health systems, and facilitating better access to healthcare.
[85] For environment, biodiversity and climate change.
[86] Supporting relocation for education and training purposes.
[87] Supporting the creation and expansion of companies, especially by expanding their research and innovation activities.
[88] 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.
[89] http://erc.europa.eu/
[90] http://ec.europa.eu/research/mariecurieactions/ Marie Curie Actions became Marie Skłodowska-Curie Actions under Horizon 2020.
[91] http://ec.europa.eu/research/fp7/index_en.cfm?pg=capacities

research potential of Convergence Regions; science in society; support to the coherent development of research policies; and international co-operation, with 2% (EUR 11.3 million) of transport nanotechnology funding, mainly (2.1%) for research for the benefit of SMEs.

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

Mechanisms for collaboration on nanotechnology and transport 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, ERA-NET Transport (ENT) (EUR 3.89 million), established in 2004 on the basis of the ETP on co-operation and co-ordination of transport research (EPTR) and involving organisations from eleven countries, aimed to create "an efficient instrument for common research programmes on topics with shared priority amongst all members" in order to co-ordinate national transport research programmes at the European level. Moreover, a specific ERA-NET was dedicated to each of maritime technologies (MARTEC), road (ENR) and air transport (AirTN), as follows:

- MARTEC[92], started in 2006 with nine countries, received around EUR 2.1 million to improve the management and coordination of research in maritime technologies;
- ENR[93], established in 2006, obtained EUR 2.5 million and involved eleven countries. It aimed to develop trans-national research programme in road transport; and
- AirTN[94] was created in 2006 by organisations coming from sixteen different countries to reinforce "the co-operation and co-ordination of research activities at national level and to expand the European dimension" in aeronautics and air transport.

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. ERA-NET Transport (ENT) became ENT II (thirteen countries, EUR 2.99 million) and ENT III (20 countries, EUR 2.3 million). ENT III has developed into a service platform for Programme Owners and Managers. It offers support for transnational research and innovation. In addition, the focus on maritime, road and air transport was maintained through:

- MARTEC II;
- Era-Net Road II (ENR2); and
- the Aeronautics ERA-NET (AirTN - Air Transport Net).

MARTEC II, established in 2011, involves 25 countries. With an EC contribution of about EUR 2 million, MARTEC II goal is to exchange real information and to build partnership across national borders.

ENR2, established in 2009 and counting partners from sixteen different countries, received an EC contribution of 1.5 million. The main purpose was to support innovative approaches for network's construction, maintenance and operation, by coordinating road research procurement to obtain a better value for money.

The same principle is at the basis of the AirTN creation that addresses to aeronautical RTD, receiving EC funding of EUR 1.9 million and involving seventeen countries.

The ERA-NET scheme under FP7 developed and strengthened the co-ordination of national and regional research programmes through ERA-NET Plus (ERANET+) 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 instance, ERA-NET Plus on

[92] https://www.martec-era.net/
[93] http://www.eranetroad.org/
[94] http://www.airtn.eu/index.html

Infrastructure Innovation (INFRAVATION)[95] was launched under FP7 in 2014. It comprises 11 countries with an EU contribution of EUR 2.67 million.

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. Examples related to nanotechnology and transport are EXCELL, POLYSACCHARIDES, NANOFUNCTION and KMN-NoE[96].

- EXCELL, the Network of Excellence to overcome the fragmentation of European research in multifunctional thin-films, received EUR 12.5 million of EU funding over five years and involves twelve institutions representing eight countries. It studies biocompatible and bioactive coatings whose application areas include marine and land transportation, as well as mechanical engineering and construction.
- POLYSACCHARIDES (integration in the field of renewable materials) received EUR 5 million over four years having sixteen partners from eight countries. The research on polysaccharides aims to "replace oil-derived materials with biodegradable and biocompatible products" in the field of transport as well as construction.
- KMN-NoE (integration in the field of multi-component materials) focuses on "multi-component materials designed for safe and durable performance in highly demanding conditions of loading and environment". For instance, materials that provide superior mechanical properties, combined with properties like "low density; excellent performance in high- temperature regimes; enhanced fracture toughness and fatigue lifetime; and superior resistance to wear, corrosion and oxidation" will be relevant for the aerospace and automotive sector as well as for micro-sensors. 36 organisations from ten countries are involved and received EUR 8.1 million over four years.
- FAME (integration in the field of hybrids and ceramics) includes fifteen organisations (from seven countries) active for example in the fields of mechanics, electronics, functional and protective coatings, sensors and catalyst. Its EU financial support is EUR 5 million.

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)[97], Member States are coming together to fund infrastructures related to transport, 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.

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

[95] http://www.infravation.net/
[96] https://ec.europa.eu/research/industrial_technologies/pdf/noes-122007_en.pdf
[97] http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=home

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)[98]. The total number of projects was 35,265, of which 25,238 were FP7 projects and 10,027 were FP6 projects. There were 210,177 participations, of which 133,615 were in FP7 and 76,562 were in FP6.

From the initial set of 35,265 projects, 3,544 were found to be related to nanotechnology in that they contained the term "nano"[99] in the title or abstract of the project. Thus, nanotechnology projects form approximately 10% of the total FP projects. The share of nanotechnology projects increased slightly between FP6 (9.1%) and FP7 (10.4%).

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

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

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

Number and share of nanotechnology transport projects

The number of projects (in FP6 and FP7 together) that were related to both transport and nanotechnology was determined by the use of a keyword search[100], to be 200, approximately 5.6% of the total number of projects related to nanotechnology. The percentage of transport nanotechnology projects was slightly lower in FP7 (5.3%) than it was in FP6 (6.6%). This is an indication that the relevance of transport has decreased within nanotechnology FP-activities from FP6 to FP7.

[98] Extraction of data from eCorda January 2015.

[99] 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".

[100] See Annex for details of keywords

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

	Numbers of projects		
	Total	**FP7**	**FP6**
Total FP projects, all topics	35,265	25,238	10,027
Nanotechnology FP projects	3,544	2,636	908
Transport nanotechnology FP projects	200	140	60
	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%
Transport NT projects	100%	70.0%	30.0%
Transport NT projects as % of all NT projects	5.6%	5.3%	6.6%
Transport NT projects as % of all FP projects	0.57%	0.55%	0.6%

Projects in FP7 comprised 70% of all transport nanotechnology with 30% of projects being in FP6. The proportion of FP7 projects is slightly lower than for either nanotechnology projects (74%) or FP projects (72%).

Funding of transport nanotechnology projects

The 200 nanotechnology transport projects received an EC contribution of EUR 586.7 million. The EC contribution for transport projects was EUR 171.3 million (29.2%) in FP6 and EUR 415.4 million (70.8%) in FP7. In FP6, the EC contribution for nanotechnology and transport represented 10.1% of the total nanotechnology EC contribution, whereas in FP7 it was 8.9% indicating a small relative decrease in transport-related funding within nanotechnology funding, as shown in the figure below.

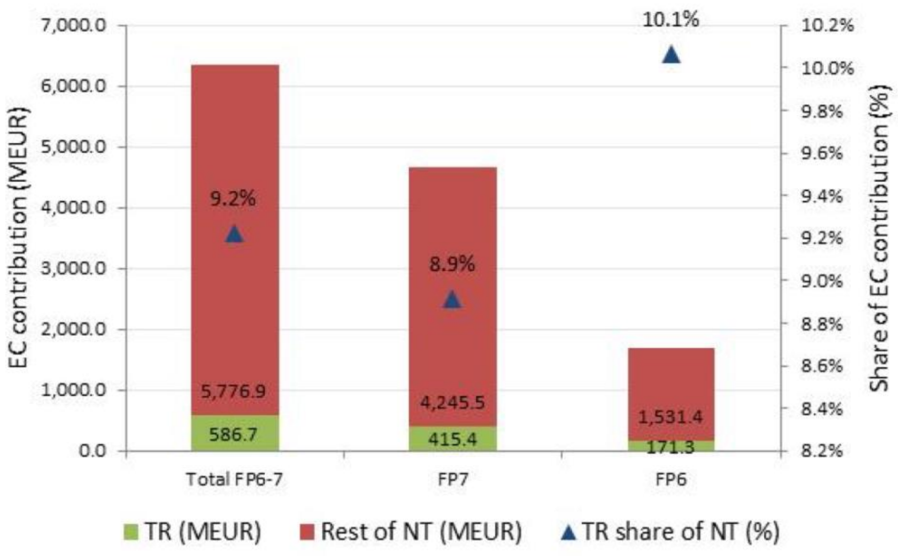

Figure 3-1: Funding of transport nanotechnology for FP6 and FP7 together, for FP7 and for FP6

3.2.2 Activities by programme and sub-programme

3.2.2.1 FP6 transport nanotechnology activities

There were 908 nanotechnology projects in FP6, approximately 9% of the total number of projects in FP6. Of those, 60 were transport-related, 6.6% of FP6 nanotechnology projects and 0.6% of FP6 projects as a whole.

FP6 was structured in three main blocks of activities:

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

There was, in addition, the EURATOM activity.

In FP6, projects specific to nanotechnology and transport made up approximately 10.2% of all nanotechnology activities as measured by EC funding allocation. They took place mainly under the priority of (i) Focusing and integrating the ERA. In fact, 96.3% of all funding for transport activities under FP6 came from this priority. The remaining 3.7% was funded under (ii) Structuring the ERA.

Within these Thematic Priorities:

- NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had 72.3% of the total (EUR 123.9 million) for 33 projects (an average of EUR 3.75 million per project);
- Information Society had 6 projects and EUR 27.9 million of EC funding (16.3% of total) (an average of EUR 4.65 million per project);
- Other programmes which gathered EC funding were Aeronautics and space (5.6%), Human resources and mobility (3.2%), Horizontal research involving SMEs (1.5%) and Research and innovation (0.5%).

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

FP6 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP6	FP6 NT	FP6 TR	FP6	FP6 NT	FP6 TR	FP6	FP6 NT	FP6 TR
I Focusing and Integrating ERA	**4,735**	**455**	**47**	**13,445.0**	**1,383.6**	**165.0**	**80.5%**	**81.3%**	**96.3%**
Thematic Priorities	3,374	389	44	12,027.5	1,314.8	162.4	72.1%	77.2%	94.8%
1. Life Sciences	602	20	0	2,336.5	54.1	0.0	14.0%	3.2%	0.0%
2. Information Society	1,089	80	6	3,798.9	346.1	27.9	22.8%	20.3%	16.3%
3. NMP	444	271	33	1,534.2	870.1	123.9	9.2%	51.1%	72.3%
4. Aeronautics and Space	241	5	4	1,066.1	11.6	9.5	6.4%	0.7%	5.6%
5. Food Quality and Safety	189	0	0	754.2	0.0	0.0	4.5%	0.0%	0.0%
6. Sustainable Development	666	10	1	2,300.9	30.5	1.0	13.8%	1.8%	0.6%
7. Citizens and Governance	143	3	0	236.6	2.4	0.0	1.4%	0.1%	0.0%
Specific Activities	1,361	66	3	1,417.5	68.8	2.6	8.5%	4.0%	1.5%
Policy Support	520	29	0	604.2	40.7	0.0	3.6%	2.4%	0.0%
Horizontal Research Involving SMEs	490	29	3	463.1	24.7	2.6	2.8%	1.4%	1.5%
International Co-operation	351	8	0	350.3	3.4	0.0	2.1%	0.2%	0.0%
II Structuring the European Research Area	**5,096**	**449**	**13**	**2,744.2**	**303.1**	**6.3**	**16.4%**	**17.8%**	**3.7%**
Research and Innovation	240	3	1	224.0	3.9	0.9	1.3%	0.2%	0.5%
Human Resources and Mobility	4,546	420	12	1,723.1	219.2	5.5	10.3%	12.9%	3.2%
Research Infrastructures	147	17	0	717.6	74.3	0.0	4.3%	4.4%	0.0%
Science and Society	163	9	0	79.5	5.8	0.0	0.5%	0.3%	0.0%
III Strengthening the ERA	118	3	0	317.3	8.0	0.0	1.9%	0.5%	0.0%
Co-ordination of Activities	99	3	0	303.8	8.0	0.0	1.8%	0.5%	0.0%
Research & Innovation Policies	19	0	0	13.5	0.0	0.0	0.1%	0.0%	0.0%
EURATOM	78	1	0	185.7	8.0	0.0	1.1%	0.5%	0.0%
TOTAL	10,027	908	60	16,692.3	1,702.7	171.3	100%	100%	100%

3.2.2.2 FP7 transport nanotechnology activities

Transport nanotechnology projects comprised 0.55% of the total number of projects in FP7[101] and, with 140 transport nanotechnology projects, 5.3% of FP7 nanotechnology projects. Funding for nanotechnology and transport made up 8.9% of NT funding and 0.92% of total FP7 funding nanotechnology overall took 10.37% of the total FP7 funding.

The broad objectives of FP7 group into four categories:

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

The largest proportion of funding for nanotechnology and transport is seen under the Co-operation Specific Programme Transport with EUR 371.4 million (89.4% of total nano transport funding in FP7) with 97 projects. Within the Co-operation Specific Programme, NMP has the highest funding (EUR 168 million), followed by Joint Technology Initiatives (EUR 62.3 million), ICT (EUR 58.7 million),

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[101] Data extraction January 2015

Transport (EUR 56.4 million) and Space (EUR 23.3 million).

The Ideas Specific Programme, implemented via the European Research Council, had a funding for transport nanotechnology of EUR 17.9 million (4.3%) for 11 projects.

Marie-Curie Actions under the People Programme accounted for 3.6% of the funding (EUR 14.8 million) for nanotechnology and transport.

Research for the benefit of SMEs accounted for EUR 8.8 million of funding (2.1%) for nanotechnology and transport and Research Potential for EUR 2.4 million (0.6%), both activities under the Capacities Programme.

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

FP7 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP7	FP7 NT	FP7 TR	FP7	FP7 NT	FP7 TR	FP7	FP7 NT	FP7 TR
COOPERATION	7,834	756	97.0	28,336.3	2,803.8	371.4	63.1%	60.2%	89.4%
Health	1,008	33	0	4,791.7	157.0	0.0	10.7%	3.4%	0.0%
Food, Agri and Bio	516	25	0	1,850.7	97.1	0.0	4.1%	2.1%	0.0%
ICT	2,328	175	14	7,877.0	561.3	58.7	17.5%	12.0%	14.1%
NMP	805	412	39	3,238.6	1,595.6	168.0	7.2%	34.2%	40.5%
Energy	368	24	1	1,707.4	81.5	2.6	3.8%	1.7%	0.6%
Environment	494	10	0	1,719.3	26.9	0.0	3.8%	0.6%	0.0%
Transport	719	12	10	2,284.2	61.5	56.4	5.1%	1.3%	13.6%
Socio-economic Sciences	253	0	0	579.6	0.0	0.0	1.3%	0.0%	0.0%
Space	267	14	9	713.3	31.7	23.3	1.6%	0.7%	5.6%
Security	314	5	0	1,295.5	14.1	0.0	2.9%	0.3%	0.0%
General Activities	26	0	0	312.7	0.0	0.0	0.7%	0.0%	0.0%
Joint Technology Initiatives	736	46	24	1,966.4	177.0	62.3	4.4%	3.8%	15.0%
IDEAS	4,525	572	11	7,673.5	1,026.1	17.9	17.1%	22.0%	4.3%
European Research Council	4,525	572	11	7,673.5	1,026.1	17.9	17.1%	22.0%	4.3%
PEOPLE	10,716	1,158	22	4,777.5	579.9	14.8	10.6%	12.4%	3.6%
Marie-Curie Actions	10,716	1,158	22	4,777.5	579.9	14.8	10.6%	12.4%	3.6%
CAPACITIES	2,025	149	10	3,772.0	249.9	11.3	8.4%	5.4%	2.7%
Research Infrastructures	341	18	0	1,528.4	72.2	0.0	3.4%	1.5%	0.0%
Research for the benefit of SMEs	1,028	70	8	1,249.1	86.1	8.8	2.8%	1.8%	2.1%
Regions of Knowledge	84	4	0	126.7	7.3	0.0	0.3%	0.2%	0.0%
Research Potential	206	27	2	377.7	55.1	2.4	0.8%	1.2%	0.6%
Science in Society	183	16	0	288.4	16.5	0.0	0.6%	0.4%	0.0%
Research Policies	26	0	0	28.3	0.0	0.0	0.1%	0.0%	0.0%
International Cooperation	157	14	0	173.4	12.7	0.0	0.4%	0.3%	0.0%
EURATOM	138	1	0	358.1	1.1	0.0	0.8%	0.0%	0.0%
Fusion	4	0	0	5.2	0.0	0.0	0.0%	0.0%	0.0%
Fission	134	1	0	352.8	1.1	0.0	0.8%	0.0%	0.0%
TOTAL	25,238	2,636	140	44,917.3	4,660.8	415.4	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 nanotechnology and transport.

Table 3-5: Participations in FP6 and FP7 including funding and share of funding[102]

	Total FP6 and FP7			NT in FP6 and FP7			Transport 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%	7,671	3,019.5	47.5%	508	184.9	31.6%
REC	53,384	17,304.4	28.1%	4,696	1,778.1	28.0%	447	167.0	28.5%
PCO	25,067	7,021.3	11.4%	2,275	615.4	9.7%	439	112.0	19.1%
SME	29,428	6,882.6	11.2%	3,239	769.1	12.1%	472	106.4	18.2%
Other	24,961	4,626.8	7.5%	1,059	174.2	2.7%	110	15.5	2.6%
Total	**209,617**	**61,571.1**	**100.0%**	**18,940**	**6,356.2**	**100.0%**	**1,976**	**585.7**	**100.0%**

Higher education institutes (HES) received close to one third (31.6%) of the EC contribution for nanotechnology and transport, as shown in the table above and the figure below, similar to that of research organisations (REC, 28.5%). These were followed, again with similar figures by large companies (PCO, 19.1%) and by small and medium-sized companies (SME, 18.2%) with other organisations making up the remainder (OTH, 2.6%).

The proportion of funding going to organisations in the higher education sector (31.6%) is significantly lower than that corresponding to their share of nanotechnology funding (46.6%), and their share for FP funding overall (41.8%). The relative share for HES fell slightly from 31.8% in FP6 to 31.5% of all nanotechnology transport funding in FP7.

For research organisations, their share also dropped slightly from FP6 (29.5%) to FP7 (28.1%). Funding to companies rose from FP6 to FP7, the relative rise being in particular in the case of large companies (from 14% to 21.2% for PCOs; and from 17.5% to 18.5% for SMEs).

The distribution of funds among different types of participants in nanotechnology and transport related projects is different from those corresponding to nanotechnology projects in general or FP6 and FP7 projects together as a whole. Whereas the share of funds for research organisations is very similar in all cases, the share for higher education institutions is lower in nanotechnology and transport projects than it is in nanotechnology or FP6 and FP7 projects. In contrast, the shares for both large companies and SMEs are much higher in nanotechnology & transport projects than they are in nanotechnology projects in general or in FP6 and FP7 projects as a whole.

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

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

3.2.4 Activity by organisations receiving funding

The organisations receiving the largest amounts of funding for transport nanotechnology activities were the Fraunhofer-Gesellschaft[103] (DE) (EUR 18.73 million for 31 projects), Vysoke Uceni Technicke V Brne[104] (CZ) (EUR 17.17 million, 4 projects), the CNRS [105](FR) (EUR 11.64 million, 28 projects) and Centro Ricerche Fiat SCPA (IT) (EUR 10.56 million, 29 projects).

Out of the top 25 recipients, nine were higher education institutions, eleven were research organisations, and five were companies. The top ten organisations are from Germany (3), France (2), Belgium (1), the Czech Republic (1), Italy (1), Spain (1) and the United Kingdom (1).

[103] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.
[104] Brno University of Technology https://www.vutbr.cz/en/
[105] Centre national de la recherche scientifique

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

	Transport - Top participants	Country	No. of Projects	EC Funding (MEUR)	Share of TR Funding
1	Fraunhofer-Gesellschaft[106]	DE	31	18.73	3.20%
2	Vysoke Uceni Technicke V Brne[107]	CZ	4	17.17	2.94%
3	CNRS[108]	FR	28	11.64	1.99%
4	Centro Ricerche FIAT SCPA	IT	29	10.56	1.80%
5	CEA[109]	FR	19	9.06	1.55%
6	Airbus Defence and Space GmbH	DE	16	7.85	1.34%
7	Fundacion Tecnalia Research & Innovation	ES	12	5.13	0.88%
8	Deutsches Zentrum fuer Luft - und Raumfahrt EV (DLR)[110]	DE	7	4.95	0.85%
9	University of Cambridge	UK	10	4.73	0.81%
10	Institut von Karman de dynamique des fluides[111]	BE	1	4.58	0.78%
11	Katholieke Universiteit Leuven	BE	6	4.54	0.78%
12	Politecnico Di Torino	IT	13	4.07	0.70%
13	Ethniko Kentro Erevnas Kai Technologikis Anaptyxis (RISCS)[112]	EL	6	3.75	0.64%
14	CNR- Consiglio Nazionale Delle Ricerche	IT	11	3.75	0.64%
15	University of Birmingham	UK	3	3.74	0.64%
16	THALES SA[113]	FR	4	3.70	0.63%
17	Infineon Technologies AG	DE	6	3.69	0.63%
18	University College Cork	IE	8	3.51	0.60%
19	CSIC[114]	ES	12	3.19	0.55%
20	Alenia Aermacchi Spa[115]	IT	4	3.18	0.54%
21	EPFL[116]	CH	10	3.16	0.54%
22	University of Surrey	UK	6	2.98	0.51%
23	NXP Semiconductors Netherlands Bv	NL	4	2.96	0.51%
24	Max Planck[117]	DE	1	2.92	0.50%
25	Rheinisch-Westfaelische Technische Hochschule Aachen	DE	9	2.86	0.49%

[106] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[107] Brno University of Technology https://www.vutbr.cz/en/
[108] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr
[109] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[110] http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10002/
[111] https://www.vki.ac.be
[112] http://www.riscs-co2.eu/PartnerData.aspx?IdPartner=2
[113] https://www.thalesgroup.com/en
[114] Consejo Superior de Investigaciones Cientificas, the Spanish National Research Council www.csic.es
[115] http://www.aleniana.com/about-us/profile/alenia_aermacchi_spa
[116] École Polytechnique Fédérale de Lausanne, the Swiss Federal Institute of Technology in Lausanne www.epfl.ch
[117] Max-Planck-Gesellschaft, the Max Planck Society www.mpg.de

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

The German company Airbus Defence and Space GMBH (DE) received EUR 7.85 million for sixteen projects. Thales SA (FR) followed with EUR 3.7 million and four projects, Infineon Technologies AG (DE) came close with EUR 3.69 million and six projects. Alenia Aermacchi SPA (IT) was the fourth company, receiving EUR 3.18 million. The rest of the companies in the top 25 received less than EUR 3 million each.

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

	Transport - Top Company Participants	Country	SME	No. of Projects FP6-7	EC Funding (MEUR)
1	Airbus Defence And Space GmbH	DE		16	7.85
2	Thales SA	FR		4	3.70
3	Infineon Technologies AG	DE		6	3.69
4	Alenia Aermacchi Spa[118]	IT		4	3.18
5	Nxp Semiconductors Netherlands BV	NL		4	2.96
6	Infineon Technologies Austria AG	AT		7	2.71
7	AMS AG	AT		3	2.42
8	Daimler AG	DE		6	2.40
9	STMicroelectronics SA	IT		5	2.38
10	Phillips Electronics Nederland B.V.	NL		4	2.33
11	Isis - Innovative Solutions in Space Bv	NL	SME	3	2.19
12	Cavendish Kinetics B.V.	NL	SME	3	2.13
13	Nanocyl SA	BE	SME	6	1.96
14	MBN Nanomaterialia Spa	IT	SME	4	1.92
15	Airbus Operations GmbH	DE		2	1.79
16	Integrated Aerospace Sciences Corporation O.E.	EL	SME	5	1.71
17	Airbus Group Sas	FR		6	1.64
18	CVD Technologies Limited	UK	SME	2	1.50
19	Centro Ricerche Plast-Optica Spa	IT		4	1.47
20	Beneq OY	FI	SME	2	1.43
21	Osram Opto Semiconductors GmbH	DE		1	1.41
22	Nanomaterials Ltd	IL	SME	1	1.35
23	Acciona Infraestructuras SA	ES		5	1.27
24	AVL List GmbH	AT		4	1.25
25	Fischer Advanced Composite Components	AT		1	1.23

[118] http://www.aleniana.com/about-us/profile/alenia_aermacchi_spa

3.2.5 Participation by country

In total, 47 countries took part in transport 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	TR NT funding (MEUR)	% of funding
1	DE	109.5	18.7%
2	UK	66.9	11.4%
3	FR	66.0	11.3%
4	IT	64.8	11.1%
5	ES	45.6	7.8%
6	NL	30.5	5.2%
7	BE	27.5	4.7%
8	CZ	21.3	3.6%
9	EL	21.3	3.6%
10	SE	20.6	3.5%
11	CH	18.2	3.1%
12	AT	15.6	2.7%
13	FI	9.5	1.6%
14	NO	9.2	1.6%
15	PL	8.4	1.4%
	Total	**535**	**91.3%**

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

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

	FP Total			Nanotechnology			Transport and Nanotechnology		
	MEUR	Rank	Share of FP	MEUR	Rank	Share of NT	MEUR	Rank	Share of TR
DE	10,164.1	1	16.5%	1,121.5	1	17.6%	109.5	1	18.7%
UK	9,295.2	2	15.1%	845.9	2	13.3%	66.9	2	11.4%
FR	7,319.3	3	11.9%	760.9	3	12.0%	66.0	3	11.3%
IT	5,046.5	4	8.2%	505.2	4	7.9%	64.8	4	11.1%
ES	4,200.6	6	6.8%	481.0	5	7.6%	45.6	5	7.8%
NL	4,438.4	5	7.2%	444.3	6	7.0%	30.5	6	5.2%
BE	2,518.0	7	4.1%	258.4	9	4.1%	27.5	7	4.7%
CZ	415.7	20	0.7%	58.5	18	0.9%	21.3	8	3.6%
EL	1,425.5	12	2.3%	128.5	14	2.0%	21.3	9	3.6%
SE	2,386.7	9	3.9%	271.6	8	4.3%	20.6	10	3.5%
Total	**47,210.0**		**76.7%**	**4,875.9**		**76.7%**	**474.1**		**80.9%**

The top four countries accounted for more than half of the total EC funding for transport nanotechnology projects (52.5%). The same four countries, in the same order, head the rankings for nanotechnology projects and for FP projects overall, as seen in the table above. The list is topped by Germany with a share of 18.7%, followed by the UK (11.4%), France (11.3%) and Italy (11.1%). Other countries like Spain (7.8%), the Netherlands (5.2%) and Belgium (4.7%) follow at a distance.

The figure below shows the ranking of countries participating in transport nanotechnology projects. In some cases, the share of funding for transport nanotechnology projects is lower than the shares for both nanotechnology projects and FP projects as a whole. However, there are some cases in which the opposite is true, such as Germany, Italy, Spain, Belgium, the Czech Republic and Greece, which have higher percentages of funding for transport nanotechnology. In Italy and the Czech Republic, the shares of funding of transport nanotechnology projects are about 3% higher than their shares of nanotechnology projects funding, indicating that these countries show a higher specialisation in the field of transport nanotechnology.

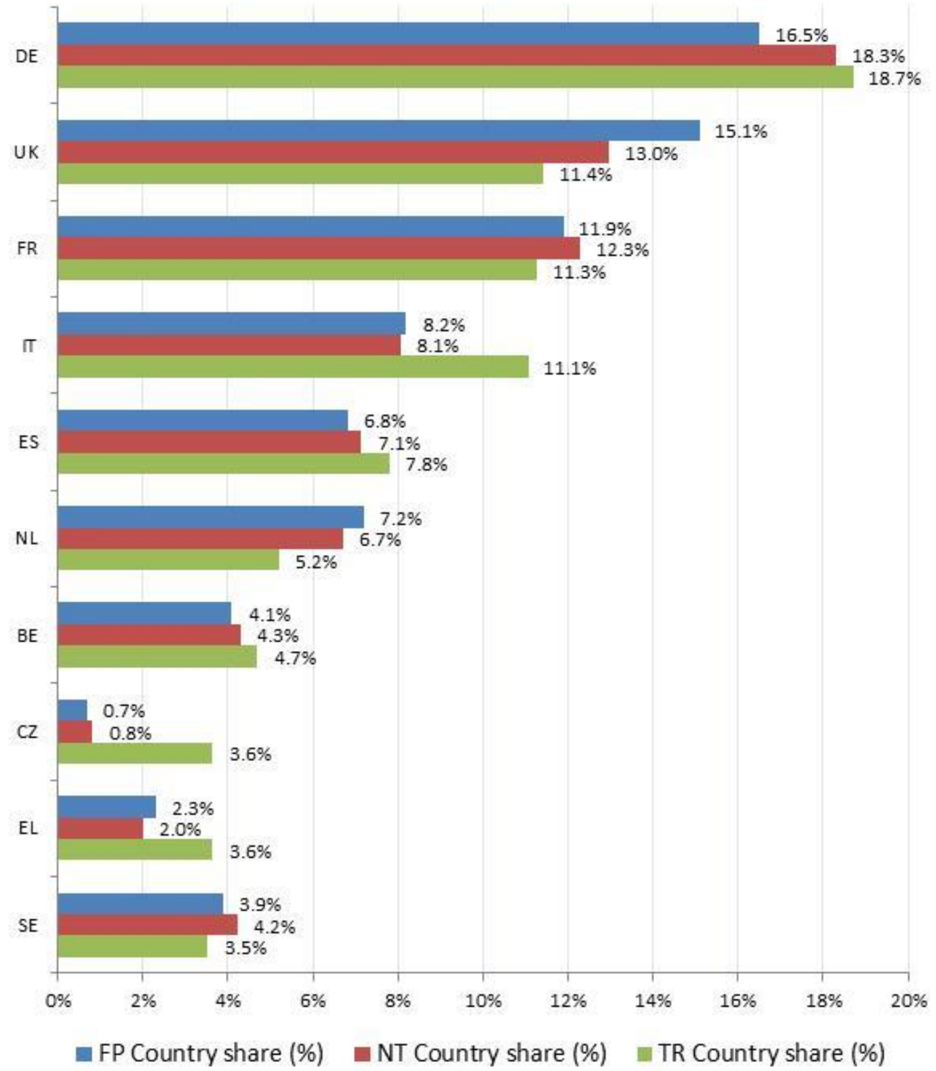

Figure 3-3: Percentage shares of FP funding by country in FP, NT and transport nanotechnology

In the figure below (the EC funding for transport nanotechnology projects in FP6 and FP7 (bars) and the country shares (points or diamonds)), five countries have increased their share of funding for transport nanotechnology projects from FP6 to FP7. These are Germany, the United Kingdom, the Netherlands, Belgium and the Czech Republic. The Czech Republic is the most significant case, as it increased its share of funding from 1% to 4.7%. France, on the other hand, had a reduced share of funding (13% in FP6 to 10.6% in FP7).

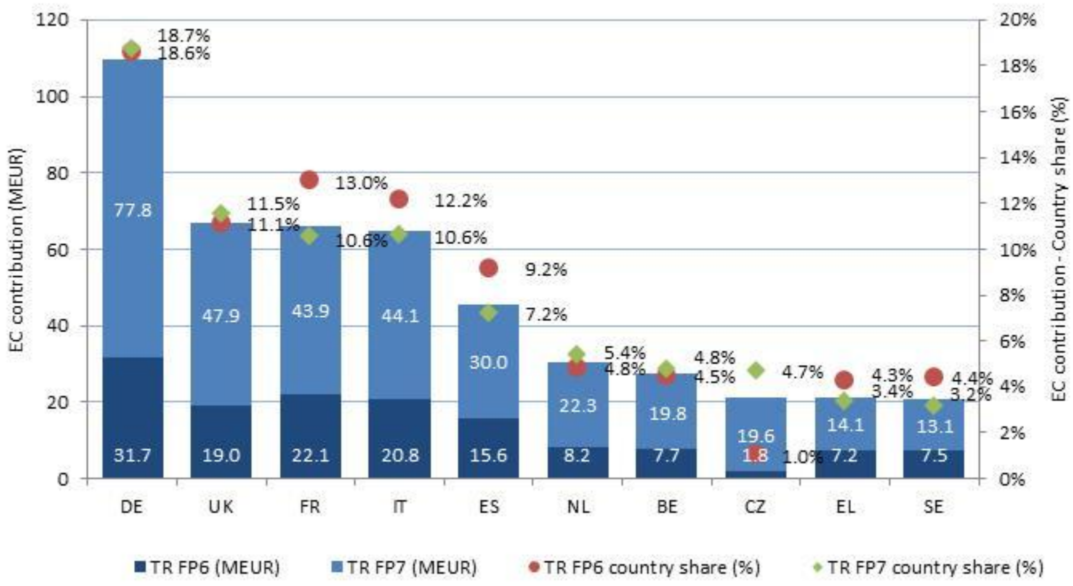

Figure 3-4: EC funding for transport NT activities in FP6 and FP7 in MEUR and country shares

3.2.6 Snapshot of outputs from FP7

A review was undertaken of 106 FP7 nanotechnology projects self-reported 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 only two were directly related to transport. The first[119] was on lubricants (oil for passenger cars and grease for industrial bearings) using nanotechnology. This project led to twenty scientific publications and one patent. The second[120] project focused on the evaluation of metallic nanoparticles as potential fuels for internal combustion engines such as those used in vehicles. It led to two publications and a patent.

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: Transport

In 2011, the European Commission Directorate General for Mobility and Transport (DG MOVE) published a White Paper called "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system"[121] in which the European Strategy for transport was explained. In relation to technology, in the section on "Innovating for the future – technology and behaviour", the report identified that fragmentation of research and development efforts in Europe is harmful, and that joint European efforts can bring the greatest European added value in areas including the following in which a role for nanotechnology can be envisaged :

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[119] The development and scale-up of innovative nanotechnology-based processes into the value chain of the lubricants market" (AddNano), funded by the FP7-CP-IP scheme and coordinated by VIRTUALPIE LTD. https://sites.google.com/site/addnanoeu/

[120] "Technologies for Synthesis, Recycling and Combustion of Metallic Nanoclusters as Future Transportation Fuels" (COMETNANO) and it was coordinated by the "Centre for Research and Technology HELLAS".

[121] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144&from=EN

- Clean, safe and silent vehicles for all different modes of transport, from road vehicles to ships, barges, rolling stock in rail and aircraft (including new materials, new propulsion systems and the IT and management tools to manage and integrate complex transport systems);
- Technologies to improve transport security and safety;
- Potential new or unconventional transport systems and vehicles such as unmanned aircraft systems and unconventional systems for goods distribution;
- A sustainable alternative fuels strategy, including appropriate infrastructure;
- Integrated transport management and information systems, facilitating smart mobility services, traffic management, and realtime information systems to track and trace freight and to manage freight flows; and
- Intelligent infrastructure (both land and space-based) to ensure maximum monitoring and inter-operability of the different forms of transport and communication between infrastructure and vehicles.

The focus is particularly on forms of mobility that are sustainable, energy-efficient and respectful of the environment. Technical innovations, such as electric vehicles, intelligent transport systems and smart grids (all potentially harnessing nanotechnology developments), can contribute to achieving this goal. Alternative fuels like bio-fuels and non-polluting energy sources, notably hydrogen, are also pathways towards a more sustainable mobility.

In addition, the Commission Communication (COM(2010)186 final) sets out a European strategy on clean and energy efficient vehicles. 'Decarbonising' transport has been identified as a priority target for the development of a sustainable transport system. Priority areas for road transport are thus electric vehicles, alternative fuels and hydrogen fuel cell vehicles[122].

3.3.2 EU policies and programmes: Industry

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

The following platforms act in the field of transport:

- ACARE[123]: Launched in 2001, the Advisory Council for Aeronautics Research in Europe engages in the planning of research activities at different levels (European/national, private/public) in priority areas including greening transport; fostering competitiveness and efficiency; and raising safety standards levels. Within its remit falls co-ordination activity around projects addressing the manufacturing challenges associated with nanoparticle-reinforced structures and the use of nanoparticles in carbon-fibre-reinforced polymers for enhanced electrical capabilities (e.g. FP7-SARITSU[124])
- ALICE[125]: The Alliance for Logistics Innovation through collaboration in Europe was created in 2013, on the basis of the European Green Cars Initiative and EIRA, the European Intermodal Research Advisory Council.
- ERRAC[126]: The European Rail Research Advisory Council was established in 2001 to renew the sector and increase competitiveness through innovation and research at European level.
- ERTRAC[127]: The European Road Transport Research Advisory Council was set up in 2003 and develops a common vision to develop a common vision for road transport research in Europe gathering the road transport stakeholders.
- Waterborne[128] started in 2005 as an industry-led initiative. It includes "deep and short sea

[122] https://ec.europa.eu/jrc/en/research-topic/sustainable-transport-and-fuels
[123] http://www.acare4europe.com/
[124] www.saritsu.eu
[125] http://www.etp-logistics.eu/
[126] http://www.errac.org/
[127] http://www.ertrac.org/
[128] http://www.waterborne-tp.org/index.php/

shipping, inland waterways, yards, equipment manufacturers, marine leisure industry", etc.

Another related platforms is EPoSS[129] that deals with Smart Systems Integration and Integrated Micro- and Nanosystems.

Research by companies in the EU is also supported through the EUREKA Eurostars[130] initiative established under Article 185 of the Treaty on the Functioning of the European Union (TFEU), in partnership between the European Commission, the Member States and the countries associated with the Framework Programmes. Eurostars supports European R&D performing SMEs to commercialise their research. It helps them to accelerate the time to market of products, processes and services to the market. It also encourages them to develop and internationalise their business. Funding of up to EUR 100 million was made available through EUREKA for the period 2008-2013, the EU contribution comprising a maximum of one third of the funding provided by the participating countries. Funding for Eurostars has continued with a total public budget of EUR 1.14 billion in 2014-2020, EUR 861 million of national funding and EUR 287 million of EU funding from Horizon 2020. In the 39 success stories identified for Eurostars, three relate to nanotechnology and one is linked to transport applications but it is not clear that there are any that combine both at this time.

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[131]. Examples in transport include:

- Clean Sky (CS)[132]: established in 2008 with a budget of EUR 1.6 million, it aims to increase aircraft fuel efficiency and reduce NOx and noise emissions. It has six Integrated Technology Demonstrators: SMART Fixed Wing Aircraft , Green Regional Aircraft, Green Rotorcraft , Sustainable and Green Engines, Systems for Green Operations and Eco-Design. The initiative has been extended for 2014-2020 through Clean Sky 2 (CS2) and received EUR 4 million (EUR 1.8 from the EU and EUR 2.2 million from industry).
- Shift2Rail[133] is a JTI that aims to "integrate new and advanced technologies into innovative rail product solutions" and more specifically to the life-cycle cost of railway transport, increasing railway capacity and reliability. Started in 2009 but established in 2014, it will receive an EU contribution of EUR 450 million for the period 2014-2020.
- The JTI FHC[134] Fuel Cells and Hydrogen Initiative Joint Undertaking (JU) was established in 2008 (launched under FP6) with the aim of establishing the necessary conditions for fuel cells and hydrogen technology to be introduced in the market. This goal included creating a critical mass of research resources that would persuade industries, investors and public authorities to embark on a long-term programme. As the enormous challenges posed by the transition from an oil- to a hydrogen-based economy have not yet been overcome, despite significant investment of resources, the timescale for FHC was extended from its original end-date of 2013. Activities are continuing under the latest Framework Programme, Horizon 2020 (H2020), with this phase (2014-2020) having a total budget of EUR 1.33 billion provided on a matched basis between the EU (represented by the European Commission), industry, and research.
- The Bio-Based Industries[135] (BBI) Joint Undertaking is a EUR 3.7 billion public-private partnership, between the EU and the Bio-based Industries Consortium, which became fully operational in October 2015. The funding is EUR 975 million of EU funds (H2020) and EUR 2.7 billion of private investments. BBI aims to create a strong European bio-based industrial sector, thereby significantly reducing the EU's dependency on fossil-fuels, helping the EU meet climate change targets, and leading to greener and more environmentally-friendly growth. Its focus is

[129] http://www.smart-systems-integration.org/public
[130] https://www.eurostars-eureka.eu/
[131] http://era.gv.at/directory/142
[132] http://www.cleansky.eu/
[133] http://www.shift2rail.org/
[134] http://www.fch.europa.eu/
[135] http://www.bbi-europe.eu

on developing biorefining technologies, growing associated markets and jobs (particularly in rural and under-developed areas). Benefits envisaged by BBI include the productive use of waste, agricultural and forestry residues; diversification and increase of the income of farmers; replacement of at least 30% of oil-based chemicals and materials with bio-based and biodegradable ones by 2030; and reduction of CO_2 emissions by at least 50% compared to fossil alternatives.

In addition to institutionalised PPPs (like FHC), there are contractual PPPs (cPPPs). One in particular is linked to the transport sector, namely the European Green Vehicles Initiative (EGVI)[136], the continuation under FP7 of the European Green Cars Initiative (2009-2013). The partnership, focusing on energy efficiency of vehicles and alternative powertrains, has the main goal of accelerating research, development and demonstration of technologies for the efficient use of clean energies in road transport. Its multi-annual roadmap is co-ordinated with the roadmaps from the three ETPs involved (ERTRAC, EPoSS and SmartGrids). The estimated budget is EUR 1.5 billion (EUR 750 million from the H2020 and the same from industrial partners)[137]. EGVI includes in its portfolio of reports the project LISSEN[138] (lithium sulphur superbattery exploiting nanotechnology) from an FP NMP call on materials: innovative automotive electrochemical storage applications based on nanotechnology.

3.3.3 Other EU policies and programmes: Energy efficiency and environment

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

In 2010, the European 2020 Energy Strategy[139] defined European energy goals to 2020. The Strategy stated the aim to achieve an 80% to 95% reduction in greenhouse gases compared to 1990 levels by 2050 and to:

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

With specific reference to emissions from civil aviation, around 3% of total greenhouse gas emissions in the EU come from that form of transport. Bio-fuels are seen as having a potential role here as they have a lower carbon footprint than conventional fuels. As a consequence, the European Commission launched the European Advanced Biofuels Flightpath[140] in 2011, in collaboration with Airbus, some European Airlines and bio-fuel producers. The EU, together with the European Committee for Standardisation (CEN), is also working towards improving the technical quality standards of biofuels and biofuel blends for vehicle engines[141].

Fuel quality in general was first addressed in 1998 and then in 2009 with the EU Fuel Quality Directive[142] on petrol and diesel specifications, which also envisaged the reduction of the greenhouse gas emissions for road transport.

Among the policies to make transport more efficient and mitigate its environmental impacts, are[143]:

- The inclusion of aviation in the EU Emissions Trading System (ETS);
- Strategies to reduce emissions from cars and vans, including emissions targets for new vehicles; and to reduce heavy duty vehicle fuel consumption and CO_2 emissions;
- A target to reduce the greenhouse gas intensity of fuels;
- Rolling resistance limits, tyre labelling requirements and mandatory tyre pressure monitors on new vehicles;
- Legislation to encourage national authorities to deploy gas and electricity infrastructure; and,

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[136] www.egvi.eu
[137] http://ec.europa.eu/research/press/2013/pdf/ppp/egvi_factsheet.pdf
[138] www.lissen.eu
[139] https://ec.europa.eu/energy/en/topics/energy-strategy/2020-energy-strategy
[140] https://ec.europa.eu/energy/node/76
[141] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels
[142] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0030
[143] http://ec.europa.eu/clima/policies/transport/index_en.htm

- Requirements on public authorities to take account of life time energy use and CO_2 emissions when procuring vehicles.

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

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

The European Institute of Innovation and Technology (EIT)[144] aims to enhance Europe's ability to innovate, adapting quickly to the fast pace of development, being one step ahead in providing solutions to rapidly emerging societal problems and developing products that meet the demands and desires of consumers.

Related to transport needs, KIC InnoEnergy was one of the first Knowledge and Innovation Communities (KICs) supported by the EIT. Among its specific fields of activity are actions on fuels including biofuels (production, transportation, storage and utilisation); energy efficiency (including transport, which had the highest consumption percentage in the EU in 2012 at 32%); energy storage (including electric vehicles and smart batteries and, more specifically, lithium ion batteries and supercapacitors) and smart and efficient buildings and cities.

Climate KIC is also one of the Knowledge and Innovation Communities involved in the environmental impact of transport. For instance, green mobility and green transport are topics they deal with in their working area "Urban Transitions".

3.3.5 Other EU policies and programmes: Structural and Investment Funds

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

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

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

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

The first two ESI Funds above are the ones most relevant to transport and nanotechnology, albeit that the topic is likely to capture only a small part of their budget, particularly in comparison with the funding under the Framework Programmes and the NMP theme in particular. The last two will also have potential relevance in the use of nanotechnology in fuels and coatings (e.g. anti-fouling for ships).

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

3.3.6 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)[145] 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 transport.

[145] 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 TRANSPORT

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.

Specific initiatives at Member State level, past[146] or present, that relate, either specifically or in general, to nanotechnology and transport include:

Austria: The Austrian NanoInitiative[147] (2004-2011, total funding EUR 70 million, administered by the Austrian Research Promotion Agency (FFG)). The initiative works on a collaborative basis across Austria and transnationally with consortia of research institutes, universities and firms working on problem-driven basic research questions with a medium-term perspective (5-7 years). The focus of the programme, matching the remit of its funding agency FFG, was to invest in projects with considerable market potential, relevant to Austrian companies. The type of activities begun under the programme are now continuing under the thematic areas FFG's research funding programmes. Since 2012, nanotechnology has been supported, largely under open calls, via FFG's thematic research funding e.g. Production of the Future.

Also in Austria, at regional level, Styria's Economic Strategy 2020 (Wirtschaftsstrategie Steiermark 2020 (2011)[148] 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 including transport[149]. The 2011 strategy bundles activities in these fields under three major leading themes: i) mobility, ii) eco-technology, and iii) health technology.

Belgium: In 1984, the Government of Flanders granted EUR 62 million (as initial investment) to create the first associated lab of IMEC[150] in Leuven. IMEC is a research institute that provides laboratories, facilities and technical support rooms. For the period 2002-2006, the contribution of the Government of Flanders was EUR 34 million (24% of IMEC's total revenue, with over EUR 100 million coming from contract research). In 2007, the Government of Flanders granted additional funding of around EUR 48 million. IMEC is relevant to transport as it focuses on R&D in microelectronics, nanotechnology, design methods and technologies for ICT systems, including activity in wireless communication and expertise in radar systems.

France: The French Agence National de la Recherche (ANR) channels public funding into priority areas including Nanotechnologies & Manufacturing. The P2N programme[151] has aimed, since 2006, 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 extraordinary potential of the nanotechnologies. P2N also addresses nanotechnologies for sustainable development. Complementary to P2N, the Sustainable Electricity Production and Management (PROGELEC) programme aims to accelerate French research for the development of

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

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

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

[149] 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.

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

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

renewable energies, which have relevance to transport and other areas, and the integration of innovative systems for optimised electricity management. The objectives are to reinforce the partnerships between the industrial and scientific communities, and to improve the competitiveness of French technologies by fostering technological breakthroughs.

Germany: In 1999 - the German Federal Ministry of Education and Research (BMBF) launched the Framework Concept for the Production of Tomorrow. In 2004, the German Innovation Initiative for Nanotechnology - "Nanotechnology Conquers Markets[152]" was launched, funding five leading-edge innovation programmes, one being NanoMobil which was put in place due to the importance of the automotive industry in Germany. The objective of this programme was to trigger research and development projects in nanotechnology for applications in traffic technology, in particular in the automobile industry and its suppliers, taking into account especially the areas of safety, ecology/sustainability and comfort.

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 traffic and mobility, (as well as environment, nano-electronics, information and communication and healthcare systems and biotechnology,).

In 2011, the German Ministry for Education and Research (BMBF) published the Action Plan Nanotechnology 2015[153], 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 (mobility, climate/energy, health/food and agriculture, communication and security). In the field of Mobility of this Plan there was a specific mention of the important contributions of nanotechnology to safety, sustainability and comfort in the automobile sector. It was also mentioned that electric mobility was the central field of application of nanotechnology in the mobility sector (naming as important the "National Electromobility Development Plan", the National Platform for Electric Mobility and the "Joint Agency for Electric Mobility" (GGEMO) as investment platforms). The uses for nanotechnology mentioned in this strategy include "nanotechnology for cost-effective and resource-saving mobility", "nanotechnology for electric mobility" and "nanomaterials for intelligent streets".

Slovakia: The Ministry of Education, Science, Research and Sports (MESRS)[154] published the Action Plan for the Innovation strategy for smart specialisation (RIS3) 2014-2020[155]. The Action Plan focused on measures to encourage R&D expenditure of companies and applied research. The Action Plan also identified seven priority areas that include automotive & mechanical engineering industries and material research and nanotechnologies.[156]

Spain: In Spain, in the Sixth National Scientific Research, Development and Technological Innovation Plan (2008-2011), the Strategic Action for Nanoscience and Nanotechnology, New Materials and New Industrial Processes (SANSNT) addressed seven priorities, industry and environment and high performance materials and coatings between them, including those relevant to transport.

Within the Spanish State Plan for Scientific and Technical Research and Innovation 2013-2016, funding support instruments was made available for Key Enabling Technologies development and dissemination, including nanotechnology, (e.g. R+I+i projects, innovation and technology modernisation projects).

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

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[152] http://d-nb.info/97392179x/34
[153] http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf
[154] https://www.minedu.sk/about-the-ministry/
[155] http://s3platform.jrc.ec.europa.eu/regions/SK
[156] http://s3platform.jrc.ec.europa.eu/documents/10157/511834/PPT_Slovakia_Dublin%20FINAL%2026%206%202014.pdf

The UK Enabling Technologies Strategy 2012-2015[157] also addresses four enabling technologies - advanced materials; electronics, sensors and photonics; information and communication technology (ICT); and to support business in developing high-value products and services in areas such as transport, energy, the built environment, food and healthcare. Nanotechnology is identified as having a significant underpinning role across most of these technology areas.

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

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

- From France, the web site of Campus France[158] states:

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

- From Germany, the Trade and Invest Agency[159] website provides the information that: "Approximately half of the nanotechnology companies in Europe are from Germany; the country is number one in Europe in the nanotechnology industry. German companies manufacture products in the areas of nanomaterials, nanotools, nanoanalytics, and nanotools accessories (e.g. vacuum and cleanroom technology, plasma sources, etc.). They also manufacture and utilise nano-optimised components and systems, and they provide services in the areas of consulting, contract coating, technology transfer, and commissioned analysis and research …". Many of these applications of nanotechnology are relevant to transport, a large and important industry in Germany.

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

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

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

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
AT	Austrian NANO Initiative[160] (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[161]	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[162]	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[163]	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[164]	139.8 for P2N over 8 years
FR	Investissements d'avenir	From 2011	Generic	Excellence initiatives including nanobiotechnology and bioinformatics	IND SME PRO	ANR	12 per annum
DE	Nanotechnology Conquers Markets	2004-2006	Directly Targeting NT	Five leading-edge innovation programmes including NanoforLife – pharmaceuticals and medical	All	BMBF	24 over 3 years

[160] https://www.ffg.at/nano-aktuell ; https://www.ffg.at/11-ausschreibung-produktion-der-zukunft
[161] http://innovationsfonden.dk/en/about-ifd
[162] www.tekes.fi
[163] https://www.anses.fr/fr/lexique/nanotechnologies
[164] http://www.agence-nationale-recherche.fr/

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
DE	Nano Initiative – Action Plan	2006-2010	Directly Targeting NT	Cross-departmental initiative led by BMBF: to speed up the use of the results of nanotechnological research for innovations; introduce nanotechnology to more sectors and companies; eliminate obstacles to innovation by means of early consultation in all policy areas; and (4) enable an intensive dialogue with the public.	All	BMBF	640 over 5 years
DE	Innovation Alliances	2007-2012	Directly Targeting NT	For strategic long-term co-operation between multiple industry and public research partners. Funds R&D, other innovation-related activities. Public and private funds are combined in a 1:5 ratio.	All	BMBF	500 over 6 years
IT	Fondo per la Crescita Sostenibile (FCS) (Fund for sustainable growth)	2002-2004	Targeting NT	In September 2014 MISE issued the call for industrial R&D projects of the FCS, covering the fields of ICTs, nanotechnology, advanced manufacturing, advanced materials, biotechnology, technologies associated with the EU Horizon 2020 programme.	Mainly SMEs	MISE	300
LT	High Technology Development Programme	2012-Ongoing		The High Technology Development Programme in 2012 aims to encourage scientists, researchers and students to establish start-up or spin-off companies. 13 new companies obtained public funding. The high-tech areas concerned are: information technology, nanotechnology, mechatronics lasers technology and biotechnology	SMEs	MITA	13 companies obtained public funding for a maximum of around EUR 20,000 each
NL	NanoNed	2004-2011	Directly Targeting NT	NanoNed was organised into eleven independent flagships based on regional R&D strength and industrial relevance, including NanoFabrication and NanoElectronics	IND SME HEI PRO and Individuals	Dutch Ministry for the Economy	235 over 8 years
NL	NanoNextNL	2011-2015	Directly Targeting NT	Consortium-based system (over one hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities). Stakeholders collaborate on fundamental and applied research projects. It includes NanoFabrication.	IND SME HEI PRO and Individuals	Dutch Ministry for the Economy	125 over 5 years
NL	Top sectors	2010 to date	Directly Targeting NT	The Top Sector Policy involves government support in nine key economic areas (the top sectors) through a combination of generic (i.e. financial) instruments and a focused emphasis on achieving optimum cooperation in the „golden triangle" formed by companies, research institutions and government. The policy works through Top Consortia for Knowledge and Innovation (TKIs).	IND SME HEI PRO	Dutch Ministry for the Economy	Objective for public and private sector to participate in the Top Consortia for Knowledge and Innovation (TKIs) for an amount of at least EUR 500 million by 2015, 40% of which from trade and industry.

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
ES	Strategic Action of Nano Science, Nano technologies, new materials and new industrial processes	2008-2011	Directly Targeting NT	To enhance the competitiveness of industry by generating new knowledge and applications based on the convergence of new technologies, where nanotechnology plays a central role.	IND SME HEI PRO	Ministry	33 over 4 years
PT	International Iberian Nanotechnology Laboratory	2005 to date	Directly Targeting NT	International research organisation in the field of nanoscience and nanotechnology, the result of a joint decision of the Governments of Portugal and Spain. Becoming a state-of the art research environment (including nanofabrication facilities) for nano-biotechnology, nano-electronics, nanomedicine and materials science at nanoscale. INL hosts researchers from the EU and non-EU countries including Brazil.	IND SME HEI	Governments of Portugal and Spain	46.5 (of which 30 from ERDF Spain – Portugal" Operational Programme) over 7 years
SK	Action Plan for the Innovation Strategy for Smart Specialisation (RIS3) 2014-2020	2014-2020	Targeting NT, but not only	The Action Plan focused on measures to encourage R&D expenditure of companies and applied research. The Action Plan identified also seven priority areas that include material research and nanotechnologies and information and communication technologies.	Industry	MESRS	Around 42 for nanotechnology Around 10 for ICT
UK	Micro and Nanotechnology Manufacturing Initiative[165]	2003-2007	Directly Targeting NT	Support for collaborative R&D and capital infrastructure, co-financed by industry	Industry	DTI	329 over 4 years, over 100 from public funds
UK	UK Nanotechnologies Strategy	2009-2012	Directly Targeting NT	Targets the ways by which nanotechnologies can address major challenges facing society such as environmental change, ageing and growing populations, and global means of communication and information sharing.	IND SME HEI PRO	TSB, EPSRC, BBSRC and MRC	
UK	Key Enabling Technologies Strategy	2012-2015	NT as Underpinning Technology	Addresses four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having a significant underpinning role across most of these technology areas, particularly in the healthcare and life sciences sectors.	Business mainly	Innovate UK	GBP 20m a year in higher-risk, early-stage innovation across advanced materials; biosciences; electronics, sensors and photonics; and ICT

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

5 POLICIES AND PROGRAMMES IN OTHER COUNTRIES[166]

5.1 Europe

5.1.1 Non-EU Member States

5.1.1.1 Norway

From 2002 to 2011, Norway addressed nanotechnology through its Programme on Nanotechnology and New Materials (NANOMAT)[167], the first thematic investment area being *Energy and the environment*.

In 2012, a follow-on programme to run until 2021 was initiated, the Nanotechnology and Advanced Materials Programme (NANO2021)[168]. Managed by the Research Council of Norway[169], 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[170])[171].

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[172]) but this dropped to USD 2.6 billion (EUR 1.9 billion[173]) by the end of 2010, falling further thereafter. A gradual privatisation of RUSNANO began in 2011. The mission of RUSNANO is to grow the national nanotechnology industry through the commercialisation of nanotechnology and the co-ordination of nanotechnology-related innovation. It acts as a co-investor in nanotechnology projects having substantial economic or social potential.

RUSNANO has a very wide range of activities spanning from research to foresight to infrastructure, education, standards and certification. Its research projects include work on the Manufacturing of New Generation Lithium-Ion Accumulators for Energetics and Electric Transport. In December 2011,

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[166] 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)
[167] http://www.forskningsradet.no/prognett-nano2021/Artikkel/About_the_programme/1253970633592?lang=en
[168] http://www.forskningsradet.no/servlet/Satellite?c=Page&pagename=nano2021%2FHovedsidemal&cid=1253969916237&langvariant=en
[169] http://www.forskningsradet.no
[170] At the current exchange rate, October 2015
[171] Nanotechnology and Advanced Materials – NANO2021: Work Programme
[172] Average yearly conversion rate, 2008-2009 (*source*: www.wolframalpha.com)
[173] Average yearly conversion rate, 2010 (*source*: www.wolframalpha.com)

within the framework of that project, the largest worldwide plant for manufacturing of high capacity lithium-ion accumulators of Liotech-company was started.

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[174]. 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[175]. 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[176], and Nano-Cluster Bodensee[177]. 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 and Quebec.

Alberta

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

Following the announcement in 2007 of the Government of Alberta's Nanotechnology Strategy, nanoAlberta was created as an implementation organisation for that Strategy. NanoAlberta provides leadership to and co-ordination of the Province's wide range of capabilities, organisations and individuals with the aim of gaining a return of CND 20 billion (EUR 13.4 billion[178]) 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 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[179] specifically targets four priority sectors: microsystems, health, industrial materials and forestry. It covers infrastructure, financing of innovation, knowledge

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[174] https://www.kti.admin.ch/kti/en/home/unsere-foerderangebote/Unternehmen/internationale-netzwerke-und-forschungskooperationen-neu/spezialthema-japan-schweiz1/foerderlandschaft-schweiz.html
[175] http://www.swissmntnetwork.ch/content/
[176] http://www.i-net.ch/nano/
[177] http://www.ncb.ch/wordpress_neu/
[178] Current conversion rates, October 2015
[179] http://www.nanoquebec.ca/media/plan-action_en1.pdf

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[180]). QNI has particular strengths in micro-nanofabrication, characterisation, synthesis and modelling. Other infrastructure can be accessed but is not funded via QNI.

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

5.2.1.2 United States of America (US)

The National Nanotechnology Initiative[181] was launched in 2000 across a group of eight Federal agencies with some responsibility for nanotechnology research, application and/or regulatory activity, and has grown to include 25 Federal agencies. It aims to create collaborations and bring together expertise to work on shared goals, priorities, and strategies thereby leveraging the resources of the participating agencies. The goals of the NNI Goals are to advance world-class nanotechnology research and development; foster the transfer of new technologies into products for commercial and public benefit; develop and sustain educational resources, a skilled workforce and the supporting infrastructure and tools to advance nanotechnology; and support the responsible development of nanotechnology.

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

The NSET Subcommittee is composed of representatives from agencies participating in the NNI and NSET has Working Groups on Global Issues in Nanotechnology; Nanotechnology Environmental & Health Implications; Nano-manufacturing, Industry Liaison, & Innovation; and Nanotechnology Public Engagement and Communications, the most relevant for transport being manufacturing.

In February 2014, the National Nanotechnology Initiative released a Strategic Plan[182] 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 2014 NNI Strategic plan mentions the different priorities and interests of Federal agencies, that are relevant to transport, for example:

- The Department of Energy (DOE) views nanoscience and nanotechnology as having a vital role to play in solving the energy and climate-change challenges, particularly for energy storage, alternative fuels, energy efficiency and solar energy collection and conversion.
- The National Reconnaissance Office (NRO) has an R&D programme that focuses on nanoelectronics, nanomaterials, and energy generation and storage using nanotechnologies.

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[180] Current conversion rates, October 2015.
[181] http://www.nano.gov/
[182] http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf

- NASA focuses R&D activities also on energy generation, storage, and distribution.

The NNI's budget supplement proposed by the Obama administration for Fiscal Year 2015 provided for USD 1.5 billion (EUR 1.2 billion[183]) of funding. Cumulative NNI investment since fiscal year 2001, including the 2015 request, totals almost USD 21 billion (EUR 17 billion[184]). Cumulative investments in nanotechnology-related environmental, health, and safety research since 2005 is nearly USD 900 million (EUR 680 million[185]). The Federal agencies with the largest investments are the National Institutes of Health (NIH), the National Science Foundation (NSF), the Department of Energy, the Department of Defence, and the National Institute of Standards and Technology (NIST).

Some of the above-mentioned institutions (like NIST, with its main focus on measurement sciences and standards development) have areas dedicated to nanotechnology as well as to the transport-relevant area of energy (having a specific portal dedicated to each of them)[186] [187]. NIST provides facilities to support production, through the Centre for Nanoscale Science and Technology (CNST)[188], established in 2007. The CNST facilitates the access to commercial state-of-the-art nanoscale measurement and fabrication tools. In addition, NanoLab enables researchers to collaborate on developing instruments designed to reveal the nanoscale physical and chemical processes and properties critical to advances in energy conversion, transport and storage[189]. One focus area covers the theory and modelling of materials for renewable energy; nanostructures for energy conversion; opto-electrical characterisation of nanostructured photovoltaic materials and devices; nanoscale functional and structural characterisation of thin-film inorganic solar cells; and nanostructured thermo-electrics, all of which are potentially relevant to transport applications.

The US Department of Energy (DoE) has established five Nanoscale Science Research Centres that provide facilities and instruments to the international academic, industry and government research community for successfully peer-reviewed research projects[190]. The centres are: Centre for Functional Nanomaterials (CFN), Centre for Integrated Nanotechnologies (CINT), Centre for Nanophase Materials Sciences (CNMS), Molecular Foundry (TMF) and Centre for Nanoscale Materials. The last one is a joint partnership between the DOE and the State of Illinois, is one of offices of the DoE[191] with the main goal of conducting basic research and instrumentation development in nanotechnology[192]. The DOE programmes *EV Everywhere* (for electric vehicles) and *SunShot* (for photovoltaics) are using engineered nanomaterials and nanoscale processes

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[193]) (FY 2015), funds approximately 24% of all federally-supported basic research (except for medical sciences) conducted by America's colleges and universities[194]. Current topics (many of which would address nanotechnology and transport) include: biomass conversion, biofuels & bioenergy; photovoltaic (PV) solar energy (particularly oriented to nanotechnology); advanced batteries for transportation and renewable energy storage[195].

The US Department of Defence contributes to nanotechnology research through its Defence Nanotechnology Research and Development programme[196]. This document is partially connected to transport-related matters, for instance energy storage for navy devices and systems and thermal energy conversion.

In additional to these Federal initiatives, there exist several policy initiatives at State level[197]. Programmes for the promotion of nanotechnologies currently exist in 23 states. Notable examples

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[183] Average yearly conversion rate, 2015 (*source*: www.wolframalpha.com)
[184] Average yearly conversion rate, 2001-2015 (*source*: www.wolframalpha.com)
[185] Average yearly conversion rate, 2005-2015 (*source*: www.wolframalpha.com)
[186] http://www.nist.gov/nanotechnology-portal.cfm
[187] http://www.nist.gov/energy-portal.cfm
[188] http://www.nist.gov/cnst/index.cfm
[189] http://www.nist.gov/cnst/erg/index.cfm
[190] http://science.energy.gov/bes/suf/user-facilities/nanoscale-science-research-centers/
[191] http://www.anl.gov/cnm/about-us
[192] http://www.anl.gov/cnm/group/nanophotonics
[193] Current conversion rate, November 2015 (*source*: www.wolframalpha.com)
[194] http://www.nsf.gov/about/
[195] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501026
[196] http://www.nano.gov/sites/default/files/pub_resource/dod-report_to_congress_final_1mar10.pdf
[197] http://www.nano.gov/initiatives/commercial/state-local

are the Texas Emerging Technology Fund[198], the Oklahoma Nanotechnology Initiative[199], the Illinois Nanotechnology "Collaboratory"[200], and the Oregon Nanoscience and Micro-Technologies Institute (ONAMI)[201]. The State-level organisations typically undertake some or all of the following activities: fostering collaboration on nanotechnology topics and challenges between researchers and research centres; higher education/industry joint projects; education and outreach; access to technology experts and infrastructure; early-stage funding and investment opportunities; technology transfer and commercialisation; and awareness raising in the community.

5.2.2 South America

5.2.2.1 Argentina

A first initiative to foster nanotechnology in Argentina was established in 2003 when the national Science and Technology Secretariat started to organise research networks in the field. In 2004, the Secretariat, looked to address gaps in what being done under the National Agency for Scientific and Technological Promotion (ANPCYT, Agencia Nacional de Promoción Científica y Tecnológica[202]) 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)[203] was initiated in 2005 by the Economy and Production Ministry, with the aim of stimulating training and developing technical infrastructure to promote advances in nanotechnology and the adoption of nanotechnology by industry. It also aimed to encourage the participation of researchers, institutions and companies from Argentina in international networks.

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

In 2011, the Ministry of Science, Technology and Productive Innovation published the Argentina Innovadora 2020 (Innovative Argentina Plan 2020): National Plan of Science, Technology and Innovation. The plan focuses on three general-purpose technologies (nanotechnology, biotechnology and information and communication technology (ICT)) 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[204]) 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

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[198] 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.
[199] http://www.oknano.com /
[200] http://nano.illinois.edu/collaboration/index.html
[201] http://onami.us/
[202] http://www.agencia.mincyt.gob.ar/frontend/agencia/fondo/agencia
[203] http://www.fan.org.ar/en/
[204] Average yearly conversion rate, 2001(*source*: www.wolframalpha.com)

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[205]) 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[206]) to c. USD 30 million (EUR 24 million[207]) 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[208] initiative, enabling scientists throughout Brazil to conduct experiments at 26 "open" laboratories offering the very best equipment for research in nanotechnology. University students and staff can use the facilities free of charge – provided that they submit a good research proposal – while scientists working in industry are able to access specialist equipment and expertise at highly subsidised rates.

In 2013, MCTI launched the Brazilian Nanotechnology Initiative (IBN) with funding estimated to be BRL 440 million (EUR 148 million[209]) 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.

Brazil has a collaboration with the International Iberian Nanotechnology Laboratory (INL)[210] which has already received more than 25 researchers from Brazilian research centres dedicated to research at the nanoscale.

5.3 Asia

5.3.1 Eastern Asia

5.3.1.1 China

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

The National High Technology Research and Development Programme (the 863[211] 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.

[205] Average yearly conversion rate, 2004-2007 (*source*: www.wolframalpha.com)
[206] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[207] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[208] Sistema Nacional de Laboratórios em Nanotecnologias ftp://ftp.mct.gov.br/Biblioteca/39717-SisNANO.pdf
[209] Average yearly conversion rate, 2013-2014(*source*: www.wolframalpha.com)
[210] http://inl.int/about-inl/what-is-inl
[211] 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.

The 863 Program 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[212]. The 973 Programme complements the 863 programme, funding basic research on nanomaterials and nanostructures (i.e. carbon nanotubes). The National Steering Committee for Nanoscience and Nanotechnology (NSCNN) was established in 2000 to coordinate and streamline all national research activities including overseeing the 863 and 973 programmes. The NSCNN consists of the Ministry of Science and Technology (MOST), the Chinese Academy of Sciences (CAS), the National Natural Science Foundation (NSFC), the National Development and Reform Commission (NDRC), the Ministry of Education (MOE) and the Chinese Academy of Engineering (CAE).

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

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

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

5.3.1.2 Japan

Strategic prioritisation of nanotechnology started in Japan under the Second Science and Technology Basic Plan (STBP) 2001-2005. Among the eight priority R&D topics of national importance were nanotechnology, as well as manufacturing technology and materials, energy, ICT, environmental sciences and life sciences, and the cross-cutting areas of infrastructure and frontier research. Nanotechnology was seen as being relevant to a broad range of fields and it was expected to help Japan to maintain its technological edge. Total governmental funding of this field grew in these years from JPY 85 billion (EUR 782 million)[213] in 2001 to JPY 97 billion (EUR 709 million[214]) in 2005.

In the subsequent STBP[215], 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,

[212] http://www.chinaembassy.bg/eng/dtxw/t202503.htm
[213] Average yearly conversion rate, 2001 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)
[214] Average yearly conversion rate, 2005 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)
[215] https://www.jsps.go.jp/english/e-quart/17/jsps17.pdf

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)[216]. There were five sub-areas under nanotechnology and materials – nano-electronics; fundamentals for nanotechnology and materials; materials; nanotechnology and materials science; and nano-biotechnology and biomedical materials.

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

The same priorities were incorporated in 2011 into the Fourth Science and Technology Basic Plan (2011-2015) with a budget of EUR 250 billion (JPY 25 trillion). As with the New Growth Strategy, and in contrast to the previous Basic Plan for Science and Technology, the Fourth Basic Plan shifted away from emphasising technologies towards "demand driven and solution-oriented topics" as well as to "problem solving and issue-driven policies" and the "deepening the relationship between society and science and technology." Two broad based areas are prioritised: Life Innovation and Green Innovation and an emphasis has been placed on technologies to reduce global warming, provision and storage of energy supply, renewable energies, and diffusion of such technologies. As there is no specific emphasis on individual technologies, nanotechnology is incorporated across research and development without being specifically targeted. In the still limited information existing about the Fifth Science and Technology Basic Plan (2016-2020) nanotechnology is mentioned as a technology to be consolidated[217].

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)[218] of the Korean National Nanotechnology Initiative (KNNI). Nanotechnology was also identified as one of six priority fields in the National Science and Technology Basic Plan (2002–2006). The NT Development Plan was approved by the NSTC on in July 2001 and the NT Development Promotion Act passed in November 2002 by the National Assembly. The initiative is now in its 3rd phase (2011-2020), with focus on 'clean nanotech'. Investment in phase 1 (2001-2005) was 105.2 billion Won (EUR 83 million[219]); phase 2, 277.2 billion Won (EUR 1,541.8 million[220]).

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[221] (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)[222]. In total, 24 nanotechnology-related centres now exist in Korea.

Under the Nanotechnology Development Promotion Act 2002, Korea also established in 2004 the Korean Nano Technology Research Society (KoNTRS)[223] as a mechanism for co-operation between

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[216] Average yearly conversion rate, 2006 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)
[217] http://www.jeupiste.eu/news/5th-science-and-technology-basic-plan-adopted
[218] http://www.nstc.go.kr/eng/
[219] Average yearly conversion rate, 2001-2005 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[220] Average yearly conversion rate, 2006-2010 (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[221] http://www.kanc.re.kr/kancEnglish/center/center_overview.jsp
[222] https://www.ibs.re.kr/eng/sub02_04_03.do
[223] http://kontrs.or.kr/english/index.asp

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.[224]

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

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

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

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

2012 saw the creation of the Nano-Convergence Foundation (NCF)[226] 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[227]) 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[228]) each.

5.3.1.4 Taiwan (Chinese Taipei)[229]

The National Nanoscience and Nanotechnology Programme[230] 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[231]) and actual expenditure estimated to be USD 625 million (EUR 486 million[232]) 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-

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

biotechnology. Industrial applications are the remit of the Industrial Technology Research Institute (ITRI). ITRI has 13 research laboratories and centres in areas of key relevance to transport including optoelectronics, electronics, mechanical and systems, applied materials, and mechanics, as well as in biomedicine and chemistry. The Mechanical and Systems Research Laboratories [233] and the Green Energy and Environment Research Laboratories, are highly relevant for the transport sector.[234] For instance, in the former they have developed eco-friendly logistics electric vehicles, and in the latter, innovative automotive fuels.

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 many transport-relevant areas and covers nano-instrumentation, nano-optoelectronics, nano-electrics, energy and environmental nanotechnology, nano-materials and nano-biotechnology and applied nanotechnology in traditional industries.

5.3.2 Southern Asia

5.3.2.1 India[235]

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[236]) in nanomaterials research and commercial development over the five-year duration of the initiative, 2002-2006. The funding was used for projects, centres of excellence, conferences, advanced courses (schools) and post-doctoral fellowships. Within its basic and application-oriented research programmes, it supported work on nanomaterials.

A capacity-building programme for nanoscience and nanotechnology (called Nano Mission)[237] was announced in 2007. It was implemented by DST with a budget of EUR 155 million over 5 years. In that time, India raised its publication output in nano-science and –technology generating about 5000 research papers and about 900 PhDs directly from Nano Mission funding. Under the programme, scientists were given access global state-of-the-art facilities in countries including Japan and Germany. The programme is also seen as having resulted in products including nano hydrogel-based eye drops, pesticide removal technology for drinking water, water filters for arsenic and fluoride removal and nano silver based antimicrobial textile coatings. Finally, it facilitated discussions on

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[233] https://www.itri.org.tw/eng/Content/Messagess/contents.aspx?SiteID=1&MmmID=617751556732477253
[234] https://www.itri.org.tw/eng/Content/Messagess/contents.aspx?SiteID=1&MmmID=617763640501161230
[235] 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
[236] Average yearly conversion rate, 2002-2006 (*source*: www.wolframalpha.com)
[237] http://nanomission.gov.in/;

standards for nanotechnology at national level.

The continuation of the Nano Mission was approved by the Government in February of 2014 and EUR 91 million (INR 650 crore) were sanctioned for the time period 2012 to 2017[238]. 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)[239] has a network of 38 laboratories and other partners involving about 4600 scientists in research and development across a wide range of disciplines, including nanotechnology, and for application areas including aerospace and energy.
- In 2003, the CSIR launched the New Millennium Indian Technology Leadership Initiative (NMITLI) to foster public-private partnerships via grant-in-aid funding to public partners and soft loans to their industrial partners. The initiative specifically targeted nanosciences and nanotechnologies; biotechnology; energy and materials.[240]
- 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[241].
- The MST's Science and Engineering Research Council (SERC)[242] supports frontier and interdisciplinary research. Support for nanotechnology projects has been provided through its R&D schemes for basic science and engineering science.

5.3.2.2 Iran[243]

The Islamic Republic of Iran ranked 23rd in the world in nanotechnology in 2007, second to Korea in citations in Asia[244], but, by 2012, it had moved to 10th place[245, 246]. In 2013, Iran ranked 20th in science production in the world (Thomson Reuters) and 18th in science production for medicine. According to the Ministry, its share of global science production rose from 1.39% in 2013 to 1.69% percent in 2014, as measured by indicators including the number of scientific papers, the quality and quantity of documents, patenting inventions, industrial plans, partnership with foreign universities, and the use of technology in domestic organisations.

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

Iran began its nanotechnology activities with a Study Committee for Nanotechnology in 2001. Its work led to the development of the Iran Nanotechnology Initiative Council (INIC)[247], 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[248] (EUR 9 million[249]).

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

[238] http://timesofindia.indiatimes.com/home/science/Govt-approves-Rs-650-crore-for-Nano-mission/articleshow/30722422.cms
[239] www.csir.res.in/
[240] http://www.csir.res.in/external/heads/collaborations/NM.pdf
[241] http://www.teriin.org/div/ST_BriefingPap.pdf
[242] www.dst.gov.in/about_us/ar05-06/serc.htm
[243] See also http://www.sciencedev.net/Docs/Iran_Nano.pdf (2010)
[244] http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file11959.pdf
[245] http://statnano.com/report/s29
[246] http://www.nanotech-now.com/news.cgi?story_id=45237
[247] http://nano.ir/index.php?lang=2
[248] http://www.nanotech-now.com/news.cgi?story_id=36557
[249] Average yearly conversion rate, 2004-2010 (*source*: www.wolframalpha.com)

in Iran[250]. 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[251].

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)[252], a body established in 2006 as a collaboration between the INIC and the Institute of Standard and Industrial Research of Iran (ISIRI)[253].

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[254].

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

5.3.3 South-Eastern Asia

5.3.3.1 Malaysia

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

The Malaysian National Nanotechnology Initiative (NNI) was established in 2006 to advance nanotechnology and related sciences by clustering local resources and knowledge of Malaysian researchers, industry and the government. The NNI paved way for the establishment in 2010 of the National Nanotechnology Directorate under the Ministry of Science, Technology and Innovation (MOSTI). The National Nanotechnology Directorate (NND)[255] 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[256] was created in 2011 as a company under the Ministry of Science, Technology and Innovation (MOSTI). It is responsible for commercialisation of nanotechnology research and development; industrialisation of nanotechnology; facilitation of investments in nanotechnology; and human capital development in nanotechnology. NanoMalaysia identified as key economic clusters as jumpstart sectors of nanotechnology the following: electronics, devices and systems; food and agricultural; energy and environment; and wellness, medical and healthcare.

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

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[250] http://blogs.scientificamerican.com/guest-blog/science-and-sanctions-nanotechnology-in-iran/
[251] http://nano.ir/index.php?ctrl=static_page&lang=2&id=397&section_id=22
[252] http://nanostandard.ir/index.php?lang=2
[253] http://www.isiri.com/
[254] http://statnano.com/strategicplans/1
[255] http://www.mosti.gov.my/en/about-us/divisions-departments/national-nanotechnology-directorate-division-nnd/
[256] http://www.nanomalaysia.com.my/index.php?p=aboutus&c=whoweare

Engineering (INEE)[257] (with research groups on memory devices, photonics and novel silico devices) and the Institute of Micro Engineering and Nano-electronics (IMEN), at UKM[258], specialised in MEMS/NEMS and nano-electronics and micro- and nano-electronics system.

In 2014, the Malaysian government launched the National Graphene Action Plan (NGAP) 2020[259], which outlined five potential industries that could best benefit from graphene — rubber additives (relevant to tyres for vehicles), lithium-ion batteries anode/ultra-capacitors, conductive inks, nanofluids and plastic additives. These application areas were seen as enablers for the domestic production of Electric Vehicles and Hybrids by 2020 and as potential areas where high value technologies could be created for the automotive sector such as lubricants and rubber products.

5.3.3.2 The Philippines[260]

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.

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[261] was developed. Thirteen technology scanning panels were established, including one on 'Exploiting Nanotechnologies'. There were also panels on materials and infrastructure, manufacturing, intelligent systems, semiconductors, energy, environmental technologies, broadband, information storage, the grid, information management, engineering science in medicine, and frontiers in chemicals, the first six of these being the most relevant to transport.

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[262], and the Roadmap (ITR5) of the Infocomm Development Authority[263]. It links nanotechnology research and development to industrial development and supports collaboration between industry, research institutes and universities. The aim is for an enhancement of applied research in nanotechnology to enable industrial clusters including ICT, electronics, precision machinery, transportation machinery, engineering, chemicals, food, and environmental. The Plan also indicates nanotechnology is fundamental and horizontal to these clusters.

The main funding agency for nanoscience and nanotechnology (NST) in Singapore is the Agency for Science, Technology & Research (A*STAR)[264]. A*STAR's Nanotechnology Initiative started in 2001 with the target of building on existing capabilities to develop specific areas of NST research always with applications and potential use by industry as a goal. In 2003, A*Star established the Institute of Bioengineering and Nanotechnology (IBN) which research activities are focused on green chemistry and energy, as well as nanomedicine, synthetic biosystems, biodevices & diagnostics[265].

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, nano-composite physical vapour deposition (PVD) coatings and others. Characterisation is also a relevant part of the

257 http://inee.unimap.edu.my/
258 www.ukm.my/
259 http://www.nanomalaysia.com.my/img/ngap/NGAP_2020_Booklet.pdf
260 http://www.techmonitor.net/tm/images/d/d1/10jan_feb_sf3.pdf
261 https://www.mti.gov.sg/ResearchRoom/Pages/Science-and-Technology-Plan-2010.aspx
262 www.edb.gov.sg
263 www.ida.gov.sg
264 www.a-star.edu.sg/
265 http://www.ibn.a-star.edu.sg/about_ibn_6.php?expandable=0

initiative.[266]

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

5.3.3.4 Thailand

Thailand has been active in nanotechnology since at least 2003 when it established NANOTEC[267] 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 nano-composites; nanoscale simulation; and functional nanomaterials and interfaces.

In 2012, the National Nanotechnology Policy Framework (2012-2021)[268] and the Nanosafety and Ethics Strategic Plan (2012-2016)[269] were approved by government for implementation by the Ministry of Science and Technology, and relevant agencies. The Framework has three primary goals:

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

The overall strategic direction of the Framework encompasses four target clusters, including manufacturing industry and Energy & Environment, and defines eight targeted industries including Automotive. 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)[270] in 2002 as a shared action of the Forum for National Infrastructures for Research & Development (TELEM)[271] and the ministry for the economy (now called the Ministry for Industry, Trade and Labour)[272]. 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

[266] 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
[267] http://www.nanotec.or.th/th/wp-content/uploads/2013/05/NANOTEC-brochure11.pdf
[268] http://www.nanotec.or.th/en/wp-content/uploads/2012/02/The-National-Nanotechnology-Policy-framework-exe-sum.pdf
[269] http://www.nanotec.or.th/en/
[270] http://www.nanoisrael.org/
[271] http://www.trdf.co.il/eng/fundinfo.php?id=2846
[272] http://www.economy.gov.il/English/Pages/default.aspx

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[273] 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[274]) per annum for basic NST equipment plus another almost USD 10 million (EUR 8 million[275]) per annum for new infrastructure and facilities.[276] 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[277] 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[278]) 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[279, 280], in 2005 (before the official launch of the programme), the other five research universities receiving support in 2006. The main research areas of INNI are nanomaterials (including nanostructures, solid nanomaterials and nanochemistry), nanoelectronics (including electronics and photonics), nanobiotechnology (including biology, biotech engineering, applied biosciences and medicines), and "nanowater" (including nanomembranes, nano-filtration and other nanotechnologies used in water remediation).

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[281]. 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[282]

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

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[273] 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.
[274] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[275] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[276] Figures for funding under the programme to 2012.
[277] http://www.nanoisrael.org/category.aspx?id=1278
[278] Average yearly conversion rate, 2006 (*source*: www.wolframalpha.com)
[279] 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.
[280] Israel Institute of Technology http://www.technion.ac.il/en/
[281] http://www.nanoisrael.org/category.aspx?id=13671
[282] A review of nanotechnology development in the Arab World, Bassam Alfeeli et al., Nanotechnology Review, 2013 (05/2013; 2(3):359-377)

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[283]; and the CNT established in 2006 at the KAU[284]. 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)[285] established in 2010 at the KSU in the Riyadh Techno Valley. The KAIN covers areas including energy, telecommunications, manufacturing and nanomaterials, medicine and pharmaceuticals, food and environment, and water treatment and desalination. Companies such as the energy company Saudi National Oil Company (established as an Arabian American Oil Company, known now as Saudi ARAMCO), and the Saudi Basic Industries Corporation (SABIC) are collaborating on nanotechnology research with the nanotechnology centres. There are more than 20 projects in the field of nanotechnology for these two organisations alone.

5.3.4.3 Turkey

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

Projects in nanotechnology are supported by the Scientific and Technological Research Council of Turkey (TUBITAK) and the Ministry of Development (MoD) and, between 2007 and 2014, it is estimated[286] that nanotechnology received State support of about one billion Turkish Lira, or c. USD 500 million (EUR 367 million[287]). Over 20 nanotechnology research centres, departments and graduate schools have been established including NanoTam[288] and Unam[289] at Bilkent University Sabanci University Nanotechnology Research and Application Center (SUNUM)[290] (with a focus on renewable energy systems and energy applications); and the Micro and Nanotechnology Department at the Middle East Technical University[291].

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

[283] King Fahd University of Petroleum and Minerals, Riyadh
[284] King Abdul Aziz University, Jeddah
[285] http://nano.ksu.edu.sa/en
[286] http://www.issi2015.org/files/downloads/all-papers/0720.pdf
[287] Average yearly conversion rate, 2007-2014 (*source*: www.wolframalpha.com)
[288] http://www.nanotam.bilkent.edu.tr/eng/main.html
[289] http://unam.bilkent.edu.tr/?page_id=576
[290] http://sunum.sabanciuniv.edu/
[291] http://mnt.metu.edu.tr/

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[292]), 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[293] 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 areas closest to transport that the Research Strategy identified among the grand challenges was the importance of developing clean energy solutions (with *Nanostructured materials for clean energy* highlighted among the selected areas of research, as well as nanoporous membranes and fuel cells).

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

Australia also operates a network to link research facilities across the country, the Australian Nanotechnology Network[294]. 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[295]. 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[296]) funding for 2003-2006 from the Ministry of Education and, in early 2006, developed a "Nanotechnology Initiative for New Zealand"[297] identifying where capability in nanotechnology could be developed in the country. The Initiative identified six programmes for nanoscience and nanotechnology research: nanomaterials for industry; nanotechnology for energy; nano-photonics, nano-electronics and nano-devices; nano- and micro-fluidics; bio-nanotechnologies; and social impacts of nanotechnology.

Also in 2006, the New Zealand government released a Nanoscience and Nanotechnologies Roadmap (2006-2015)[298]. 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. One that is particularly relevant to transport is dedicated to *Energy and Industrial* (including applications like lubricants and fuel additives, energy storage, super-hard bearings and coatings, catalysts, energy generation and transmission). Three priority areas for public funding were identified: the creation of new materials, diagnostic devices; and tools and techniques. The Ministry of Science and Innovation was put in charge of policy actions to implement the Roadmap.

The Ministry of Science and Innovation *Statement of Intent 2011-14* highlighted two high-level priorities – growing the economy and building a healthier environment and society. In addition to

[292] Average yearly conversion rate, 2010-2013 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-aud.en.html)
[293] https://www.science.org.au/publications/national-nanotechnology-research-strategy
[294] http://www.ausnano.net/index.php?page=home
[295] http://www.macdiarmid.ac.nz/
[296] Average yearly conversion rate, 2003-2006 (*source*: www.wolframalpha.com)
[297] http://www.macdiarmid.ac.nz/a-nanotechnology-initiative-for-new-zealand/
[298] http://statnano.com/strategicplans/13

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[299].

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)[300] 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)[301] by the Department of Science and Technology (DST);
- In 2005, the publication of the National Strategy on Nanotechnology (NSN)[302] by the DST. The strategy focuses on four areas:
  - establishing characterisation centres (national multi-user facilities);
  - creating research and innovation networks (to enhance collaboration: inter-disciplinary, national and internationally);
  - building human capacity (development of skilled personnel); and
  - setting up flagship projects (to demonstrate the benefits of nanotechnology towards enhancing the quality of life, and spurring economic growth).

South Africa launched its first nanotechnology innovation centres in 2007 at the CSIR[303] and MINTEK[304]. 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)[305], 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[306] enables joint projects and mobility[307] between S&T departments in those countries.

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

[299] http://www.mbie.govt.nz/
[300] http://www.sani.org.za/
[301] http://www.esastap.org.za/download/natstrat_advmanu_mar2005.pdf
[302] http://chrtem.nmmu.ac.za/file/35e56e36b6ab3a98fac6fc0c31ee7008/dstnanotech18012006.pdf
[303] http://www.csir.co.za/
[304] http://www.nic.ac.za/
[305] http://ls-ncnsm.csir.co.za/
[306] http://www.ibsa-trilateral.org/
[307] http://www.ibsa-trilateral.org/about-ibsa/areas-of-cooperation/people-to-people

6 PUBLICATIONS IN NANOTECHNOLOGY AND TRANSPORT

6.1 Overview

Around 1.8 million publications were identified[308] from the Web of Science as being related to nanoscience and technology (NST)[309] between 2000 and 2014. Of these, almost 17,000 were related to both nanotechnology and transport, around 1% of all of the output for NST.

The table below shows the publication output (number of publications = npub) between 2000 and 2014. Almost 7,000 publications on nanotechnology/transport were produced in EU28 & EFTA countries which includes here just Switzerland and Norway) around 40% of the total World nanotechnology/transport publications in the time period 2000-2014.

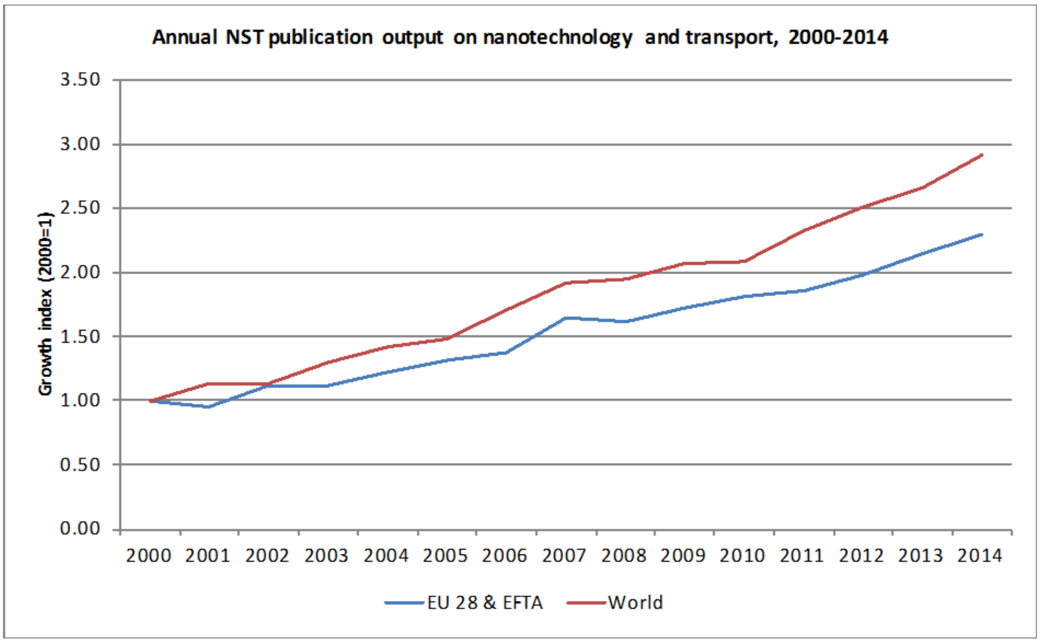
Table 6-1: Annual NST publication output for transport worldwide and in the EU28&EFTA, 2000-2014

Year	World	EU 28 & EFTA	
	npub	npub	%
2000	616	291	47.24%
2001	695	276	39.71%
2002	693	323	46.61%
2003	799	323	40.43%
2004	873	356	40.78%
2005	912	382	41.89%
2006	1,050	401	38.19%
2007	1,180	478	40.51%
2008	1,198	470	39.23%
2009	1,277	501	39.23%
2010	1,284	526	40.97%
2011	1,432	539	37.64%
2012	1,540	574	37.27%
2013	1,638	622	37.97%
2014	1,792	666	37.17%
TOTAL	**16,979**	**6,728**	**39.63%**

Source: Derived from Web of Science

The evolution over time of publications in nanotechnology and transport, as well as the entire NST field (both for (i) EU28/EFTA and (ii) the World), is depicted in the figure below, indexed by year 2000 (=1). There has been a modest growth in nanotechnology transport publications as indexed to the year 2000. For the World, there has been almost a three-fold growth while for the EU28&EFTA, it is somewhat more than a two-fold growth.

[308] http://www.vosviewer.com/Publications
[309] 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 publication output on nanotechnology and transport, worldwide and EU28&EFTA, 2000-2014
(indexed to 2000(=1))

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

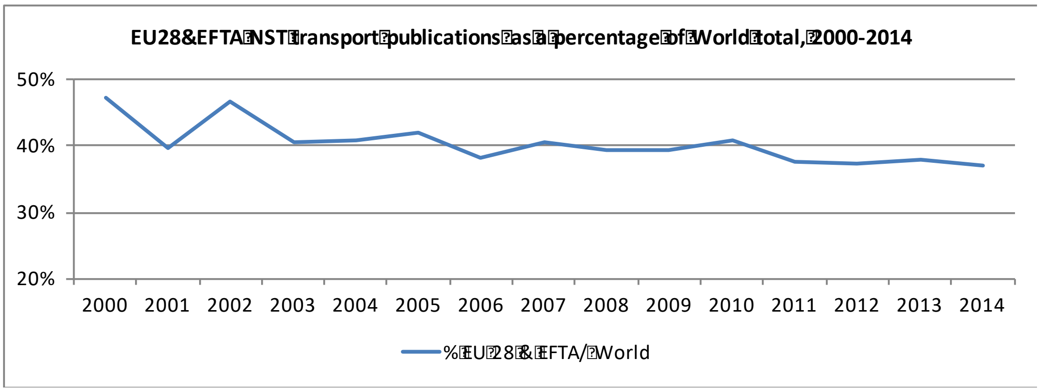


Figure 6-2: EU28&EFTA NST transport publications as a percentage of World total, 2000-2014

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

Rank	Journal	npub
1	Atmospheric Environment	1255
2	Atmospheric Chemistry and Physics	547
3	Journal of Geophysical Research-Atmospheres	537
4	Environmental Science and Technology	393
5	Journal of Power Sources	294
6	Journal of the Air & Waste Management Association	228
7	Science of the Total Environment	211
8	Surface & Coatings Technology	191
9	Journal of Propulsion and Power	179
10	International Journal of Hydrogen Energy	169

6.2 Activity by region and country

The most prolific region[310] for nanotechnology transport publications in 2014 (the most recent year for data collection) was EU28 & EFTA followed by Asia and North America.

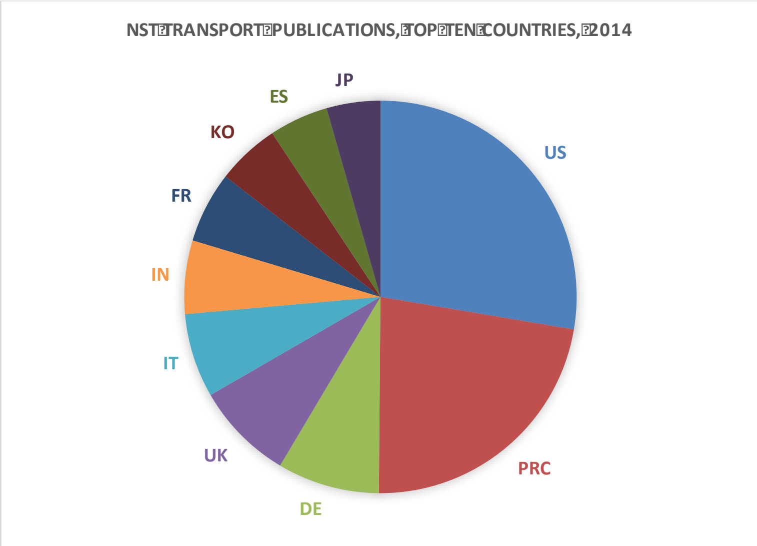
Table 6-3: Most prolific regions for nanotechnology transport publications, 2014

Region	npub
EU28 & EFTA	666
Asia	634
North America	484
Middle East	84
South and Central America	61

Source: Derived from Web of Science

The most prolific country for nanotechnology transport publications globally in 2014 was the USA, followed by the People's Republic of China (PRC), Germany, Great Britain (UK) and Italy (by numbers of publications, npub).

[310] This is based on the data for the top 25 performing countries only.



Source: Derived from Web of Science

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

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

Country	Region	npub
USA	North America	443
PRC (China)	Asia	360
Germany	EU28 & EFTA	135
United Kingdom	EU28 & EFTA	130
Italy	EU28 & EFTA	111
India	Asia	97
France	EU28 & EFTA	94
Korea	Asia	83
Spain	EU28 & EFTA	78
Japan	Asia	71
Canada	North America	60
Brazil	South & Central America	43
Switzerland	EU28 & EFTA	38
Australia	Oceania	35
Finland	EU28 & EFTA	35
Sweden	EU28 & EFTA	34
Netherlands	EU28 & EFTA	29
Poland	EU28 & EFTA	29
Singapore	Asia	28

Source: Derived from Web of Science

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

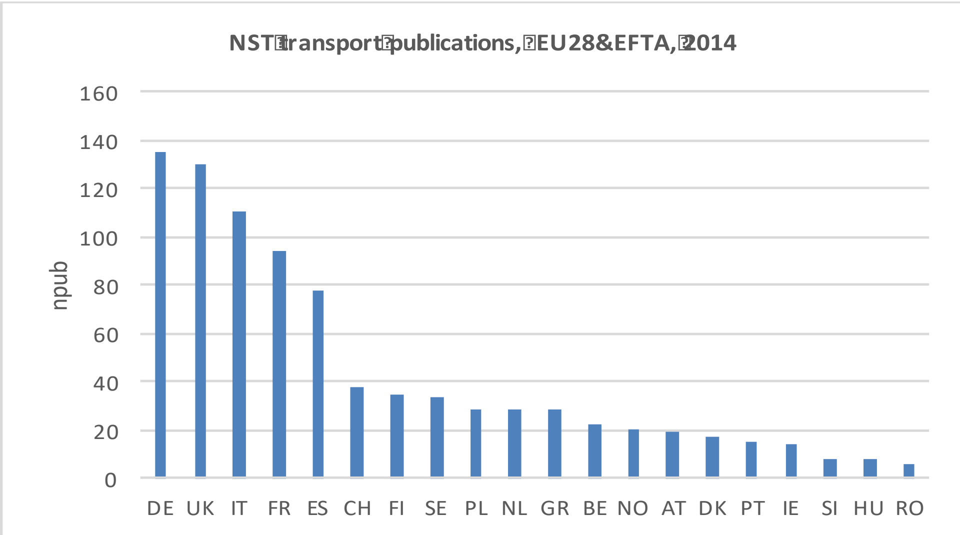


Figure 6-4: Number of NST transport publications for EU28 and EFTA countries, top 20, 2014

Data for the top NST transport publishing countries only. Source: Derived from Web of Science

6.3 Activity by organisation type

Identified from the publication data, the most active organisations in NST transport publications in 2014 are as shown in the table below for the top 25 publishing organisations. The higher education organisations with the most nanotechnology transport publications globally in 2014 were the Chinese Academy of Sciences[311], the University of California and Tsinghua University. To see European higher education institutions, it is necessary to look at the top fifty where only University College London (UCL), the University of Cambridge and the University of Copenhagen are present.

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

Rank	Country	University/ Research Institute	npub
1	PRC	Chinese Academy of Sciences	40
2	USA	University of California	28
3	PRC	Tsinghua University	26
4	USA	University of Colorado, Boulder	25
5	EU28&EFTA	University of Birmingham	20
5	EU28&EFTA	Paul Scherrer Institute	20
7	EU28&EFTA	UMIST	18
7	USA	Carnegie Mellon University	18
7	EU28&EFTA	Finnish Meteorological Institute	18
10	Saudi Arabia	King Abdulaziz University	17
11	USA	Berkeley	16
11	India	Indian Institute of Technology	16
13	EU28&EFTA	University of Helsinki	15

[311] Note that organisations such as the Chinese Academy of Sciences encompass researchers based in a large number of locations (such as universities and research institutes in China).

Rank	Country	University/ Research Institute	npub
13	Canada	University of Toronto	15
13	PRC	Harbin Institute of Technology	15
16	Korea	Korean Institute of Advanced Technology, KAIST	13
17	Singapore	National University of Singapore	12
17	USA	University of Maryland	12
17	USA	MIT	12
20	PRC	Northwestern Polytech University	11

Source: Derived from Web of Science

The top ten European higher education institutions and other research organisations are headed up by the University of Birmingham and the Paul Scherrer Institute as well as two Finnish organisations (The Finnish Meteorology Institute and the University of Helsinki), as shown in the table below of the top ten organisations for NST transport publications. Within the top ten, four are UK institutions.

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

University/Research Institute		Country	npub
1	University of Birmingham	UK	20
2	Paul Scherrer Institute[312]	CH	20
3	UMIST[313]	UK	18
4	Finnish Meteorological Institute	FI	18
5	University of Helsinki	FI	15
6	Aristotle University Thessaloniki	GR	11
7	Helmholtz Association	DE	10
7	University of Surrey	UK	10
7	University of Cambridge	UK	10
7	KTH[314]	SE	10
7	Politecnico di Torino[315]	IT	10

Source: Derived from Web of Science

While publishing at a much less frequent rate, some companies are also active. The most active companies publishing in NST and transport (2014) are shown in the table below, led by the Ford Motor Company and Aerodyne Research Inc.

[312] The Paul Scherrer Institute is a multi-disciplinary research institute which belongs to the Swiss Federal Institutes of Technology Domain covering also ETH Zurich and EPFL, https://www.psi.ch/
[313] University of Manchester Institute of Science and Technology
[314] Kungliga Tekniska Hogskolan
[315] Polytechnical University of Turin, Italy

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

Company	npub
Ford Motor Co.	12
Aerodyne Research Inc.[316]	12
General Motors Corporation	4
Aerosol d.o.o.[317]	4
Robert Bosch GmbH	3
General Motors Global R&D Centre	3
AVL List GmbH[318]	3

Source: Derived from Web of Science

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

[316] http://www.aerodyne.com/
[317] Magee Scientific Corporation is a global business and has two separate office locations: Berkeley, California, USA and Ljubljana, Slovenia, EU. The Ljubljana, Slovenia location operates as an independent EU business, Aerosol d.o.o, an SME. http://www.mageesci.com/locations.html
[318] AVL, or Anstalt für Verbrennungskraftmaschinen List, is an Austrian-based automotive consulting firm as well as an independent research institute www.avl.com

7 PATENTING IN NANOTECHNOLOGY AND TRANSPORT

7.1 Overview

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

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector) and IPC (International Patent Classification) symbols. The IPC symbols used were both those for nanotechnology, i.e. B82, and those related to the sector under consideration (transport, in this case)[319]. 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[320] applications registered at WIPO are protected under the Patent Co-operation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[321] that are members of the treaty.

7.2 Number and evolution over time of nanotechnology transport patent families

Using the above methodology, 45,127 (simple) nanotechnology patent families[322, 323] of granted patents and patent applications were found in the period 1993-2011[324]. All of these were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[325].

In the same period, the number of transport-related patent families identified among the nanotechnology patents is 317, 0.7% of all nanotechnology patent families. As applications may have been filed with multiple authorities, the percentages for PCT, EP and US do not sum to 100%. The highest percentage of applications relating to nanotechnology and transport is in the US (92.1%) and the lowest at the EPO (53.3%), the difference being almost a factor of two.

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

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

[321] 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

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

[323] 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/

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

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

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

Nanotechnology & Transport Applications (1993-2011)	Absolute Number	Percentage
Total patent families	317	100%
PCT applications	184	58%
EP applications	169	53.3%
US applications	292	92.1%

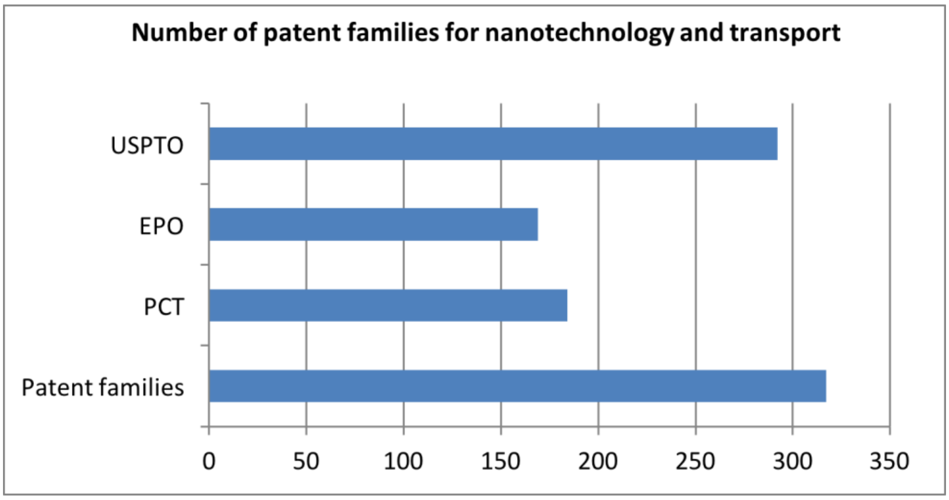


Figure 7-1: Number of patent families by filing authority (PCT, EPO, and USPTO)

As measured by the percentage of patent families, over time, the percentage of nanotechnology and transport patent applications in the EPO has dropped significantly, while PCT filings seem to have experienced an opposite trend[326]. Patent filings at the USPTO have remained significant over the whole period as, with the exception of a few years at the beginning of the period, nearly all the patent families have a filing at this patent authority. The general trend supports the concept that patenting in the US has become relatively more important over time than patenting at EPO or as a PCT.

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 South Korea. The sum of the figures for the European patent offices in this table and the EPO is just 43, considerably less than in the US.

[326] 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.

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

Receiving Authority	No. of Patent Families (1993-2011)
United States	88
Japan	26
European Patent Office (EPO)	21
South Korea	7
Sweden	7
Spain	5
Canada	5
France	5
United Kingdom	5

7.4 Activity by country of applicant

PATENT APPLICATIONS

Within the group of 317 nanotechnology and transport patent families, there is at least one EU28 or EFTA applicant in less than 29,7% of them while there is participation from the rest of the world in over 90% of cases.

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

	EU28 & EFTA	Rest of World
Number of TR nanotechnology patent families	94	296
Percentage of TR nanotechnology patent families	29.7%	93.4%

Applicants 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 countries of applicants, indicating the percentage of patent families for each. EU28 and EFTA countries are marked in bold. Percentages can sum to more than 100%, as patents may be filed with more than one authority (including PCT, US and EP applications).

By far the highest number of patent families is found where the country of the applicant is the US (151), followed by Japan (53). Next to Japan, in the table Germany and France occupy the third and fourth place in the table, with 38 and 21 patent families each.

Although with a much lower number of patent families, there are other European countries in the table. More than 50% of the countries in the table are European & EFTA countries.

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	151	62.3%	100.0%	49%
2	Japan	53	58.5%	92.5%	62.3%
3	**Germany**	**38**	**55.3%**	**73.7%**	**65.8%**
4	**France**	**21**	**52.4%**	**95.2%**	**76.2%**
5	South Korea	19	42.1%	78.9%	26.3%
6	Canada	11	63.6%	100.0%	63.6%
7	**United Kingdom**	**9**	**77.8%**	**88.9%**	**66.7%**
8	**Sweden**	**9**	**100.0%**	**88.9%**	**55.6%**
9	**Switzerland**	**8**	**87.5%**	**100.0%**	**100%**
10	China	8	62.5%	87.5%	25%
11	**Netherlands**	**7**	**100.0%**	**85.7%**	**100%**
12	**Spain**	**7**	**71.4%**	**85.7%**	**71.4%**
13	**Italy**	**5**	**40.0%**	**100.0%**	**80%**
14	India	4	100.0%	50.0%	75.0%
15	**Belgium**	**4**	**50.0%**	**100.0%**	**50.0%**

All the patents by US applicants are filed with the USPTO while roughly 62.3% are filed as PCTs, and slightly less than 50% at the EPO.

It is also the case that some European countries file more patents at the USPTO compared to the other patent authorities, including the EPO. This is the case, for instance, for the two countries with the highest amount of patent families (Germany and France)

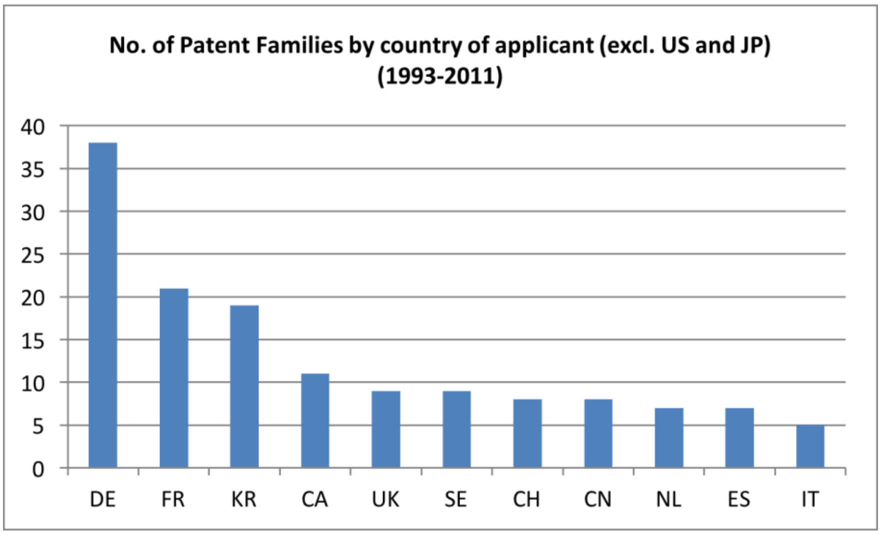


Figure 7-2: Number of patent families by country of applicant (Europe & EFTA)(1993-2011)

GRANTED PATENTS

Within the European & EFTA countries, Germany followed by France (those with the highest number of applications), also account for the highest numbers of patents granted at the USPTO and/or EPO.

Table 7-5: Country of applicant and number of patents granted at EPO and USPTO

	Country of applicant	No. of Patents Granted (1993-2011)	
		EPO	USPTO
1	Germany	9	16
2	France	7	6
3	Netherlands	5	3
4	Switzerland	3	3
5	Belgium	0	2
6	United Kingdom	0	2
7	Italy	3	2
8	Sweden	1	2

Although for some countries an apparent preference to apply for patents at the USPTO rather than the EPO was seen, in terms of the number of granted patents, only Germany has a higher number of patents granted by the USPTO that by the EPO: for all the other countries, the highest number of patents are granted by the EPO.

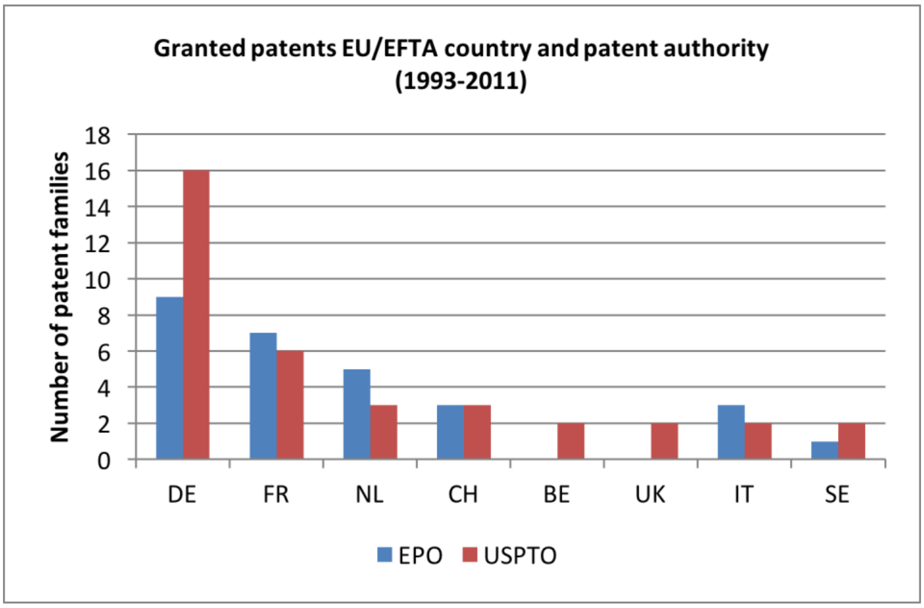


Figure 7-3: Granted patents by country of applicant for EU28/EFTA

The next table shows the percentage of patents granted, revealing that some countries with a lower amount of patent families (compared to Germany and France) have been relatively more successful in getting their patents granted.

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

	Country of applicant	Granted/ Applied
1	IT	80.0%
2	NL	71.4%
3	CH	62.5%
4	DE	55.3%
5	FR	52.4%
6	BE	50.0%
7	UK	22.2%
8	SE	22.2%
9	ES	14.3%

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

Table 7-7: 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	10	0	0	2	0	0	0	0	0	0	0	0	2
CH	1	2	0	2	0	4	2	0	0	0	0	0	2
CN	0	0	0	0	0	0	0	1	0	1	0	0	2
DE	1	2	0	33	0	0	2	0	0	2	0	0	8
ES	0	0	0	0	7	0	0	0	0	1	0	0	0
FR	0	0	0	0	0	21	0	0	0	0	0	0	6
IT	0	2	0	0	0	0	5	0	0	0	0	0	0
JP	0	0	0	0	0	0	1	51	0	0	0	0	5
KR	0	0	0	0	0	0	0	0	19	0	0	0	2
NL	0	0	0	3	0	0	0	0	0	6	0	0	1
SE	0	0	0	0	0	0	0	0	0	1	8	0	1
UK	0	0	0	1	0	0	0	0	0	1	0	0	1
US	2	0	0	9	1	4	0	5	2	2	1	0	138

7.5 Patenting activity by organisation type

7.5.1 Universities and public research organisations

PATENT APPLICATIONS

Among the top ten universities and public research organisations (PROs) with the highest number of patent families (with percentages for PCT, US and EP applications), six are located in the US and four in Europe. The number of patent families is, in general, quite low.

Table 7-8: Number of patent families for top ten universities and PROs (1993-2011)

Rank	Country	Organisation	No. of patent families	PCT	US	EP
1	US	Dartmouth College	13	15.4%	84.6%	15.4%
2	**FR**	**CNRS**	**3**	**66.7%**	**100%**	**100%**
3	**ES**	**CSIC**	**3**	**100%**	**66.7%**	**66.7%**
4	US	University of California	3	66.7%	66.7%	0%
5	**ES**	**Fundacion Instituto Tecnologico de Materiales de Asturias**	**2**	**100%**	**50%**	**0%**
6	KR	Korea Institute of Science and Technology (KAIST)	2	0%	100%	50%
7	**DE**	**Leibniz Institut für neue Materialie**	**2**	**100%**	**0%**	**0%**
8	US	William Marsh Rice University	2	100%	100%	50%
9	US	University of Houston	2	100%	50%	50%
10	US	University of South Florida	2	100%	50%	50%

GRANTED PATENTS

The next two tables show the universities and public research organisations with the highest number of granted patents, the first according to the EPO and the second according to the USPTO. The US, Korea, Japan, France and Germany are present in the table sorted by EPO patents. France (CNRS) is also seen in the table of patents sorted by USPTO numbers.

Table 7-9: Universities / research organisations granted patents, by EPO patent numbers

Rank	Country	Organisation	EP	US
1	US	Dartmouth College	1	2
2	KR	Korea Institute of Science and Technology (KAIST)	1	2
3	JP	University of Tokyo	1	1
4	JP	Aichi University of Education	1	0
5	**FR**	**French Institute of Petroleum**	**1**	**0**
6	**DE**	**Fraunhofer Society**	**1**	**0**

Table 7-10: Universities / research organisations granted patents, by USPTO patent numbers

Rank	Country	Organisation	US	EP
1	US	Dartmouth College	11	1
2	KR	Korea Institute of Science and Technology (KAIST)	2	1
3	US	Rice University	2	0
4	**FR**	**CNRS**	**2**	**0**

7.5.2 Activity of companies

PATENT APPLICATIONS

The numbers of patent families are very low for companies. The locations of the companies with the highest number of patent families are the US (four in the top ten) as well as Sweden, Japan, France and Germany, all locations of major vehicle manufacturers.

Table 7-11: Number of patent families for top ten companies (1993-2011)

	Country	Company	No. of Patent families	PCT	US	EP
1	US	PPG Ind Ohio Inc.	6	66.7%	50.0%	83.3%
2	**SE**	**Saab Ab**	**5**	**100.0%**	**80.0%**	**40.0%**
3	JP	Nissan Motor	5	0.0%	60.0%	40.0%
4	JP	Bridgestone Corp	5	80.0%	60.0%	100.0%
5	US	Dupont de Nemours & Co	4	25.0%	50.0%	75.0%
6	US	Goodyear	4	0.0%	50.0%	100.0%
7	US	Boeing	3	33.3%	100.0%	66.7%
8	FR	Michelin	3	33.3%	66.7%	100.0%
9	DE	Siemens AG	3	66.7%	0.0%	33.3%
10	FR	Michelin	3	100.0%	0.0%	66.7%

GRANTED PATENTS

The numbers of patents granted are also very low for companies.

Table 7-12: Companies granted USPTO and EPO patents (sorted by EPO patents)

Country	Company	EP	US
US	Goodyear	4	2
US	PPG Ind Ohio Inc.	3	3
JP	Bridgestone Corp	2	3
JP	Kao Corp	2	2
JP	Matsushita Elect	2	2
NL	ASML Netherlands Bv	2	2
FR	Michelin	2	1
NL	Philips	2	0

The locations of the companies with the highest number of patents, sorted by EPO patent numbers are US, Japan, the Netherlands and France. Sorting by US patents, Canada, Japan and the US head the listing.

Table 7-13: USPTO and EPO granted patents by company (sorted by US patents)

Country	Company	US	EP
CA	Integran Technologies	3	1
JP	Bridgestone Corp	3	2
JP	Nissan Motor	3	0
US	PPG Ind Ohio Inc.	3	3
US	Boeing	3	0

The next section looks at the position of the nanotechnology-related transport industry, including employment, turnover and value added, and relates the information to manufacturing.

8 INDUSTRY AND NANOTECHNOLOGY FOR TRANSPORT

As a proxy for the industry operating in nanotechnology and transport, this section presents secondary data[327] on the whole of the transport sector. It should be noted that many sources of secondary data have been used and these are not consistent. The differences result from the use of a number of methodologies to collect information and the lack of consistency of definitions. Thus, this section of the report is not intended to be a ratified and consistent reporting of industry figures for nanotechnology and industry. Rather, it contains information that may be of interest to the reader and gives an indication of the scale (or potential scale) of the industry.

The transport sector uses inputs from many other sectors such as construction, manufacturing, energy and photonics. Therefore, the economic activity within these different application areas will be presented and an indication given of the fraction applied in the transport sector. Finally, the R&D expenditures in the transport sector will be discussed with special attention to research in nanotechnology.

8.1 Overview of the transport industry

In its Structural Business Statistics, Eurostat measures the number of enterprises, turnover[328], production value[329] and value added[330], as well as the number of people employed, for each sector of the economy across the European Union (EU-27: 2008-2010 and EU-28: 2011-now)[331]. This data is used to provide an overview of the transport sector. In this report, economic activities in the transport sector are defined as the sum of the following sub-sectors:

- Manufacture of transport equipment;
- Repair and maintenance of transport equipment;
- Wholesale and retail trade of transport equipment;
- Operations and services of the transport infrastructure and equipment; and
- Construction of transport infrastructure.

While only a small proportion will be specific to nanotechnology, it is worth considering the total figures for this industry.

The table below shows the above data categories, together with the codes from the Structural Business Statistics.

Table 8-1: Overview of transport-specific codes for Structural Business Statistics, Eurostat

Code		Label
1. Manufacture of transport equipment		
C29	Manufacture of motor vehicles, trailers and semi-trailers	
	C291	Manufacture of motor vehicles
	C292	Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
	C293	Manufacture of electrical and electronic equipment for motor vehicles
C30	Manufacture of other transport equipment	
	C301	Building of ships and boats
	C302	Manufacture of railway locomotives and rolling stock
	C303	Manufacture of air and spacecraft and related machinery
	C304	Manufacture of military fighting vehicles

[327] From Eurostat
[328] Turnover is defined in these statistics as market sales of goods or services supplied to third parties (Source: Eurostat).
[329] 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).
[330] 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).
[331]http://ec.europa.eu/eurostat/statistics-explained/index.php/Structural_business_statistics_overview

	C309	Manufacture of transport equipment n.e.c.[332]
2. Repair and maintenance of transport equipment		
C3315	Repair and maintenance of ships and boats	
C3316	Repair and maintenance of aircraft and spacecraft	
C3317	Repair and maintenance of other transport equipment[333]	
G452	Maintenance and repair of motor vehicles[334]	
3. Wholesale and retail trade of transport equipment		
G451	Sale of motor vehicles	
G453	Sale of motor vehicle parts and accessories	
G454	Sale, maintenance and repair of motorcycles and related parts and accessories[335]	
G473	Retail sale of automotive fuel in specialised stores	
G4614	Agents involved in the sale of machinery, industrial equipment, ships and aircraft[336]	
4. Operations and services of the transport infrastructure and equipment		
H	Transportation and storage	
	H49	Land transport and transport via pipelines
	H50	Water transport
	H51	Air transport
	H52	Warehousing and support activities for transportation
	H53	Postal and courier activities
5. Construction of infrastructure		
F421	Construction of roads and railways	
	F4211	Construction of roads and railways
	F4212	Construction of railways and underground railways
	F4213	Construction of bridges and tunnels

Source: Eurostat, Structural Business Statistics

The total economic activity in the transport sector (the sum of data in the five categories above) is presented in the table below. Because data is missing for certain years, the data is incomplete at a highly aggregated level. Data for these years on a more disaggregated level will be presented later in this chapter.

[332]Covers: C3091- manufacture of motorcycles; C3092 – Manufacture of bicyles and invalid carriages and C3099- Manufacture of other transport equipment n.e.c.
[333] Does not cover repair and maintenance of motor vehicles
[334] Classified by Eurostat in the wholesale and retail trade, but here included as repair and maintenance
[335] Not further specified in sale or maintenance and repair
[336] Is not only related to the transport sector, because it also covers sale of machinery and industrial equipment. However, data is not further specified.

Table 8-2: Total economic activity in the transport sector

ECONOMIC ACTIVITY IN THE TRANSPORT SECTOR						
	EU 27			EU 28		
	2008	**2009**	**2010**	**2011**	**2012**	**2013**
No. of enterprises (thousands)	2,103	:	:	:	2,140	2,145
Turnover or gross premiums written (EUR million)	:	:	:	3,795,142	3,813,109	3,835,760
Production value (EUR million)	2,578,623	2,187,204	2,432,322	2,590,814	2,606,484	2,617,718
Value added at factor cost (EUR million)	:	775,262	862,129	900,413	892,836	916,673
No. of people employed (thousands)	19,373	18,877	18,300	19,044	18,916	18,805

Source: Eurostat, Structural Business Statistics

In 2013, 2,145,000 enterprises were active in the transport sector. They employed 18.8 million people in total across the EU. They were responsible for a total production value of EUR 2.6 trillion, a turnover of EUR 3.8 trillion and a value added of EUR 917 billion. Between 2011 and 2013, the turnover showed a small growth (CAGR[337] of 0.5%), while the number of people employed declined slightly (CAGR of -0.6%) during the same time period.

The table below shows a more disaggregated view of the transport sector. More than half (53%) of the enterprises active in the transport sector are in "operations and services" (transportation and storage). The "operations and services" sub-sector also has the biggest share in the number of people employed (56%), the value added (54%) and the turnover (36%).

The remainder of the enterprises are mainly active in the sub-sectors "repair and maintenance" and "wholesale and retail trade". These sub-sectors are each responsible for 22% of the enterprises. Only 2% of the enterprises are manufacturers of transport equipment but, given their large size, they contribute to a production value of 897 billion euros, which is 34% of the total production value in the transport sector. They also employ over 3 million people, 16% of total transport employment.

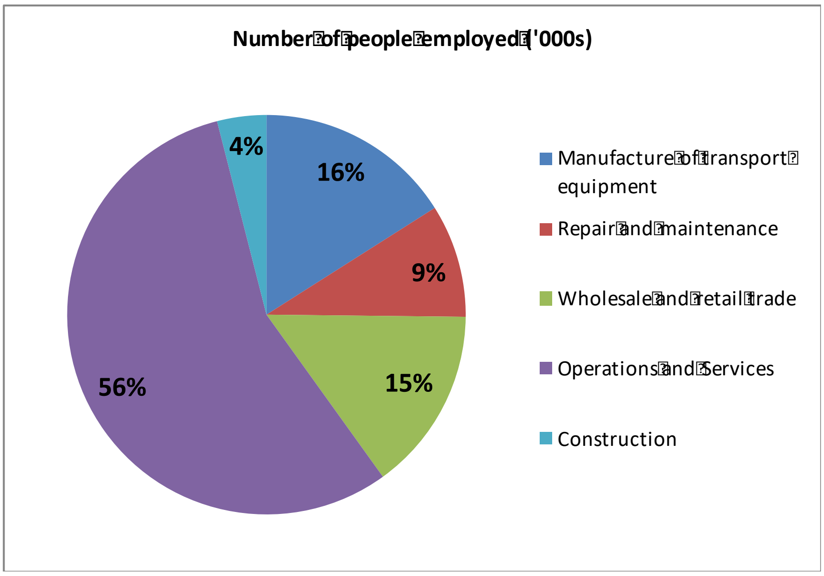
Table 8-3: Economic activity by segment in the transport sector

Manufacturing	**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 & peripherals	:	1,154	947	930	870	859
Magnetic and optical media	:	28	21	17	:	16
Total	:	4,582	3,978	4,027	:	3,803

Source: Eurostat, Structural Business Statistics

337 Compound Annual Growth Rate

The figure below shows the distribution of employment over the different sub-sectors: "operations and services" (56%), "manufacture of transport equipment" (16%), "wholesale and retail trade" (15%), "repair and maintenance" (9%), and "construction" (4%).



Source: Eurostat, Structural Business Statistics

Figure 8-1: Number of people employed in the transport sector by segment (%)

8.2 Nanotechnology in the transport industry

From data for 23 countries around the world, the OECD Key Nanotech Indicators[338] reported that, in the years 2011-2013, a total of 15,085 nanotechnology-related firms were located in those countries, 919 of them being dedicated nanotechnology firms i.e. ones that attribute at least 75% of their production of goods and services and R&D to nanotechnology-related activity. The firms were active in many different sectors.

Not all countries are included in the study but data from 12 EU countries were available, namely: Belgium, the Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Poland, Portugal, Slovenia and the Slovak Republic. These twelve EU countries were home to 2,437 nanotechnology-related companies, almost half of them located in Germany (1,110 companies).

In the transport sector, nanotechnology is used in nanomaterials for nano-composites; nano-coatings; nano-fluids and additives; nano-filters; energy storage; and nanosensors. Nanomaterials are used for the manufacture of vehicles and vehicle components. 24% of the global market for established commercial nano-composite applications is in automotive components, the second largest application area after food packaging[339].

According to Eurostat, in 2014, the manufacture of transport equipment involved 33,900 enterprises in the EU. While this is just 1.6% of the enterprises active in the total manufacturing sector[340], they were responsible for 10.4% of manufacturing employment (3.1 million employees).

The total production value of the manufacture of transport equipment was EUR 939,678 million (14.7% of total manufacturing sector) with a turnover of EUR 1.1 million and a total value added (at factor cost[341]) of EUR 211,725 million.

The table below presents the economic activity in the manufacture of transport equipment by type of vehicle.

[338] http://www.oecd.org/sti/nanotechnology-indicators.htm
[339] BCC research (2014), Nanotechnology: A Realistic Market Assessment: http://www.bccresearch.com/market-research/nanotechnology/nanotechnology-market-assessment-report-nan031f.html
[340] Structural Business Dynamics, Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do)
[341] Taking into account the cost of development and production but exclusive of tax costs.

Table 8-4: Economic activity manufacture of transport equipment by type of vehicle

	No. of people employed (2014)		Production value (2014)		Value added (2013)		Turnover (2014)		No. of enterprises (2014)	
	'000s	**%**	**EUR millions**	**%**	**EUR millions**	**%**	**EUR millions**	**%**	**'000 s**	**%**
Motor vehicles, trailers and semi-trailers	2,385	77	750,060	80	158,081	75	901,264	83	19.5	58
Ships and boats	165	5	35,942	4	8,096	4	34,197	3	8.1	24
Railway locomotives and rolling stock	109	4	23,446	2	6,332	3	24,138	2	0.8	2
Air & spacecraft & related machinery	370	12	116,244	12	35,739	17	115,222	11	1.9	5
Military fighting vehicles	12	0	2,818	0	1,012	0	3,058	0	:	:
Transport equipment n,e,c,[342]	58	2	11,167	1	2,465	1	11,457	1	3.6	11
Transport equipment: Total	**3,099**	**100**	**939,677**	**100**	**211,726**	**100**	**1,089,337**	**100**	**33.9**	**100**

Source: Structural Business Dynamics, Eurostat[343]

The manufacture of motor vehicles, trailers and semi-trailers accounts for the largest share of total production and employment, with 19,500 enterprises employing 2.4 million people in Europe, 77% of the total employment in the manufacture of transport equipment. In 2007, it was reported that the key players applying nanotechnology as of 2007 in the manufacture of motor vehicles were BMW, Renault, General Motors, Ford and Caterpillar[344]. In terms of production value and value added, the manufacture of transport equipment was also dominated by the manufacture of motor vehicles, trailers and semi-trailers (80% and 75%). In 2014, the EU produced 17.2 million motor vehicles, of which 15 million were cars.

Aerospace is one of the most important application areas for nanotechnology. Major companies in this field applying nanotechnology are Boeing and QinetiQ. Lockheed Martin is a leading company in the field of military aircraft and is also applying nanotechnology in the materials used for the structure and wings of the aircrafts and in electronic elements[345]. In total, 1,864 enterprises in the manufacture of air and spacecraft and related machinery employed 370,000 people, 12% of the total employment in the manufacture of transport equipment. The manufacture of air and spacecraft and related machinery was responsible for a value added of EUR 35.7 billion, 17% of the total value added in the manufacture of transport equipment.

The manufacture of motor vehicles, trailers and semi-trailers is further divided in four sectors: the manufacture of motor vehicles; of bodies (coachwork) for motor vehicles; of electrical parts and electronic equipment for motor vehicles; and of other parts and accessories. The turnover of these sub-sectors is respectively 72%; 3%; 3% and 22% of the total for manufacture of motor vehicles, trailers and semi-trailers (2013).

342 Covers: C3091- manufacture of motorcycles; C3092 – Manufacture of bicycles and invalid carriages and C3099- Manufacture of other transport equipment n.e.c.
343 http://appsso.eurostat.ec.europa.eu/nui/show.do
344 https://corporatewatch.org/news/2007/jul/01/nanotechnology-what-it-and-how-corporations-are-using-it-4-which-companies-are
345 http://www.lockheedmartin.com/us/what-we-do/emerging/nanotechnology.html

Nanomaterials are specifically applied in the bodies of the vehicles, as well as in the electrical parts and electronic equipment for motor vehicles. In total, these two sub-sectors employ 360 thousand people in Europe and have a turnover of about EUR 55 billion. Nanotechnology is also widely used in the tyre industry.

The latest available data on the tyre industry shows that, in 2011, 1,733 companies were active in the industry in the EU28. In the same year, these companies had a turnover of EUR 46,258 million and a production value of EUR 33,154 million. In 2013, the tyre industry in the EU-28 countries employed over 125,000 people.

Nanomaterials such as carbon black and high dispersible (HD) silica are widely used in the tyre industry. 73% of all carbon black is used in tyres[346]. Emerging nanomaterials such as new generation, highly dispersible, high surface area (HD-HS) silica and nanoclays may significantly impact on the future of the tyre industry.

Table 8-5: Economic activity in the tyre industry

Economic activity	2011	2012	2013
Number of enterprises	1733	:	:
Turnover or gross premiums written (EUR million)	46,258	45,250	43,419
Production value (EUR million)	33,154	31,413	29,683
Value added at factor cost (EUR million)	:	10,267	:
Number of people employed (thousands)	:	:	125.6

Source: Structural Business Statistics, Eurostat

Nanomaterials increase the life-cycle of tyres reducing the demand for replacement tyres. The OECD made a calculation of the impact of nanotechnology on the employment in the tyre industry by 2035, as shown in the table below. The application of nanoclays in the tyre industry is forecast to reduce employment in the EU by 1,900 jobs by 2035, while the application of HD-HS silica is expected to result in a decrease of 11,700 jobs.

Table 8-6: Potential impact of nanotechnology on employment in the tyre industry by 2035

	HD-HS silica scenario			Nanoclay scenario		
	United States	European Union	China	United States	European Union	China
Tyre demand reduction (millions of tyres)	23.8	22.6	88.9	2.1	2.8	15.3
Average tyre weight (kg)	10.2	8.8	7.9	10.2	8.8	7.9
Tonnes avoided	242 282	198 515	705 482	21 463	24 287	121 170
Annual productivity improvement	2%	2%				
Reduction in employment		11 700			1 900	

Source: OECD[347]

8.3 Innovation and R&D in the transport sector

In 2012, an average of 48% of the enterprises in the motor vehicles, trailer and semi-trailers sector were assumed to be innovative. Hungary had the lowest percentage of innovative enterprises (35%) and Germany the highest percentage (68%)[348]. In the manufacture of other transport equipment, a percentage of on average 49% were assumed to be innovative in 2012. Slovakia had the lowest fraction with 19% compared to Austria with 93%[349].

346 European Commission, Brussels, http://cordis.europa.eu/publication/rcn/12246_en.html; Flanigan, C.M., et al. (2012), "Comparative study of silica, carbon black and novel fillers in tread compounds", Rubber World, Vol. 245, No. 5, pp. 18, http://d27vj430nutdmd.cloudfront.net/9911/101311/101311.27.pdf

347 http://www.keepeek.com/Digital-Asset-Management/oecd/science-and-technology/nanotechnology-and-tyres_9789264209152-en#page65

348 Science, Technology and Innovation statistics: http://data.uis.unesco.org/ (retrieved in March 2016)

349 Science, Technology and Innovation statistics: http://data.uis.unesco.org/ (retrieved in March 2016)

The total R&D expenditure for the transport sector is unknown. The EU Industrial R&D Investment Scoreboard, however, listed the top 1000 EU-companies with their R&D expenditure by sector. Three sectors (as defined by the Commission) are relevant to the transport sector: the automobile and parts sector; the aerospace and defence sector and the industrial transportation sector. Based on these three sectors, the total transport sector spent EUR 55.3 billion on R&D in 2014. This is more than 30% of the total R&D expenditure of the top 1000 companies in the EU. It should be noted that not all companies will offer products on the general, some producing for highly-specialised markets (e.g. motor racing) and others involved on research and development rather than general manufacturing.

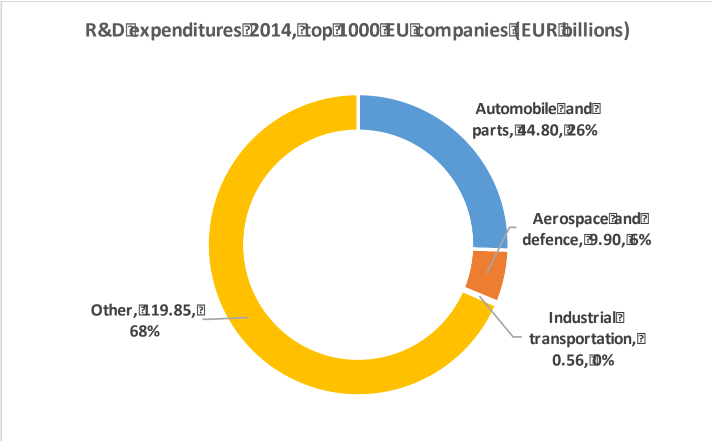


Figure 8-2: R&D expenditures top 1000 EU companies (EUR billions), 2014

The most recent data shows that, in 2014, the 47 companies active in the automobile and parts sector (and part of the top EU-1000 companies) were responsible for R&D expenditure of EUR 44.8 billion. These companies had an average R&D intensity of 7.0%, Force India Formula One Team the highest with 44.6%, and Brembo having the lowest with 0.6%. Other companies active in the area of nanotechnology include BMW and Renault which have a research intensity of 5.7% and 4.6% respectively.

In the Investment Scoreboard list, 25 companies represented the aerospace and defence sector. These companies spend a total of EUR 9.9 billion on R&D in the year 2014 and had an average R&D intensity of 8.9%. Avio had the highest research intensity (79,5%), Bae Systems the lowest (1,0%), both companies investing in nanotechnology in aerospace.

The sector industrial transportation listed several companies active in logistics: air traffic control and ports and electronic tolling systems. The 11 companies listed are responsible for a total R&D expenditure of EUR 559 million. The companies have an average R&D intensity of 1.1%. NATS, a provider of air traffic control services, is responsible for the highest research intensity of 4.0% and Deutsche Post has the lowest R&D intensity with close to 0%. It is unknown whether these R&D expenditures are for nanotechnology.

In addition to these (aerospace and defence; automobiles and parts; and industrial transportation) some other sectors are partly related to transportation. For example, in the oil equipment, services and distribution sector, some companies are engaged in the manufacturing process of pipe lines. Tenaris, Pii and and Technip spent EUR 177.9 million on R&D in 2014, Tenaris and Technip had respectively a research intensity of 1.0% and 0.8%. Both companies have declared that they invest in nanotechnology. Nanotechnology is, for example, one of 16 R&D areas of Tenaris. Tenaris uses nanotechnology for greener and enhanced steel pipes manufacturing processes.

So far, only activities directly related to the transport sector have been discussed. Most of the R&D expenditures on nanotechnology will affect the transport sector indirectly through input from other sectors. For example, the displays and sensors produced in the electronic and electrical equipment sector will be used for vehicles and traffic control. The 68 companies in this sector spend EUR 9.2 billion on R&D and had an average research intensity of 18.7%.

It should be noted that the above R&D expenditures are only for the top 1000 EU-companies. R&D expenditures by smaller companies are not included. Furthermore, the expenditures made by the EU-1000 companies on R&D do not have to be spent in the EU.

Other estimations of the total R&D in the transport sector suggest that the transport sector invested a total of EUR 38.2 billion on R&D in 2008 and EUR 42.8 billion in 2011 (based on 2008 prices)[350] [351].

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

[350] http://ac.els-cdn.com/S0967070X15300111/1-s2.0-S0967070X15300111-main.pdf?_tid=7c8314ec-e61d-11e5-a537-00000aab0f27&acdnat=1457545182_b988a59617eefd4654a62fec891b240f

[351] http://iri.jrc.ec.europa.eu/scoreboard.html

9 PRODUCTS AND MARKETS FOR TRANSPORT THROUGH NANOTECHNOLOGY

9.1 Introduction

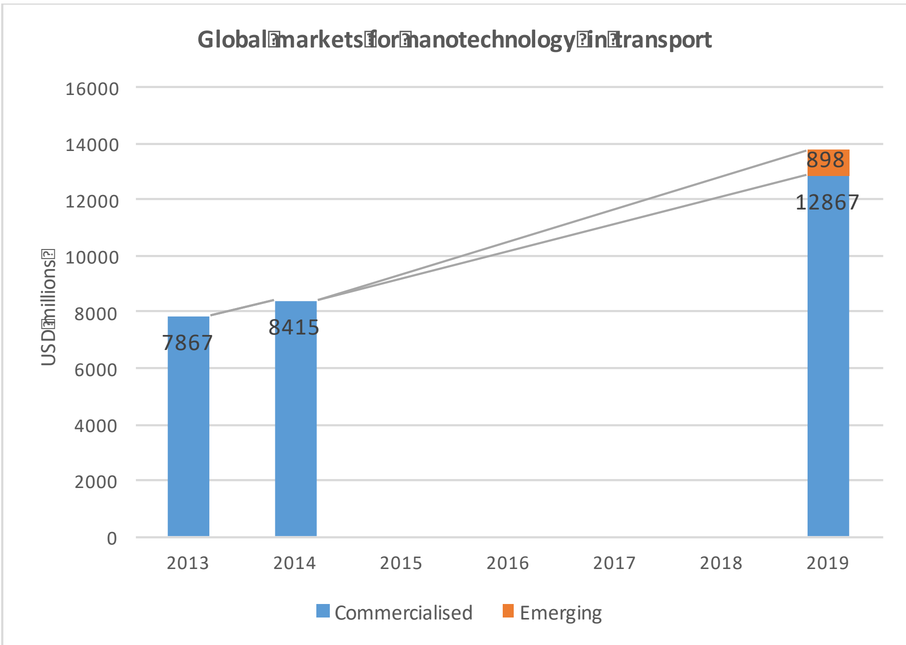
The commercial applications of nanotechnology in the field of transport include: nanotubes and particles (e.g. for use in capacitors and batteries), nanoporous materials (e.g. for use in fuel cells), thin-films and coatings (for multiple transport applications), and nano-composites (e.g. for use in vehicle parts).

Many companies identify themselves as being active in the area of nanotechnology. Where their product is generic with many applications in a wide range of sectors, one of which is transport, their product will often not appear as transport-specific. Here efforts have been made to identify products that are clearly designated as being used in transport, thereby omitting products with unspecified sectoral application areas, increasing the relevance of the products while reducing the total number. Products that are identified as for use in transport applications may also be used in other sectors e.g. energy or ICT.

This section looks at global markets and forecasts for transport products using nanotechnology, followed by information about commercialised nano-enabled products for use in transport.

9.2 Global markets and forecasts for transport products using nanotechnology

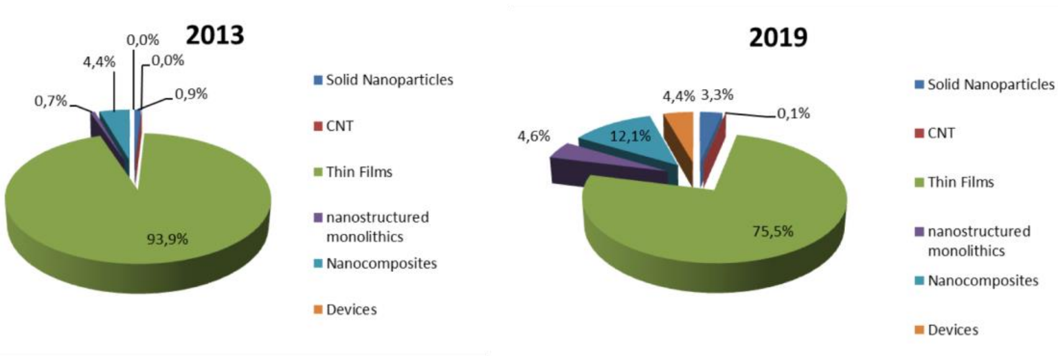
Global sales for nanotechnology products in the transport sector were estimated to be USD 7.9 billion in 2013 and are forecast to grow to USD 13.8 billion by 2019. The figure below shows the forecast growth by 2019 of commercialised products (USD 2.3 billion in 2019) and emerging products (USD 0.89 billion in 2019), much of the growth being expected in products that have already been commercialised.



Source: BCC Research, 2014

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

A comparison of global sales estimates by type of nanomaterial shows that thin-films accounted for the largest share in 2013 but that share is expected to decrease in the time period to 2019. The main reason for this is the predicted slow growth in the market for thin-film catalytic converters.



Source: BCC Research, 2014

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

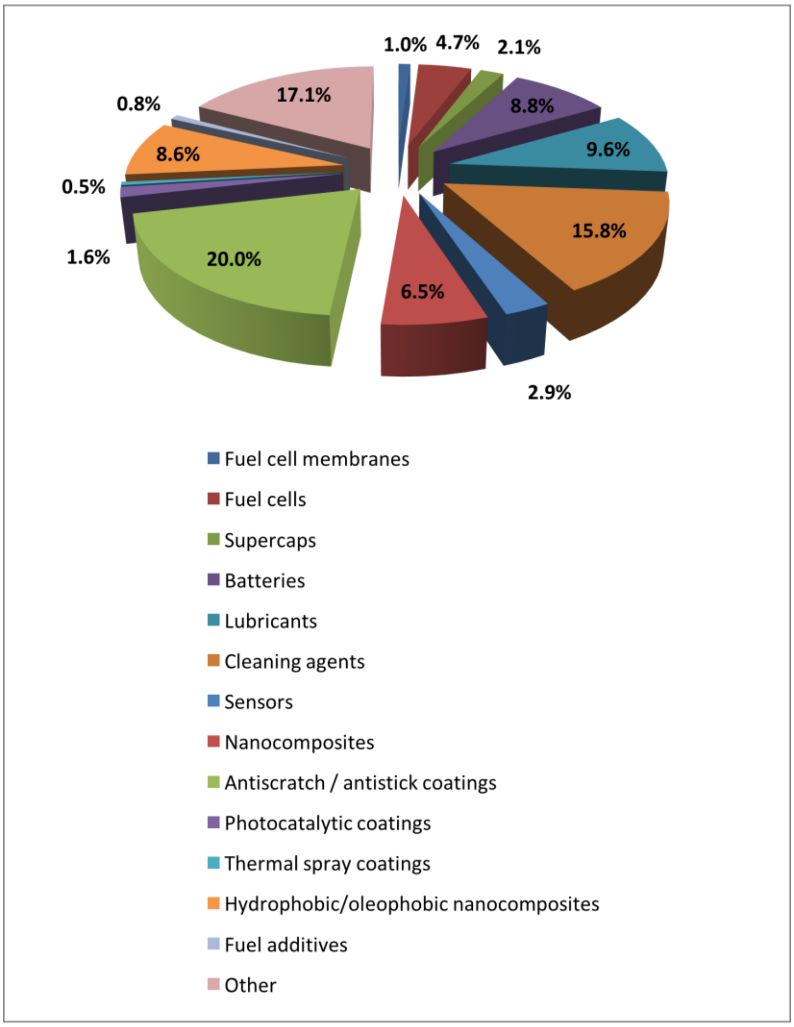
The share of nanodevices (i.e. sensors) is expected to increase by 2019 to about four times its size in 2013, while sales of nano-composites are projected to almost triple in relative share. Carbon nanotubes are currently forecast to play only a marginal role in terms of shares of sales.

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

9.3 Commercialised products for transport through nanotechnology

9.3.1 Overview

To date, 385 transport-related products using nanotechnology have been identified as being commercially-available on the market. One-fifth (20%) of those are in the area of anti-scratch and anti-stick coatings. The category ‘other’ (17.1%) has the second largest share among commercially-available products as shown in the figure below. This group comprises on the one hand to a large extent coating with IR radiation blocking properties and on the other hand anti-corrosive coatings for marine and automotive applications and polishing slurries. Cleaning agents (15.8%) represent the third biggest group of commercially-available products. Further shares worth mentioning are lubricants (9.6%), batteries (8.8%) and hydrophobic/oleophobic nano-composites (8.6%).



Source: JIIP, 2015

Figure 9-3: Nanotechnology in transport by product type

9.4 Products for transport through nanotechnology, by application market

9.4.1 Batteries

As the market for electric vehicles is growing, so too is the market for compatible batteries. New electric vehicle registrations in the EU rose from 22,532 units in 2014 to 58,689 units in 2015, a doubling in one year. Registrations of the new hybrid electric vehicles also rose substantially, from 47,291 up to 60,911 units in 2015, a growth of almost 30%[352]. The OEM[353] battery market for hybrid electric vehicles and plug-in hybrid electric vehicles in the EU is estimated by EUROBAT at 52,818 units in 2011 and 255,720 units in 2015. These numbers reflect a CAGR of 48%. Each (plug-in) hybrid electric vehicle will have one or two batteries on-board[354].

[352] http://www.acea.be/press-releases/article/alternative-fuel-vehicle-registrations-20.0-in-2015-21.1-in-q4
[353] Original Equipment Manufacturer
[354] http://www.eurobat.org/sites/default/files/automotive_battery_market_outlook_-_update_2015_0.pdf

A CURRENT PRODUCTS

RECHARGEABLE LITHIUM ION BATTERIES

TECHNOLOGY AND PRODUCTS

Lithium-ion batteries are generally based on the reversible transfer of lithium ions between two materials through an electrolyte. The cathode (positive electrode) materials are lithium transition metal oxides[355], with graphite being the most frequently used negative electrode (anode) material. With graphite, the battery operates at about 3.5 V during discharge with a high energy density[356].

Lithium-ion technology was introduced in the 1990's, increasing the energy density of battery cells by a factor of three relative to lead acid batteries and two relative to nickel-cadmium (Ni-Cd) batteries. In addition, and more significantly, the energy density of lithium-ion technology has doubled over the past 25 years. However, even lithium-ion technology falls short of meeting future application demands linked to the field of renewable energies and automotive transportation in terms of energy density, power and life span[357]. They eventually wear out, and they cannot discharge energy quickly enough for applications requiring power surges, such as camera flashguns and power tools[358].

The use of iron phosphate nanoparticles in lithium-ion battery electrodes is a possible technological approach to overcome the disadvantages of more traditional lithium-ion batteries. Several companies are working in this area:

- A123 Systems (Watertown, MA, USA) has introduced (with Nanophosphate®) a patented **lithium-ion battery cathode material** (originally developed at the Massachusetts Institute of Technology (MIT)[359]). Advantages of this technology include higher power and faster recharge, in addition to their being less combustible, than standard lithium-ion batteries. After the loss of its contract to supply batteries for GM's novel Volt electric cars in 2008, A123 Systems ran into financial problems and in 2012 became a wholly-owned subsidiary of Wanxiang Group (a Chinese developer and manufacturer of lithium iron phosphate batteries and energy storage systems).
- Valence Technology (Austin, Texas) develops and manufactures advanced **lithium iron phosphate cathode material** as well as **lithium-ion battery** modules and packs. Valence Technology's batteries are being used by Segway[360]. In 2012, Valence Technology filed for bankruptcy[361] but emerged again from bankruptcy as a private company in 2013.
- Phostech Lithium, Inc. (St-Bruno-de-Montarville, Canada) develops and manufactures **lithium iron phosphate**. It sells Life Power P1 grade (a micro-aggregate carbon lithium iron phosphate material (C-$LiFePO_4$) for use in cathodes for lithium batteries); Life Power P2 grade (a sub-micron C-$LiFePO_4$ for power tool batteries and SLI batteries, electric vehicle batteries (EVs including HEVs and PHEVs), large storage batteries, and defence applications); and lithium titanate ($Li_4Ti_5O_{12}$) (an anode material for lithium-ion batteries).

Lithium-titanate batteries (lithium titanium oxide or LTO batteries) mentioned above are another approach to overcoming the shortcomings of traditional lithium-ion batteries. The LTO technology is based on modified lithium-ion batteries and employs additional lithium titanate nanocrystals on the surface of the anode (instead of the conventional carbon material that is used in normal lithium-ion batteries). As a result, the anode has a surface area of around 100 square metres per gramme, much larger than the three square metres per gramme achieved when using conventional carbon material, allowing electrons to enter and leave the anode far more quickly. As a result of this larger surface area, re-charging of the LTO battery is faster. The improvement in the surface area of the battery drastically increases the LTO cells general stability and further improves the safety of LTO batteries[362]. A disadvantage of LTO batteries is that they have a lower inherent voltage (2.4 V),

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355 Represented by the general formula Li_yMO_2 ($y \approx 1$) where M is the transition metal
356 Elzbieta Frackowiak and François Béguin (2013), Carbon-Based Nanomaterials for Electrochemical Energy Storage, in: Javier Garcia-Martinez (ed.) (2010),Nanotechnology for the Energy Challenge, p. 194
357 Ibid
358 Graham-Rowe, Duncan (7 March 2005). "Charge a battery in just six minutes". New Scientist.
359 A123 Systems, Inc.: Nanophosphate® Basics: An Overview of the Structure, Properties and Benefits of A123 Systems' Proprietary Lithium Ion Battery Technology
360 Business Wire: Valence Technology, Inc. and Segway LLC Announce Joint Technology Development Program, November 04, 2004
361 Chapter 11 in the U.S. Bankruptcy Court for the Western District of Texas
362 Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015

which leads to a lower energy density than conventional lithium-ion battery technologies[363].

LTO batteries have applications in electric vehicles and charging stations, coaches, yachts, wind and solar energy storage power, traffic signals, solar hybrid street lighting, home storage, disaster relief, weather radar, smart grid, hospitals, telecommunications and system critical backup power systems[364]. They are used, for instance, in Mitsubishi's i-MiEVelectric vehicle[365] and Honda's Fit EV[366]. Public transportation, such as the large capacity electric bus project TOSA in the Swiss canton of Geneva, uses the high charging capability of LTO batteries to partly recharge the battery in 15 seconds while passengers are disembarking and embarking at bus stops[367]. Some examples from companies:

- In February 2005, Altairnano (Reno, Nev., USA) announced a breakthrough in nano-structured lithium titanate battery technology. They used this material to replace the carbon in conventional lithium-ion batteries and achieved better performance and a high potential for various energy storage applications[368]. Altairnano's LTO batteries are mainly for e-mobility applications but they have also deployed their LTO energy storage systems for electric grid ancillary services and in various military applications[369].
- Toshiba introduced its LTO battery in 2009 under the registered brand name Super Charge ion Battery (SCiB™). The battery is designed to offer 90% charge capacity in 10 minutes[370]. SCiB™ batteries are used in the Schwinn Tailwind electric bike[371] and in Mitsubishi's i-MiEV and Minicab MiEV electric vehicles[372].
- Other notable producers of LTO batteries include Leclanché (Yverdon-les-Bains, Switzerland) and Tiankang™ Battery (Hong Kong, special administrative region of China). Leclanché acquired Bullith AG (Willstätt, Germany) in 2006 - a spin-off from the Fraunhofer-Gesellschaft - to establish a Li-ion manufacturing line. In 2014, the "TiBox" was introduced to the market with its main usage being energy storage system[373]. Tiankang™ Battery sells its Tiankang™ smart energy storage product line of LTO batteries on the global market.

Recent developments in lithium-ion batteries are focused on the use of **silicon-based anodes** in batteries.

- Nexeon Ltd (UK) has patented a way of structuring silicon so that it delivers extended cycle life and significantly increases battery capacity. In contrast to carbon, Nexeon's silicon anode materials have a much higher capacity for lithium and as a result are capable of almost ten times the energy capacity per gramme (mAh/g).
- Amprius (Sunnyvale, CA, USA) has been working since 2008 on a multi-pronged effort in next-generation energy storage technology - using silicon, rather than carbon, as a material for the electrodes within lithium-ion batteries. Amprius's silicon anode technology was originally developed at Stanford University to significantly improve the energy density and specific energy of lithium-ion batteries.

Another recent development is in research[374] on **lithium-oxygen** (or lithium-air) cells as a replacement for lithium-ion batteries. Lithium-oxygen batteries have a theoretical energy density ten times that of lithium-ion cells, bringing their energy density close to that of gasoline and making them attractive for use in powering vehicles.

Company snapshot: Lithium ion batteries: Nexeon Ltd

Founded Nexeon operates as a battery materials and licensing company that develops silicon

[363] Green Car Congress: Toshiba Developing 3.0 Ah High Power SCiB Li-Ion Cell for HEV Applications. 21 May 2008.
[364] Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015
[365] Mitsubishi Chooses Super-Efficient Toshiba SCiB Battery For EVs. Integrity Exports. 2011-06-18.
[366] Toshiba's SCiB battery for the Fit EV. Green Car Congress. Nov 17, 2011.
[367] http://www.tosa2013.com/en#/tosa2013
[368] Bright Hub Engineering: Lithium Titanate Batteries Explained, 1/27/2011
[369] Ibid
[370] http://www.scib.jp/en/
[371] Syonyk's Project Blog: Schwinn Tailwind Battery Pack Teardown and Analysis, Sunday, June 7, 2015
[372] http://www.toshiba.co.jp/about/press/2011_06/pr1603.htm
[373] Leclanché: TiBox, Product Information
[374] http://graphene-flagship.eu/graphene-shows-promise-for-next-generation-rechargeable-batteries

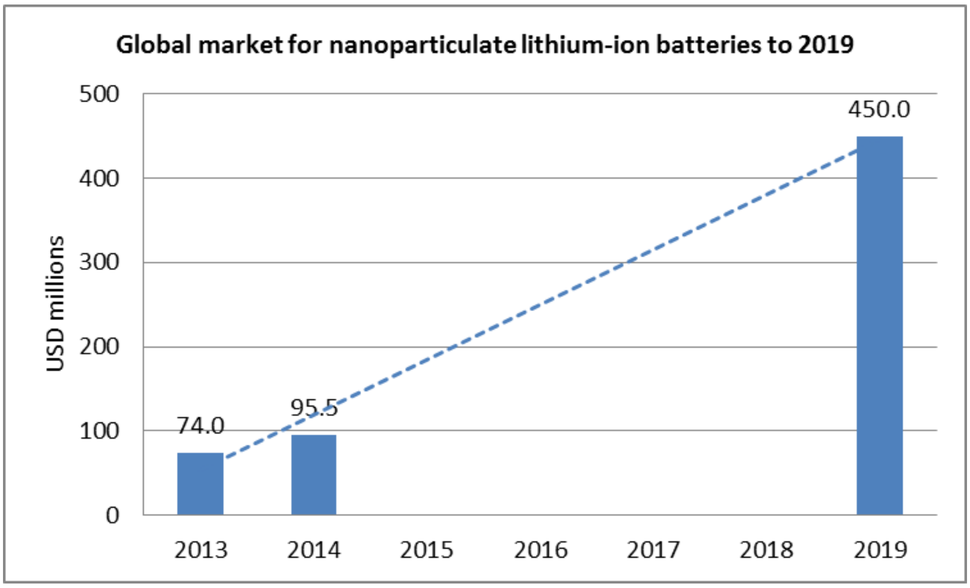
anodes for lithium-ion batteries. It sells silicon anode technology solutions for various applications, including consumer electronic, electronic vehicle, sustainable energy, aerospace, medical, and the defence industries in the United Kingdom and internationally. The company was founded in 2005 and is based in the United Kingdom with an additional office in Tokyo, Japan. Nexeon has taken in USD 62 million in funding so far from Invesco Perpetual, Wacker Chemie (ETR:WCH), and Imperial Innovations. With a total of USD 36 million invested in Nexeon so far, Nexeon is one of Imperial Innovations' most significant assets. Nexeon has a growing patent portfolio of over 40 patent families with a wide territorial coverage and more than 100 patents have been granted to date. Their patents granted and patents applied for cover various technologies, focusing on, but not limited to, the use of high capacity silicon material as an active agent in the negative electrode of a lithium-ion battery. Nexeon patents address, for example, electrodes comprising silicon nanowires/fibres coupled to a substrate or as part of an interconnected conducting network in a composite; and electrodes where the active material comprises silicon or tin inside carbon nanotubes.

See www.nexeon.co.uk

MARKET DATA AND FORECASTS

The market for advanced lithium-ion batteries incorporating nanoparticulate electrode materials was estimated to be USD 330 million in 2013. Material costs represent about 45% of the value of all types of storage battery shipments including, it is assumed, nanoparticulate lithium-ion batteries. Materials used in fabricating the electrodes of these batteries in turn account for about half of the total material cost of lithium-ion batteries, or USD 74 million in 2013, based on the projected value of nanoparticulate lithium-ion battery sales[375].

The market for nanoparticulate lithium-ion batteries is forecast to grow at a CAGR of 36% between 2014 and 2019, from USD 95.5 million in 2014 to USD 450 million in 2019[376].



Source: BCC Research, 2014

Figure 9-4: Global market for nanoparticulate lithium-ion batteries to 2019

[375] BCC Research (2014), Nanotechnology, a realistic market assessment
[376] Ibid

Case study: A123

A123 was established in 2001 based on the proprietary Nanophosphate EXT technology from the Massachusetts Institute of Technology (MIT), and currently has a workforce of more than 2000 people worldwide. The company is now a fully-owned subsidiary of the Chinese Wanxiang Group Corporation, having been acquired by the Wanxiang Group in 2008 when the company faced the threat of bankruptcy. Wanxiang Group Corporation, which is a large auto parts manufacturer with considerable US operations, invested up to USD 450 million (EUR 338 million) in A123. The company has over 2000 employees globally.

During its establishment, the company received almost USD 130 million (EUR 98 million) from the U.S. Department of Energy in grant funds to set up its Michigan factory. The U.S. government spent about USD 1 billion on grants dedicated to electric-vehicle-battery plants in 2010, funding manufacturers including LG Chem, Johnson Controls Inc., Ener1 Inc. and A123. Market revenue forecast for electric vehicle batteries segment proved to be too optimistic and far exceeded actual results, impacting on market participants. The nanotechnology utilised by A123 systems proved to be viable.

A123 batteries, manufactured in Livonia and Romulus, Michigan, have been put into use in vehicle models such as the BMW 3-Series, Chevrolet Spark and McLaren MP4-12C. The company, with its Chinese parent, has also initiated actions to capture electric vehicle market share in China as the market evolves.

The company generated revenue of nearly USD 209 million (EUR 157 million) in 2014. It currently operates manufacturing plants in Michigan (USA) and in Hangzhou and Changzhou (China), all three operating at full scale due to significant demand. This high demand has influenced A123 systems to further expand its manufacturing facilities by establishing a USD 100 million (EUR 75 million) capital expansion project across its manufacturing network. An additional sum of over USD 200 million (EUR 150 million) will be invested in expansion over the next three years, depending on the growth of the target markets.

A123 systems focuses mainly on the automotive market i.e. batteries providing energy to the main drivetrain of hybrid/electric vehicles. The advantage of the A123 technology lies in the improvement of power delivery capability at low temperature and the battery life at high temperature. A number of automotive models by global manufacturers such as the Nissan LEAF have been facing this challenge associated with the extreme heat of certain locations including Arizona, Texas and California.

Apart from main drivetrains, the company has also directed its efforts towards small batteries for applications such as stop-start systems in gasoline-powered cars. The company recently introduced its most advanced 12 Volt Starter Battery for low voltage automotive applications. The product, based on A123's new UltraPhosphate™ technology has been claimed to have achieved more than 25% greater cold cranking power as compared to most commercially available lead-acid batteries. The starter battery business of A123 was initiated in 2011 which led to successful supply relationships with five vehicle manufacturers in Europe.

B Emerging markets: Batteries

B1 Paper batteries using carbon nanotubes

Technology and product trends[377]

Researchers at Rensselaer Polytechnic Institute (RPI) (Troy, NY, USA) have developed a paper-thin, lightweight, flexible battery based on **carbon nanotube** technology. The battery has a cellulose base (hence its being termed a **'paper battery'**) in which aligned carbon nanotubes are infused, acting as electrodes and enabling electricity flow. The paper battery combines all of the components of a battery into a single structure, thereby improving its energy efficiency. It can provide a long and steady power output (similar to that of a conventional battery) or a short burst at a high energy level (similar to that of a supercapacitor).

[377] BCC Research (2014), Nanotechnology, a realistic market assessment

A New York-based start-up, the Paper Battery Co., was founded in 2008 to commercialise the technology developed at RPI. Potential applications include energy-storing building materials. There are a number of performance and processing issues to be resolved before the technology can be commercialised but the research team at RPI expect that products (possibly in the form of supercapacitors, see also the section below) will be commercialised, possibly reaching the market in just a few years. The performance issues include improving consistency so that the voltage and power are always the same, increasing storage capacity and enhancing cyclability. There also need to be improvements in the process so that the paper batteries can be mass-produced at a competitive cost.

Meanwhile, other groups are developing **nanotube-based batteries**. MIT researchers have demonstrated a new battery electrode based on specially treated carbon nanotubes that can last for thousands of cycles without any loss in performance. Researchers at LG Chem (Korea) have fabricated a new type of lithium-ion anode from germanium nanotubes that reportedly holds three times more charge than batteries using conventional graphite anodes. Even greater increases in battery capacity (i.e., up to a 10% increase) could result from the use of sheets of aligned carbon nanotubes coated with silicon, a technology under development at North Carolina State University.

MARKET POTENTIAL

As of 2014, the nanotube-based battery application that appeared closest to commercialisation was "paper" batteries such as the ones being commercialised by the Paper Battery Co. By 2019, when the company's paper batteries are expected to be on the market, the market for printed and other ultrathin batteries is expected to exceed USD 2 billion. However, carbon nanotube "paper batteries" will compete with ultra-thin batteries made using a variety of other technologies, including standard semiconductor deposition and lithographic techniques. Using carbon nanotube ink-printed RFID tags as a guideline for estimating the market share that will be achieved by CNT paper batteries, it is forecast that paper batteries will take achieve a market share of 1.5% of the total of USD 2 billion (i.e. USD 30 million). As the electrode accounts for an estimated 45% of the cost of the battery and carbon nanotubes account for about half of the cost of the electrodes, carbon nanotubes make up 22.5% of the total cost of the battery. This percentage, applied to projected sales of USD 30 million, yields a potential market for carbon nanotube battery electrode materials of USD 6.8 million in 2019.[378]

B2 CNT SUPER-CAPACITORS/ ULTRA-CAPACITORS

TECHNOLOGY AND PRODUCT TRENDS

Supercapacitors (sometimes called ultra-capacitors) [379, 380, 381] are high-capacity electrochemical double-layer capacitors characterised by high energy and power density. They consist of two electrodes surrounded by an electrolyte and divided by a separator. Since the loading capacity depends on the electrode surface, a significant performance enhancement of supercapacitors may be achieved through nano-structuring and the associated increase in surface area. Super-capacitors occupy the space between electrolytic capacitors and rechargeable batteries.

Work on both single-walled and multi-walled carbon nanotubes (**SWCNTs and MWCNTs**) has seen promising results for their potential use as electrochemical supercapacitor electrodes. Composites have been developed with a nano-tubular backbone coated with an active phase having pseudo-capacitive properties. Such composites, e.g. CNT/oxide composites, may enable a new generation of supercapacitor, their advantages being that: (i) the percolation of the active particles is more efficient with nanotubes than with the traditional carbon materials; (ii) the open mesoporous network formed by the entanglement of nanotubes allows the ions to diffuse easily to the active surface of the composite components; and (iii) since the nanotubular materials are characterised by a high resiliency, the composite electrodes can easily adapt to the volumetric changes during charge and discharge, greatly improving the cycling performance[382]. Several companies are pursuing this route, for example:

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[378] BCC Research (2014), Nanotechnology, a realistic market assessment p.145
[379] With capacitance values greater than 1,000 farads at 1.2 volts
[380] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.46
[381] https://www.quora.com/What-is-meant-by-super-capacitor
[382] Hui Pan, Jianyi Li, and Yuan Ping Feng (2010), Carbon Nanotubes for Supercapacitor, Nanoscale Res Lett. 2010; 5(3): 654–668.

- FastCAP Systems (Boston, MA, USA) is developing ultra-capacitors that are based on **carbon nanotubes**. The ultra-capacitors are symmetric devices comprised of carbon nanotube-based electrodes and an ionic-liquid-based electrolyte. Ionic liquids are non-volatile molten salts that are extremely stable over a wide temperature range. The morphology of the high surface area carbon nanotube based electrodes are specifically engineered with a particular pore size and shape to facilitate electrolyte access. FastCAP is looking to supply the market for fleet vehicles such as city and school buses, taxi cabs and delivery vehicles.
- Skeleton Technologies (Harjumaa, Estonia), has introduced its new SkelCap series ultra-capacitor family with devices ranging from 2.47 kW to 12.53 kW. SkelCap cells offer power densities of more than 40 kW/kg and energy densities of up to 10 Wh/kg: about four times the gravimetric power density and twice the gravimetric energy density of competitor products. The basis behind the new generation of ultra-capacitor devices is Skeleton's patented **carbide-derived carbon** (CDC) SkeletonC material, which enables the modification of pore size and structure at the single nanometre level. The surface of the Skeleton C carbon particles contains larger pores than the inside of the particles—allowing increased access to nanopores by the liquids, in turn raising the energy density. The low internal resistance of the nanostructured material also raises the power density. CDC has very high volumetric capacitance of 100 F cm^3 [383].

MARKET POTENTIAL

It is difficult to forecast the market value of new technologies still under development. By analogy with the battery market for nanotube electrodes, a combined market for CNT super-capacitors/ ultra-capacitors of USD 13.6 million in 2019 is predicted[384].

B3 GRAPHENE ULTRA-CAPACITORS

TECHNOLOGY AND PRODUCT TRENDS

Graphene is often suggested as a replacement for activated carbon in supercapacitors, in part due to its high relative surface area (which is even greater than that of activated carbon). The surface area is one of the limitations of capacitance and a higher surface area means better electrostatic charge storage. In addition, graphene-based supercapacitors are lightweight and have good elastic properties and mechanical strength. Graphene-based supercapacitors are said to be capable of maintaining over tens of thousands of charging cycles their ability to store almost as much energy as lithium-ion batteries and to charge and discharge in seconds. This is achieved, for example, by using a highly porous form of graphene with a large internal surface area (made by packing graphene powder into a coin-shaped cell which is dried and pressed[385]. Some examples of activities within research organisations and companies include:

- Researchers from Lawrence Livermore National Laboratory (LLNL, USA) have developed new supercapacitor electrodes made from **modified graphene aerogels**. The electrodes have high surface area, good electrical conductivity, chemical inertness and long-term cycling stability. The researchers report that the graphene aerogel can improve the performance of commercial carbon-based supercapacitor electrodes (carbon black with binder materials) by more than 100% due to their improved density and pore size distribution and increased conductivity[386].
- MIT researchers have discovered that crumpling **graphene paper** (made from graphene sheets bonded together) results in a low-cost material that is useful for extremely stretchable supercapacitors for flexible devices. The crumpled graphene paper (a "chaotic mass of folds") is used in a supercapacitor that can be bent, folded or stretched to as much as 80% of its original size. It can be crumpled and flattened up to a 1,000 times without significant loss of performance[387].
- Researchers from Korea's Sungkyunkwan University have developed supercapacitors that can charge (and discharge) 1000 times faster than current graphene supercapacitors, while also having three times their energy capacity. The technology is based on a **graphene oxide film**

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383 http://www.greencarcongress.com/2012/06/skelcap.html
384 BCC Research (2014), Nanotechnology, a realistic market assessment p.145
385 http://www.graphene-info.com/graphene-supercapacitors
386 http://phys.org/news/2014-10-energy-storage-future.html
387 http://news.mit.edu/2014/crumpled-graphene-energy-storage-1003

using a carbon nanotube, which is cut and heat treated to vertically align graphene oxide flakes within it and form vertically-structured graphene electrodes. The resulting electrodes, which can also be given increased porosity, operate much faster than the solid and vertically-structured graphene used in existing supercapacitors[388].

- In May 2013, Lomiko Metals, Stony Brook University (SBU) and Graphene Labs signed an agreement to investigate graphene-based applications – mainly supercapacitors and batteries. On December 2013, the companies announced a significant milestone, receipt of a prototype graphene supercapacitor. The supercapacitor prototype was made using **graphene composite material** prepared using a proprietary technology developed at Graphene Labs. The measured specific capacitance of the prototype was found to be around 500 Farad per gramme of the material. This value is comparable with the best values reported in the literature for a supercapacitor of this type[389].
- Graphenex UK Limited (Walsall, UK) is an R&D start up, established in 2014 that aims to develop prototype high energy supercapacitors based on **graphene materials**. The company is currently developing an ultra-compact graphene hexagonal supercapacitor for various application areas.

MARKET POTENTIAL[390]

According to industry sources, graphene super-capacitors/ultra-capacitors are on the cusp of commercialisation and could be commercialised in next five years, by 2019. It is estimated that the global market for electronic and capacitive energy storage devices (including supercapacitors, ultra-capacitors and air capacitors) was USD 1.4 billion in 2013 and USD 1.7 billion in 2014, rising to USD 4.2 billion in 2019.

The share of the market of graphene super-capacitors was zero in 2013/14. There are many competing technologies as well as technical, cost-manufacturability issues that need to be resolved. Graphene ultra-capacitors therefore appear unlikely to capture more than 1% (USD 42 million) of the super-capacitor market by 2019. As the graphene electrode accounts for an estimated 45% of the cost of the battery and graphene account for about half of the cost of the electrode, graphene makes up 22.5% of the total cost of the battery, which extrapolates to a potential 2019 market for graphene materials in ultra-capacitors of USD 9.5 million.

B4 AEROGEL SUPERCAPACITORS

Carbon aerogels, as nanoporous substances, make suitable graphitic electrode materials for super-capacitors due to their extremely high surface area and adjustable pore distribution and size. They have the potential to enable supercapacitors with power densities of more than 10 kW/kg, for application fields including mobile applications where there high and short bursts of energy (e.g. in energy recovery in electric vehicles when braking)[391].

Aerogel supercapacitors are interesting for commercial applications such as mobile devices as their high power density means that smaller batteries can be used (super-capacitors having a size range from that of an AA cell to approximately a third of that of an AAA cell). In addition, super-capacitors offer an extension of battery life. Standard batteries may withstand thousands of cycles of charge and discharge but suffer a decrease in capacity with each use. A super-capacitor can undergo hundreds of thousands of cycles with no degradation in performance. In addition to providing pulsed power, an aerogel capacitor can furnish hold-up power (in case of a power failure) delivering currents in the milliamp range for hours or even days, of value for hard-disc drives and remote sensors[392]. Aerogel supercapacitors are currently used to a limited extent in back-up power supplies for microelectronic devices. In the longer term, aerogel supercapacitors also are of particular interest in automotive applications (e.g. for hybrid vehicles and as supplementary storage for battery electric vehicles).

PowerStor® by Cooper Industries plc[393] (Dublin, Ireland), acquired by the Eaton Corporation

[388] http://www.businesskorea.co.kr/english/news/sciencetech/4156-supercapacitor-tech-electric-vehicles-be-charged-1000-times-faster
[389] http://www.graphene-info.com/graphene-supercapacitors
[390] BCC Research (2014), Nanotechnology, a realistic market assessment p.54-55
[391] Ibid
[392] David G. Morrison, Carbon Foam Whips Up Greater Power Density For Supercapacitors, Electronic Design, Apr 3, 2000
[393] http://www.cooperindustries.com/content/public/en/bussmann/electronics/brands/powerstor.html

(Dublin, Ireland) in 2012, is the producer of what is currently the only aerogel super-capacitor that is commercially available.

Market potential[394]

Potential electrochemical device applications include aero capacitors and water purification devices. The global market for electronic and capacitive energy storage devices (including supercapacitors, ultra-capacitors and aero-capacitors) has been estimated as USD 1.4 billion in 2013 and USD 1.7 billion in 2014, rising to USD 4.2 billion in 2019 (CAGR of 20% in 2014 to 2019).

9.4.2 Fuel cells

Technology and product

A fuel cell is an electrochemical energy converter in which a fuel (for example, hydrogen, methanol, ethanol or methane) reacts with an oxidant (oxygen, air, etc.) on electrodes separated by an electrolyte (e.g., a proton-conducting polymer membrane). The electrodes act as catalysts for oxidation at the anode and reduction of oxygen at the cathode.[395]

Nano-structured fuel cell electrodes increase the surface area per unit weight of catalysts and enhance the contact between fuels and catalysts, leading to improved cell efficiency. The preparation of nanoscale electro-catalysts for fuel cells typically starts from colloidal nanomaterial precursors, for example, colloidal platinum (Pt) sols[396]. Nanoscale thin-film platinum catalyst material is currently used in proton exchange membrane fuel cells (PEMFCs), phosphoric acid fuel cells (PAFC), and direct methane fuel cells (DMFCs).

Researchers at the University of Copenhagen have demonstrated the ability to significantly reduce the amount of platinum needed as a catalyst in fuel cells. The researchers found that the spacing between platinum nanoparticles affected the catalytic behaviour, and that by controlling the packing density of the platinum nanoparticles they could reduce the amount of platinum needed.

Researchers at Brown University are developing a catalyst that uses no platinum. The catalyst is made from a sheet of graphene coated with cobalt nanoparticles, potentially reducing the cost resulting from the use of platinum based catalysts[397].

In 2012, fuel cell industry revenues almost reached USD 1 billion market value worldwide, with Asian pacific countries shipping more than three-quarters of the fuel cell systems worldwide, but, by October 2013, no public company had yet become profitable[398].

Tanaka Kikinzoku Kogyo K.K. expanded its production facilities for fuel cell catalysts in 2013 to meet anticipated demand resulting from the Japanese 'ENE-Farm'[399] scheme for home fuel cells, with a planned installation of 50,000 units[400] and strong market growth[401].

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394 BCC Research (2014), Nanotechnology, a realistic market assessment, p.172

395 Elena Serrano, Kunhao Li, Guillermo Rus, and Javier García – Martínez (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.22.

396 Elena Serrano , Kunhao Li , Guillermo Rus , and Javier García – Martínez (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010),Nanotechnology for the Energy Challenge, p.24

397 https://genesisnanotech.wordpress.com/2015/04/26/nanotechnology-in-fuel-cells/

398 Wesoff, Eric: Will Plug Power Be the First Profitable Fuel Cell Company? Greentech Media, October 21, 2013

399 "ENE-FARM" is the nickname given to the world's first fuel cell for practical home use that has made its debut in Japan. This fuel cell is a new energy system which extracts hydrogen from LP gas and combines it together with ambient oxygen to generate electrical power, while simultaneously capturing residual heat that is used to heat up water. In comparison to conventional electrical supply grid systems, it has the capability for a very high efficiency ratio and significant reduction of CO2 gas emissions. http://www.j-lpgas.gr.jp/en/appliances/

400 FuelCellToday: Latest Developments in the ENE-Farm Scheme, 27 Feb 2013

401 FuelCellToday: Tanaka Precious Metals Constructs Dedicated Plant for the Development and Manufacture of Fuel Cell Catalysts, 26 Feb 2013

Company snapshot: eZelleron GmbH

eZelleron GbmH is a start-up company and a spin-off from Fraunhofer-Gesellschaft e.V. (Europe's largest application-oriented research organisation). The core business of eZelleron is energy storage for mobile applications and their target market covers consumer products (portable and mobile electronic devices), power tools, portable lighting, medical equipment and portable chargers.

Headquartered in Dresden, Germany, and with an office in Wilmington, US, eZelleron was founded in 2008 by materials scientist Dr Sascha Kuehn, also owner and CEO of the company. In 2009, it received USD 3.54 million of seed funding from eCapital Entrepreneurial Partners AG (a German entrepreneur-led venture capital company), TGFS Technologiegruenderfonds Sachsen (an early stage VC fund for high tech start-ups) and Fraunhofer Venture.

eZelleron has a team of twenty-five experts working on products including Kraftwerk®, an award-winning fuel-cell-powered fast-charging device for mobile applications, a crucial product for the company (https://www.kickstarter.com/projects/ezelleron/kraftwerk-highly-innovative-portable-power-plant/posts/1396357). The company raised over USD 1.5 million in 2015 from over eleven thousand investors through a crowdfunding campaign on Kickstarter (www.kickstarter.com).

See: http://www.ezelleron.eu/en/index.html

MARKET DATA AND FORECASTS[402]

The 2013 market for platinum nanocatalyst thin-film materials used in phosphoric acid fuel cells (PAFC), polymer electrolyte membrane fuel cells (PEMFC) and direct methanol fuel cells (DMFC) was worth over USD 20 million. Consumption of platinum group metal (PGM) nanocatalyst materials used in fuel cell electrodes is driven mainly by sales of fuel cell types that incorporate these materials. It is estimated that combined sales of PAFC, PEMFC and DMFC fuel cells were c. USD 1.1 billion in 2013 and USD 1.4 billion in 2014 and will rise to nearly USD 7.3 billion by 2019, a CAGR of 38% from 2014 through 2019.

Given that platinum thin-film catalysts are estimated to represent between 1.3% and 1.9% of the total cost of fuel cells, depending on the type of fuel cells, an estimate can be made of the consumption of platinum nano thin-film catalyst materials for each type of fuel, as shown in the table below.

Table 9-1: Global market for fuel cells and platinum thin-film catalysts to 2019 (USD millions)

Type	2013	2014	2019	CAGR% 2014-2019
	USD millions			
PEMFCs				
Total sales	985.0	1,269.4	4,517.1	28.9
Pt consumption at 1.9%	18.7	24.1	85.8	28.9
PAFC				
Total sales	50.0	59.6	143.4	19.2
Pt consumption at 1.8%	0.9	1.1	2.6	18.8
DMFC				
Total sales	63.0	117.2	2,617.1	86.1
Pt consumption at 1.3%	0.8	1.5	34.0	86.7
Total Pt catalyst consumption	20.4	26.7	122.4	35.6

Source: BCC Research, 2014

[402] BCC Research (2014), Nanotechnology, a realistic market assessment, p.148-149

Thus the expected sales of platinum as thin-film catalysts in 2019 would be USD 122 million, up from USD 27 in 2014 (CAGR 36%).

9.4.3 Fuel cell membranes

A CURRENT PRODUCTS: FUEL CELL MEMBRANES

TECHNOLOGY AND PRODUCTS

A key performance limitation in polymer electrolyte fuel cells is the so-called "mass transport loss". Typically, perfluorosulphonic acid (PFSA) polymer electrolyte membranes (for example, Nafion™) are used in polymer electrolyte fuel cells (PEMFCs) because of their excellent electrochemical stability and conductivity. Unfortunately, methanol cross–over and membrane dehydration processes hinder the efficiency of the cells. Nanostructured membranes can help address some of these issues[403].

DuPont™ Nafion® PFSA membranes are non-reinforced films based on chemically-stabilised perfluorosulphonic acid/PTFE[404] copolymer in the acid (H+) form. The physical properties remain the same for the chemically stabilised membranes, which exhibit substantially lower fluoride ion release compared to the non-stabilised polymer – a sign of improved chemical durability. Nafion ® PFSA membranes are widely used for Proton Exchange Membrane (PEM) fuel cells and water electrolysers. The membrane performs as a separator and solid electrolyte in a variety of electrochemical cells that require the membrane to selectively transport cations across the cell junction. The polymer is chemically resistant and durable[405].

However, Nafion has some disadvantages, such as suffering from chemical crossover and an inability to retain water at higher temperatures, limiting fuel cell operation to 80˚ Celsius. New proton-conducting materials are needed in order to improve the commercialisation of PEMFCs[406].

Researchers at the University of Illinois have developed a proton exchange membrane using a silicon layer with pores of about five nanometres in diameter capped by a layer of porous silica. The silica layer is designed to ensure that the water stays in the nanopores. The water combines with the acid molecules along the wall of the nanopores to form an acidic solution, providing an easy pathway for hydrogen ions through the membrane and giving the membrane much better conductivity of hydrogen ions (100 times better conductivity was reported) in low humidity conditions than the membrane normally used in fuel cells[407].

The EU-FP7 funded project ZEOCELL investigated the properties of several multifunctional nano-structured materials for high-temperature operation. For this purpose, ZEOCELL developed and comprehensively studied seven electrolyte membrane compositions using one or more of the following materials: porous poly-benzimidazole (PBI), protic ionic liquids (PILs) and microporous zeolites/zeotypes. Their morphological, physicochemical, mechanical and electrochemical properties were evaluated in depth. Polymer membrane architecture is crucial for proton transport. Hence, PBI films with random and straight pores were developed for use as proton conductor supports. Suitable functionalisation protocols for microporous materials were established using grafting and filming techniques. Other aspects affecting performance were also studied through phosphoric acid doping, PIL embedding, and the addition of inorganic fillers such as microporous zeolites and titano-silicate nanocrystals[408].

Company snapshot: Bing Energy Inc.

Bing Energy Inc. is a manufacturer of nanotechnology-based membrane fuel cells established in Tallahassee, U.S. The company was founded in 2009 by a group of researchers, entrepreneurs and manufacturing professionals and it is based on patented technology developed at Florida State University (FSU) by Dr Jim Zheng.

[403] Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.22.
[404] PTFE: polytetrafluoroethelyne
[405] DuPont Fuel Cells: DuPont™ Nafion® PFSA Membranes, product information
[406] Jurado J, et al. (2002), Protonic Conductors for Proton Exchange Fuel cells: an overview, Chem. Ind. 56 (6): 265
[407] https://genesisnanotech.wordpress.com/2015/04/26/nanotechnology-in-fuel-cells/
[408] http://cordis.europa.eu/result/rcn/86118_en.html

The Company specialises in membrane electrode assemblies, thin membranes composed of carbon nanotubes which make power generation and energy transfers more efficient and cleaner. Bing's fuel cells cost around USD 10,000 each. Their main markets are the transportation industry and distributed generation. In 2014 Bing Energy Inc. employed ten people in the US with its main facility for manufacturing being in Rugao, China. The Chinese government has a 40% stake in Bing's Chinese subsidiary, taken in exchange for the manufacturing and staff facilities and an investment of USD 7.5 million over five years for equipment and other capital.

In 2015, Bing Energy purchased the assets of US-based EnerFuel, a company with c. 40 patents and prototypes in the area of vehicle range extension using hydrogen fuel cells, a market of great interest to Bing for the US as well as China.

See: http://www.bingenergyinc.com/

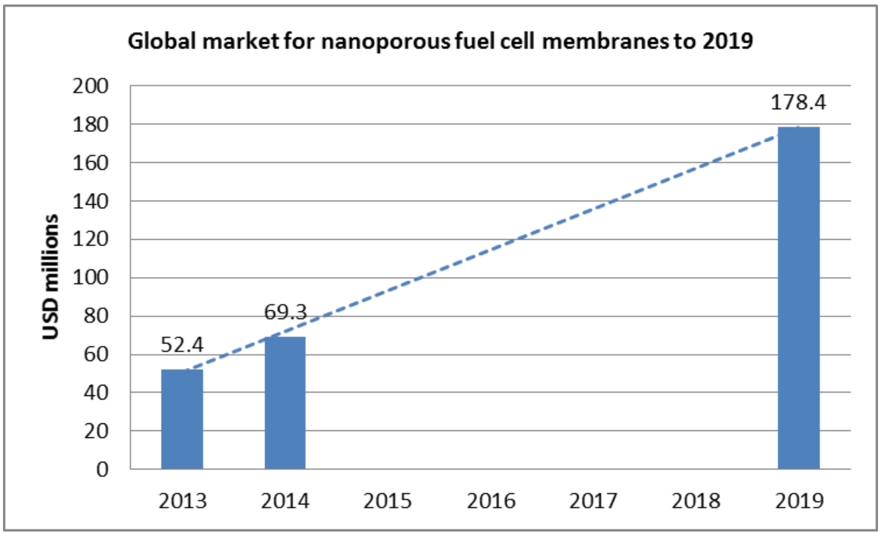
MARKET DATA AND FORECASTS

Sales of Nafion fuel cell membrane materials were estimated to be c. USD 52 million in 2013 while sales of PEMFC and DMFC were an estimated USD 1 billion in 2013. DuPont estimates that the cost of the Nafion membrane represents about 5% of the total cost of a fuel cell. Nafion was used in most PEMFC and DMFC fuel cells on the market in 2013. As shown in the following table, total sales of PEMFC and DMFC fuel cells are expected to exceed USD 7 billion annually by 2019[409].

Table 9-2: Fuel cell sales by technology type to 2019

Technology	2013	2014	2019	CAGR% 2014-2019
	USD (millions)			
PEMFC	985	1,269.4	4,517.1	28.9
DMFC	63	117.2	2,617.1	86.1
Total	1,048	1,386.6	7,134.2	38.8

Source: BCC Research



Source: BCC Research

Figure 9-5: Global market for nanoporous fuel cell membrane materials to 2019

Increasing competition from alternative (nanoscale and non-nanoscale) fuel cell membrane materials are expected to impact on the future market for nanoporous polymer membranes like

[409] BCC Research (2014), Nanotechnology, a realistic market assessment

Nafion. While fuel cells equipped with Nafion and similar nanoporous polymer membrane materials account for most of the market in 2013 and 2014, their share is expected to decline to about half of the global market by 2019[410]. This is expected to be compensated for by the overall growth in the size of the market, as seen in the figure above.

B Emerging markets: Nano-composite fuel cell membranes

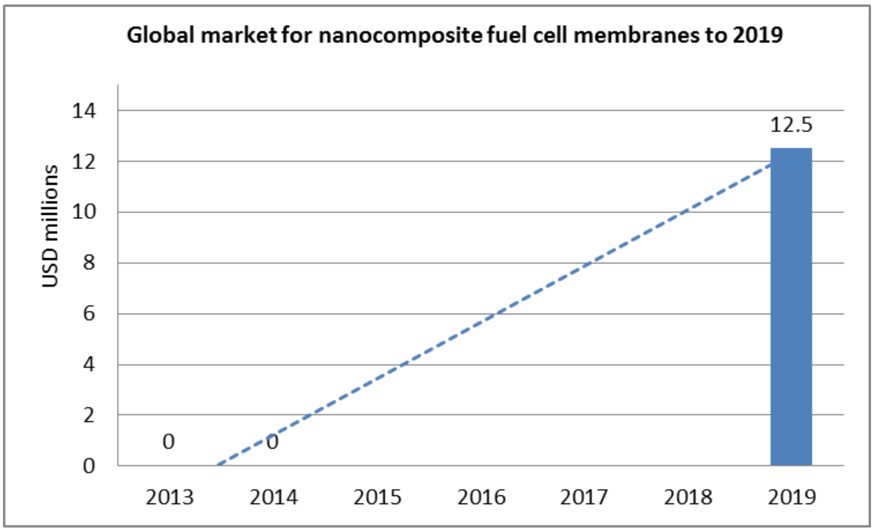
Technology and product trends

Nano-composite membranes are being developed for use in PEMFCs and DMFCs as a potential replacement for existing polymer membranes such as DuPont's Nafion. To overcome the limitations of existing technology, a variety of nano-composite membranes incorporating inorganic nanoparticles such as clay, ZrO_2, SiO_2, TiO_2 and zeolites have been developed. As a group, these nano-composite membranes show higher conductivity and water uptake than unmodified Nafion as well as better thermomechanical properties[411].

SiM Composites[412] (Quebec, Canada), has developed an alternative **nano-composite membrane** technology that it calls SiMION. Data are not available on the composition of SiMION, but it may use a modified polyetheretherketone (PEEK) polymer in which silica nanoparticles are embedded. According to the company, SiMION membranes have been used by several customers, although it is not clear whether these applications are tests or actual commercial products. In any event, the quantities involved are probably small[413].

Market potential

Sales of PEMFC and DMFC fuel cells are projected to grow from USD 1 billion in 2013 and USD 1.4 billion in 2014 to USD 7.1 billion in 2019, a CAGR of 38.8% from 2014 to 2019.



Source: BCC Research, 2014

Figure 9-6: Global market for nano-composite fuel cell membranes to 2019

Sales of PEMFCs are expected to be USD 4.5 billion, and DMFC sales USD 2.6 billion. The average cost of a PEMFC fuel cell is estimated at around USD 2,000, so total 2019 PEMFC sales of USD 2.72 billion implies that around 2,258,500 units will be sold. Since each PEMFC uses an average 10 m^2 of membrane, consumption of all types of PEMFC membrane material should be about 22.6 million m^2 in 2019. If the relationship between sales of DMFCs and DMFC membranes is proportional, consumption of DMFC membranes would be about 13.1 million m^2 by 2019[414].

[410] Ibid
[411] BCC Research (2014), Nanotechnology, a realistic market assessment, p.124
[412] http://www.simcomposites.com/
[413] Ibid
[414] BCC Research (2014), Nanotechnology, a realistic market assessment p.203

9.4.4 Coatings

Coatings (and thin films) can be used during manufacture as well as for the repair and maintenance of vehicles. It has been estimated that half of nano-coatings are applied by original equipment manufacturers (OEM), the other half in refinishing[415]. Nano-coatings are also used for the maintenance of infrastructure.

Research on companies active in the global nano-coating market indicated that, as of November 2011, out of the 250 nano-coating companies surveyed, 50 companies were targeting the automotive industry, 35 the aerospace market and 20 the marine market [416]. Based on these figures, since nano-coating companies can serve multiple markets, the percentage of nano-coating companies targeting the transport sector lies in the range of 20% to 42%. Based on other figures[417], almost 40% of the nano/smart coatings market was being applied in the transport sector (automotive, airline and marine).

A CURRENT PRODUCTS

A1 THIN FILMS IN CATALYTIC CONVERTERS

TECHNOLOGY AND PRODUCTS

A catalytic converter is a device used to reduce the toxicity of emissions from an internal combustion engine. It converts harmful toxic combustion products and their by-products into less toxic substances[418].

Most present-day vehicles that run on gasoline are fitted with a "three-way" converter, so named because it converts the three main pollutants in vehicle exhausts: an oxidising reaction converts carbon monoxide (CO) and unburned hydrocarbons (HC), and a reduction reaction converts oxides of nitrogen (NOx) to produce carbon dioxide (CO_2), nitrogen (N_2), and water (H_2O). The first widespread introduction of catalytic converters was in the US market where, in 1975, gasoline-powered cars were so equipped to comply with tightening regulations by the U.S. Environmental Protection Agency on exhaust emissions. These were "two-way" converters that combined carbon monoxide and unburned hydrocarbons (HC) to produce carbon dioxide and water. Two-way catalytic converters of this type are now considered obsolete, having been replaced, except on lean burn engines, by three-way converters[419].

Most catalytic converters contain a nano-scale thin film of platinum, palladium, and/or rhodium catalyst that convert harmful gases into less harmful substances. The nano-catalyst materials are dispersed over a high-surface-area refractory aluminium oxide support structure. The refractory oxide support is designed to maximise the surface area and the thermal stability of the catalyst[420].

The nano-catalyst film is typically formed *in situ* via a chemical process involving the decomposition or reduction of salts impregnated on the oxide support material. The support structure itself is a nano-scale alumina thin-film, fabricated by depositing a wash-coat containing the oxide particles onto the carrier, followed by drying to form a porous coating. A three-way catalytic converter has a stainless steel body that contains catalytic material as a layer on a substrate (the washcoat). The particles of the noble metal catalyst in the wash-coat are nano-scale. Research is currently in progress, amongst other things, to minimise the amount of noble metal while maintaining the same catalytic performance[421]. Alternatively, a chemical precipitation process, in which the high surface area support particles are formed *in situ* from an aqueous solution, may be used to fabricate the support. These are well-established technologies.

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[415] BCC research CHM075A http://www.bccresearch.com/market-research/chemicals/automotive-coatings-chm075a.html

[416] http://www.nanowerk.com/news/newsid=23444.php Future Markets (2011)

[417] BCC research (2014), Global markets and advanced technologies for paints and coatings: http://www.bccresearch.com/report/download/report/chm049d

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

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

[420] BCC Research (2014), Nanotechnology, a realistic market assessment, p.59

[421] Federal Environment Agency of Germany (2010): Applications of Nanomaterials in Environmental Protection

In 2009, Mazda Motor Corp. of Japan introduced a "single nanocatalyst" technology that reduces the amount of platinum group metal (PGM) catalysts by as much as 70%. Mazda plans to introduce the technology progressively to other models and markets and may eventually license the technology to other manufacturers[422].

Company snapshot: Catalytic converters: Umicore SA

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

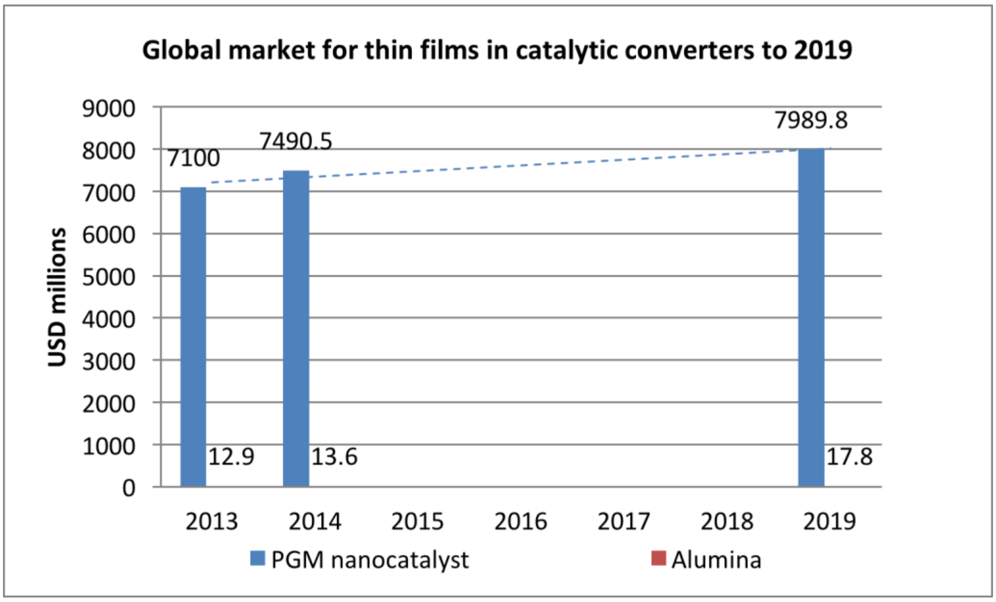
Umicore is one of the world's leading producers of catalysts used in automotive emission systems for light-duty and heavy-duty vehicles. Umicore's catalysts perform in a wide range of powertrains, including gasoline and diesel engines, natural gas, and alternative fuels, and are increasingly important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

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

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

MARKET DATA AND FORECASTS

Catalytic converters are used mainly in light motor vehicles, but also in non-vehicular emission control applications such as power lawn mowers and fork-lifts. These catalytic converters are a major market for platinum group nanocatalysts (i.e., platinum, palladium and rhodium) and for nano-scale alumina, as shown in the figure below.



Source: BCC Research, 2014

Figure 9-7: Global market for thin films in catalytic converters to 2019

The overall weight ratio of alumina support materials to nanocatalysts used in catalytic converters is about 41:1. The total consumption of PGM nanocatalysts (new as well as recycled) was 235,440

[422] http://www.mazda.com/en/innovation/technology/env/other/singlenano_tech/

metric tonnes in 2013. Thus, 5,742 metric tonnes of alumina were consumed in the production of catalytic converters (including non-vehicular converters) in 2013.

At an average price of USD 2,243 per metric tonne, the value of these alumina support materials was USD 12.9 million in 2013. Based on projected trends in the number of vehicular and non-vehicular catalytic converters, consumption of alumina support materials is projected to reach USD 13.6 million in 2014 and USD 17.8 million in 2019[423].

A2 High-strength coatings (nano-structured steel)

Technology and products

Steel is traditionally one of the most important materials in car body construction. Light metals and plastics are increasingly being used in cars given current requirements for lightweight construction, so the share of steel in cars is decreasing overall. In the mid-70’s, a mid-range vehicle had a proportion of steel of a maximum of 75% in its total weight. In the interim, this share has dropped to 50% and is expected to drop further[424].

The types of steel used are changing continuously towards high-strength steel grades in order to satisfy future requirements for lightweight construction and crash safety. One possible way to produce such high-strength steels is using nanotechnologies[425]. The range of possible properties available via nanostructuring may include steels with the hardness of alumina ceramics and the strength of carbon-based fibres. Other potential attributes may be superior corrosion resistance over nickel-based superalloys, higher strength-to-weight ratios than titanium alloys, and better weldability than cobalt-based materials[426].

In 2013, the UK National Institute for Materials Science introduced the world's first bulk nano-structured metal into commercial production. The nano-structure-controlled high-strength steel has the thickness of ferrite platelets of between 20 and 50 nm[427].

Market data and forecasts[428]

The market for high-strength steel coatings was valued at USD 65 million in 2013 and is forecast reach almost USD 77 million in 2014 and USD 175 million in 2019. NanoSteel Inc. (Rhode Island, USA) is currently the main vendor of nano-structured steel coatings, although there are a few other companies, such as Sandvik. NanoSteel does not publish separate sales data on its different product lines, but it has been estimated that the company sold at least USD 50 million worth of nano-structured steel coatings in 2013. The overall market for high-strength steel coatings is forecast to grow at a CAGR of at least 18% over the next five years.

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[423] BCC Research, 2014

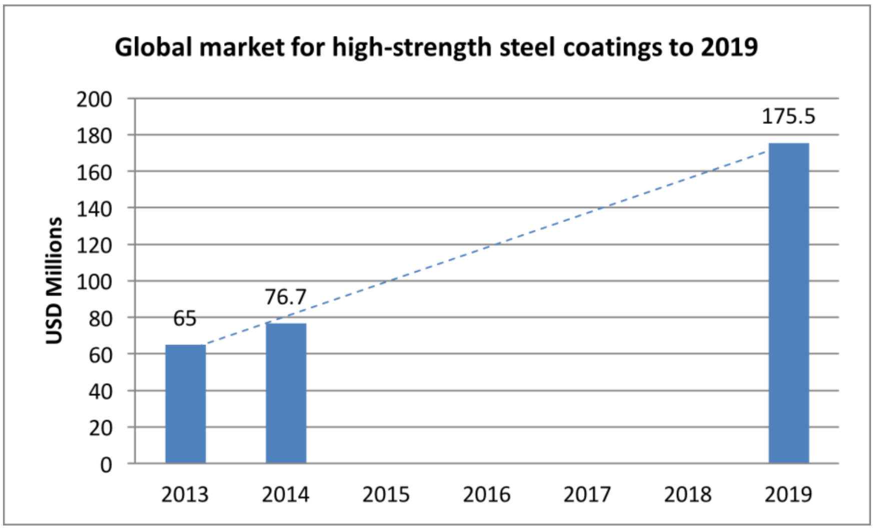
[424] Rudolph, S. (2006), „Neue Alternativen im Automobilbau: Zunehmende Konkurrenz für den Werkstoff Stahl “, DOW JONES Stahlmonitor, Nr. 4, 18. April 2006.

[425] Hessian Ministry of Economy, Transport, Urban and Regional Development (2008), Nanotechnologies in Automobiles, p.15

[426] BCC Research (2014), Nanotechnology, a realistic market assessment, p.64

[427] National Institute for Materials Science: "World's first commercial nanostructured bulk metal." ScienceDaily, 10 November 2013.

[428] BCC Research (2014), Nanotechnology, a realistic market assessment, p.161



Source: BCC Research, 2014

Figure 9-8: Global market for high-strength steel coatings to 2019

A3 PHOTOCATALYTIC COATINGS

TECHNOLOGY AND PRODUCTS

When exposed to light, certain semiconducting materials trigger or accelerate chemical reactions resulting, for example, in the decomposition of organic molecules. Due to their large surface area, nano-sized catalyst particles show a significantly enhanced reactivity compared to larger particles or bulk material. Numerous materials are under examination. However, none currently appear to match the efficiency of titanium dioxide (TiO_2). Its application requires illumination in the UV or at the extreme blue edge of the visible spectrum[429].

These activated agents can oxidise and decompose many types of chemical substances including organic compounds, oil, ammonia, nitrogen oxide (NOx), hydrogen sulphide, and cigarette smoke and tar. Such photocatalytic reactions can be used to sanitise, treat or deodorise air, water, surfaces and fabrics[430].

A process for producing photo-catalytic, self-cleaning coatings was developed by scientists at Singapore's A*STAR (Agency for Science, Technology and Research), and licensed to Haruna (S) Pte Ltd. The patented process produces a coating containing the nano-particle, titanium dioxide (TiO_2). When exposed to an ultraviolet light source, such as the sun, the coating aids in decomposing organic substances such as microbes on its surface. In addition, the hydrophilic nature of the coating causes water that comes into contact with it to form an even layer, thereby allowing the dust and dirt that have accumulated on the surface to be washed away. These two properties of the coating create the "self-cleaning" effect[431].

At least a dozen companies worldwide (including Toto Transport, Toshiba Lighting and Technology, Daikin Industries, Hitachi Metals, Mitsubishi Materials, Deutsche Steinzeug Cremer & Breuer AG, Nissan Motor Co., Matsushita Refrigeration, Airtech, Purifics Environmental Technologies, Matrix Photocatalytic, Lynntech and Kawasaki Heavy Industries) have introduced, or are developing, photocatalytic products[432].

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[429] Observatory Nano (2011), Nano-composite Materials, BRIEFING No.10, p.1
[430] BCC Research (2014), Nanotechnology, a realistic market assessment, p.64
[431] http://phys.org/news/2008-11-photo-catalytic-coating-exteriors.html
[432] BCC Research (2014), Nanotechnology, a realistic market assessment, p.65

The Nissan Motor Company Ltd.

The Nissan Motor Co., Ltd. was founded in Yokohama (Japan) in 1933. In 2013, it was the sixth largest automotive manufacturer worldwide and the second car manufacturer in Japan. It designs and manufactures vehicles (including cars and trucks) and vehicle parts and accessories; engines, manual transmissions, and other related components; industrial equipment engines and other related components, and axles; specially equipped vehicles; and rechargeable lithium-ion batteries. Nissan is also involved in various marine businesses, including boat development and production. Related activities include financial services for companies in the Nissan Group; auto credit and car leasing, cards, insurance, and inventory financial services; consulting related to the analysis and assay of raw materials; and demonstration test and commercialisation studies for the automotive re-uses of lithium-ion batteries. In 2014, the company introduced a self-cleaning nano-paint technology, called Ultra-Ever Dry®, in its zero-emissions electric vehicle Nissan LEAF.

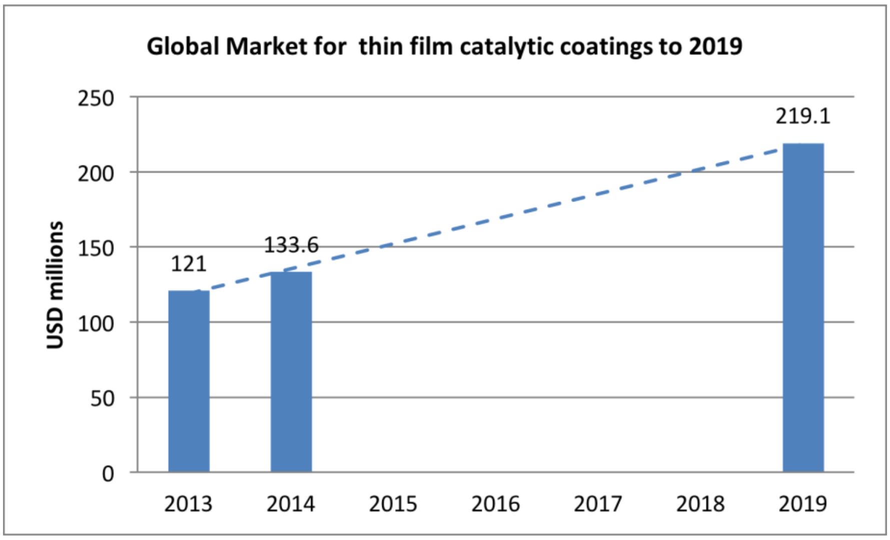
In the fiscal year 2014, the Nissan Motor Co., Ltd. had over 244,500 employees, sold 5.3 million vehicles and generated revenue of 11.38 trillion yen (EUR 82 billion).

http://nissannews.com/en-US/nissan/usa/releases/nissan-creates-world-s-cleanest-car-a-zero-emissions-nissan-leaf-with-self-cleaning-nano-paint-technology

MARKET DATA AND FORECASTS[433]

Nanoscale titanium dioxide thin-films are used as photocatalytic coatings in a variety of products, ranging from anti-fogging mirrors, self-cleaning ceramic tiles and pollution-controlling construction materials. The total consumption of nanoscale TiO_2 thin-film materials in 2013 was estimated at 5,900 metric tonnes with a value of USD 121 million.

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



Source: BCC Research, 2014

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

[433] BCC Research (2014), Nanotechnology, a realistic market assessment, p.157

A4 Anti-scratch/anti-stick coatings

Technology and products

Anti-scratch/anti-stick coatings incorporating nanomaterials have a wide range of consumer, commercial, industrial and institutional uses. Anti-scratch/anti-stick coatings incorporate a variety of nanomaterials, including alumina, silica, titania, zirconia and silicon carbide[434].

Currently, up to 6 m^2 of glass are processed in manufacturing a car, 1.2 m^2 for the windscreen alone. Glass panes will become increasingly important for design and aesthetics. The lightweight construction potential of this technology is enormous, especially with the substitution of mineral glass by polymer glass. Polymer glasses, especially polycarbonates with excellent impact strength and light weight, have already been used for a long time in head-light covers and lenses. In order to make them even more scratch-resistant, they can be coated with acrylate or polysiloxane paints. In these paints extremely hard as aluminium oxide (alumina) nanoparticles added to the substrate matrix during the hardening process result in high abrasive resistance with good impact strength. Due to the small size of the filler particles and their fine distribution, this coating is also highly transparent[435].

PPG introduced CeramiClear, the world’s first nanoparticle-containing automotive OEM clearcoat, in 2002. Since then, PPG has introduced several re-finish products that incorporate the CeramiClear system. Both products reportedly perform to the same standards as the OEM CeramiClear finish in terms of scratch, mar and acid-etch resistance and gloss retention[436].

Nanoparticles such as Degussa’s AEROSIL R9200 for car varnishes, which account for much of the improvement in scratch resistance, are also gaining in importance. Traditionally, AEROSIL can also be found in other layers of the car body shell, where it is used for pigment stabilisation, rheology control and corrosion resistance[437].

NANO-X GmbH

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

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

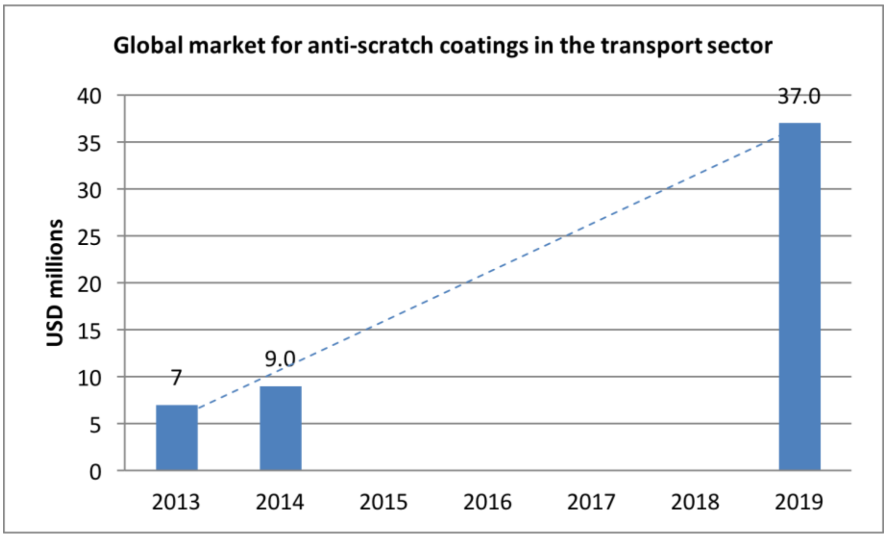
[434] BCC Research (2014), Nanotechnology, a realistic market assessment, p.65
[435] Hessian Ministry of Economy, Transport, Urban and Regional Development (2008), Nanotechnologies in Automobiles, p.12
[436] BCC Research (2014), Nanotechnology, a realistic market assessment, p.66
[437] Hessian Ministry of Economy, Transport, Urban and Regional Development (2008), Nanotechnologies in Automobiles, p.11

MARKET DATA AND FORECASTS[438]

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

The total market for nano-structured anti-scratch coatings was estimated at 980 metric tonnes with a value of USD 74 million in 2013, a figure expected to grow to USD 82 million in 2014 and USD 145 million in 2019 (a CAGR of 12.1% between 2014 and 2019).

Ophthalmic coatings and floor finishes are segments that are expected to grow at CAGRs of 8.2% and 8.1%, respectively, from 2014 through 2019. The market for other types of anti-scratch coatings (especially automotive clearcoat) is expected to grow much faster (at a CAGR of over 32%) between 2014 and 2019.



Source: BCC Research, 2014

Figure 9-10: Global market for alumina and other oxide nanoparticles used in automotive anti-scratch coatings to 2019

A5 THERMAL SPRAY COATINGS

TECHNOLOGY AND PRODUCTS

Thermal-spray metallic coatings are coatings of metals such as zinc, copper and brass. Thermal-spray coatings are applied by melting a wire feedstock and propelling the molten droplets in a stream of compressed air on the surface to be treated. These coatings repel zebra mussels through the slow dissolution of metal ions into the water. Zinc thermal spray also provides excellent corrosion resistance on steel surfaces. Copper and brass should never be applied directly to steel because the steel will corrode. Thermal spray coatings should not be used on non-ferrous metal substrates but with proper surface preparation they may be used on concrete, for example. Thermal spray coatings are potentially the most durable and lasting repellent coatings for zebra-mussels[439].

Tefcite has been developed by Reintjes Surface Technologies and is a long lasting, environmentally friendly anti-fouling technology with a proven service life of over 10 years. Tefcite is a composite material that incorporates copper-based particulates within a polymer thermoplastic powder. The

[438] BCC Research (2014), Nanotechnology, a realistic market assessment, p.157

[439] http://el.erdc.usace.army.mil/zebra/zmis/zmishelp/antifouling_foul_release_and_thermal_spray_coatings.htm

coating is applied using a patented thermal spray technology that provides a tough, impact resistant and smooth surface that is immediately cured[440].

Several firms have been active in developing and commercialising thermal spray coatings in the transport sector including coating specialists like Liburdi, Seram Coatings AS, Precision Coatings, Inc. but also nanopowder/feedstock producers such as Altair Nanotechnologies Inc., Inframat Corp. and NEI Corp.

Case study: Altair Nanotechnologies, Inc.

Altair Nanotechnologies, Inc., or Altairnano, provides nanomaterial technology and nanomaterials worldwide. The company manufactures nanocrystalline materials through a proprietary technology. Potential application areas for the nanomaterials include batteries, solar cells, paints, catalysts, pharmaceuticals and cosmetics.

Altairnano is a Canadian corporation, with its principal assets and operations in the United States. Founded in 1973, the company is headquartered in Reno, Nevada (US) with a 100,000 square foot facility, and a 70,000 square foot manufacturing facility in Anderson, Indiana (US). In 2010, Altairnano had revenue of USD 7.8 million (EUR and just over 100 employees.

Altairnano entered the battery industry roughly ten years ago when its material scientists identified novel ways to use nanoscale technologies to process lithium titanate oxide (LTO) materials. Research and development work in the company led to the commercialisation of a large format, nano lithium titanate (nLTO) battery cell, which had key advantages over other lithium ion battery (LiB) technologies, even those that used LTO materials. The products are suitable for use in the electric grid, transportation and industrial sectors.

In addition to specialising in battery solutions for hybrid and electric vehicles, Altairnano has developed products to reduce fuel consumption, emissions, noise pollution and maintenance costs.

http://www.altairnano.com/solutions/transportation/

Oerlikon Metco is offering thermal sprayed coatings for flight gas turbines that are used in many different places and for many different functions. Protective coatings for high temperature corrosion resistance, thermally insulating coatings, clearance control coatings and the repair of superalloy components with coatings of similar composition are examples for applications. Next to the coating of numerous small parts, the newest development in the automotive sector for Oerlikon Metco is coatings for aluminium engine blocks. The cylinder bores of the engines are coated by means of a special rotating plasma gun manipulator, which can apply the coating to the interior of the small bores with a wear resistant surface[441].

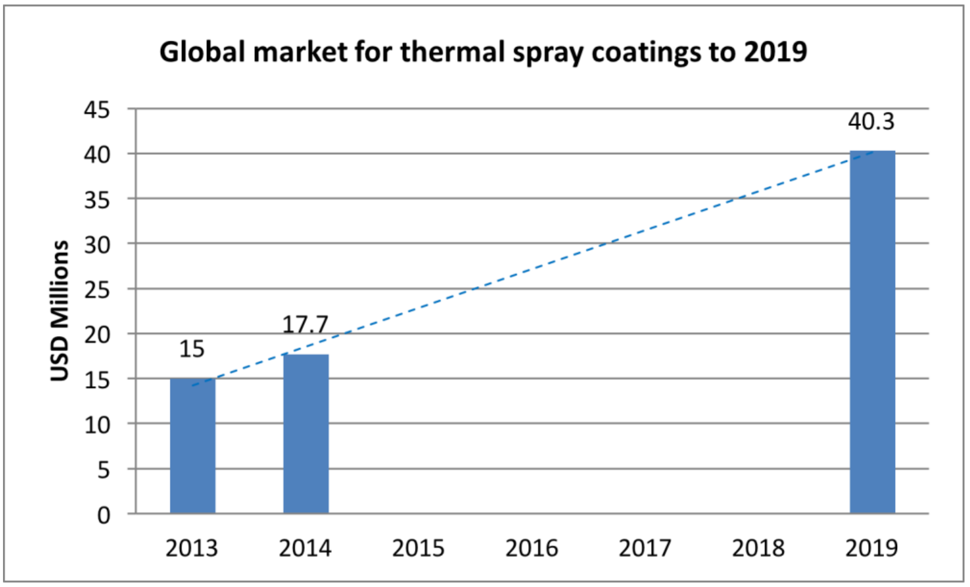
There are also numerous commercial applications for the coating, although its comparatively high cost currently limits its use to the most demanding applications[442].

MARKET DATA AND FORECASTS[443]

The global consumption of nanoscale thermal spray coating materials was estimated to be about 160 metric tonnes or in the region of USD 15 million in 2013. The thermal spray coatings market is relatively mature, growing at a CAGR of perhaps 5% per year.

The market for nanoscale thermal spray coatings, on the other hand, has been growing by as much as 25% per year since they were introduced over 10 years ago, as new applications were developed and end users were informed about their advantages. In the future, growth in nanoscale coatings is expected to be driven by the ability of manufacturers to develop new applications, while reducing feedstock costs.

440 http://www.spraywerx.com/applications/ship-building/tefcite-antifouling-technology/
441 http://www.oerlikon.com/metco/en/products-services/coating-equipment/thermal-spray/
442 BCC Research (2014), Nanotechnology, a realistic market assessment, p.40
443 BCC Research (2014), Nanotechnology, a realistic market assessment, p.159



Source: BCC Research, 2014

Figure 9-11: Global market for thermal spray coatings to 2019

The earliest market for nanoscale thermal spray coatings was in repair applications for the U.S. Navy. Industry participants say that they are moving beyond repair applications, however, to new applications for both military and commercial customers. Other potential applications include new marine construction and turbine blades.

It is difficult to enumerate all the potential commercial applications, which are just emerging or yet to emerge and they are expected to continue to grow at their historical rate of 25% per year in volume terms through to 2019. (Since most current applications of the coatings are military, the market should not be affected significantly by the current recession.) However, it is expected that the price of the nanoscale materials will reduce by at least 30% by 2019.

Case study: ANS-Applied Nano Surfaces

Applied Nano Surfaces, Sweden (ANS) was established in 2007 to commercialise the outputs of research carried out at Uppsala University/Ångström Laboratory in the early 2000's. It is a nanotechnology-enabled materials company currently working with many of the global automotive companies as well as large scale manufacturers of bearings, pumps, rock drills and compressors. It employs around 16 people at present, about half of them in the R&D division. The workforce consists of PhDs and engineers with Masters degrees. ANS has offices in Sweden, Germany and Canada.

The company has two core offerings, ANS Triboconditioning® and ANS Tricolit®. ANS Triboconditioning®[444] is used for smoother surfaces and friction-reduction coatings in steel and cast iron components, thereby reducing energy consumption. The ever-increasing demand of fuel/energy efficiency by the end customer is driving the market for ANS. The technology is versatile and can be easily implemented on pre-existing infrastructure e.g. production machinery already being used in turning, honing or grinding processes. ANS Tricolit®[445] is a friction-reduction coating which can be applied in the form of a spray to various materials, such as stainless steel, aluminium, steel and plastic.

The company is privately held, mainly by the Sjätte AP Fonden (The Sixth Swedish National Pension Fund) and FourierTransform AB (a Swedish state-owned venture capital company) and the company founders. It is mostly funded by its owners and through loans.

[444] http://appliednanosurfaces.com/products/ans-triboconditioning/
[445] http://appliednanosurfaces.com/products/ans-tricolit/

ANS is currently planning to raise EUR 1.5 million in equity in 2016. It has started discussions with several VC-firms and new investors may also become involved. ANS is currently funding the process development, R&D activities, customer project work and market introduction using project revenues (approximately 30%) and the rest through its own capital (equity and loans). The target is to make its market activities cash flow positive in 2018/2019.

Though ANS mainly targets the automotive sector (engine and transmission parts) with around 60% of total sales, its products can also be used in the heavy industrial equipment industry (e.g. for compressors and hydraulic engines). ANS is currently working on client-funded projects and selling the products on a license basis.

ANS has had a steady growth in terms of number of customer projects per year, which grew from 3 in 2009 to 49 in 2015 (7, 16, 32,35, 39 respectively in 2010, 2011, 2012, 2013 and 2014). Revenues from customer projects have been steady around EUR 0.3 million per year for the last 5 years. ANS has increased its efficiency over time, so the cost per customer project has gone down. In 2016, ANS is expecting its first license revenues from customers.

So far, the total R&D investment has been EUR 3.5 million (accumulated value end 2015). In 2015, R&D investment was about EUR 1 million and in 2014 about EUR 0.7 million. The reflected budget for 2016 R&D-investment is about EUR 1.1 million.

The company owns two granted US patents (US patent number US 9032597 B2, US 8545930 B2) and has two patent applications (US Patent number US 2010/0272931 A1, US 2013/0104357 A1). ANS partnered with Bodycote (market participant in the heat and surface treatment vertical) in December 2014[446]*.*

ANS estimates its own total market value (license revenue potential) to be EUR 0.5 billion per annum based on current products and the application of the technology within the customer base currently being targeted for its yearly license revenue potential. The total market potential according to ANS, adding new customers as well as new application areas, is estimated be more than EUR 2 billion per annum in license revenues. In this established market, ANS targets a 25% market share, with primary focus on European manufacturers as well as American entities.

So far in 2016, the company is set to reach a revenue of EUR 0.5 million. The funding to date is around EUR 6 million, most of which has been directed towards developing the technology and protecting intellectual property (IP). The company is currently progressing with the launch of a new variant of the ANS Tricolit® which is expected to make various kinds of heat treatment solutions more effective. The aim is to provide a combination of wear resistance and low friction for combustion engines and transmissions in automotive applications as well as a range of industrial applications exposed to high loads, friction and wear. This technology has thus a potential to target a very large market looking for new solutions to minimise friction losses, thereby reducing energy consumption and CO_2*-emissions.*

The company generated revenue of around EUR 0.4 million in 2015, around 20% (EUR 0.08 million) from ANS Tricolit® and 80% from ANS Triboconditioning®, in both cases around 50% coming from the automotive sector.

The company focuses highly on growth, both with respect to the workforce and the revenue. The company plans to generate revenue of EUR 3.5 million in 2018 and to boost the workforce from 16 in 2016 to 24 in 2018. Furthermore, the market for the application of nanotechnology in industrial equipment is expected to gather sufficient potential by 2018 and thus, ANS projects an ambition to generate revenue in the range of EUR 5 to 6 million by 2019.

ANS recently participated in a Horizon 2020 grant application together with Gnutti Carlo (developer and supplier of high performance heavy duty valve train and fuel injection components) and received very a high score on the application but was not awarded funding. The consortium is currently reviewing the options on how to proceed. So far, ANS has not been involved in developing environmental or regulatory activity or health and safety projects.

[446] http://appliednanosurfaces.com/newsroom/

ANS has received support from Swedish research programmes such as FFI-programmes[447] *and from Sweden's Vinnova. The programmes have been successful in supporting the development of the technologies in projects together with ANS' customers. Total grants to ANS in 2013-2015 were EUR 0.3 million. ANS has also received EUR 2 million loans from Sweden's Department of Energy to support company development.*

The projects were stated by the company as having had very positive evaluation by the state agencies. Also for ANS the programmes have been very important as the programmes have targeted development and research of the ANS technologies on specific applications together with end customers. The results of these programmes have been a signed license deal with Gnutti Carlo.

ANS expressed its interest in participating in EU programmes that could help to support the final industrialisation and market roll out of the technologies for specific applications and markets. Time to market is deemed to be very important to enable the maximum impact of the technologies and to support customers in meeting future CO_2 *emission targets. Thus focused R&D and customer support work is necessary to take the last step to introduce ANS technologies into full scale manufacturing. EU programmes could support such a step by providing a framework for the work within an established consortium, supporting external research in universities as well as providing some of the funding that would accelerate progress and shorten the time to market.*

ANS welcomes the local support available from Swedish state programmes. These have been instrumental in supporting the development of the company by bringing together industry participants (end-users of ANS technology), researchers in Universities and ANS development staff. However, these state grants are limited in terms of budget and thus the work has had to be kept very lean and focused, carefully balancing the activities and internal and external resources deployed. Even though the national programmes are limited, thus reducing the possible scope of activities, applying for EU funding takes more time and requires more of the limited resources of the company.

ANS's R&D strategy is to industrialise its proprietary unique low-friction processes in order to achieve implementation readiness for customer manufacturing lines. In this work, the strategy of the company is to work closely with partners (machine builders and tool suppliers) and end-users (automotive companies producing engine parts and original equipment manufacturers (OEMs)). Such work includes joint testing of treated parts and assessment of the benefits brought by the technology, tests performed both by automotive companies and OEMs. The commercial strategy is to sign license deals with component manufacturers and OEMs and implement the technologies directly in the customer's production lines. The customer pays a license fee for each part treated.

The main factor limiting commercialisation by ANS is financing. There are a limited number of venture capital firms investing in the early stages of development of ground-breaking new technologies for the automotive and transportation industry due to the high level of effort and finance required. ANS has been successful so far in raising capital but such activities are time consuming and result in a compromise of focus on other important areas.

[447] FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety.

9.4.5 Nano-composites

A CURRENT PRODUCTS

A1 AUTOMOTIVE PARTS

TECHNOLOGY AND PRODUCTS

A nano-composite material is a solid multiphase material where at least one or more phases have dimensions of less than 100 nanometres (nm). This leads to unique properties when compared with conventional composite materials. The improved properties of the nano-composite materials can include better mechanical properties, a higher chemical resistance, a decreased gas permeability and a good electrical conductivity at low filling grades in comparison with conventional filler materials as well as good (or better) processing capabilities. In most cases a nano-scale filler material such as clay, carbon black, carbon nanotubes, silicon carbide or graphene is embedded in a matrix material which could be for example a polymer like polyester, epoxy, polyamide and others. The filler of reinforced materials considerably controls the properties of synthetic materials[448].

The automotive and aircraft market can benefit from nano-composite materials. They offer the possibility to significantly reduce overall weight by reducing the weight of mechanical and electronic components. Increasingly, carbon nanotubes as filler materials are being used in the automotive market mainly for fuel system components and body parts. Also epoxy resin systems are finding increasing interest in the automotive and aircraft industry[449].

Polymer based nano-composites can find use in tyres, fuel systems, gas separation membranes in fuel cells and seat textiles, mirror housings on various vehicle types, door handles, engine covers, intake manifolds and timing belt covers, with some of these already being exploited. For example, a thermoplastic nano-composite containing nano-flake reinforcements (e.g. trade name Basell TPO-Nano) is being employed for the development of stiff and light exterior parts, like the step-assists by GM. Also, porous polymer nano-composites can be employed for the development of pollution filters. Other promising technological application in the horizon is in airbag sensors, where nano-optical platelets are kept inside the polymer outer layer for transmitting signals at speed of light gaining milliseconds to bring down the level of possible impact injuries[450].

Polymer/carbon nanotube nano-composites containing 2% to 5% nanotubes are used in fuel lines and exterior painted parts. Because the carbon nanotubes are highly conductive, they offer sufficient protection against static build-up caused by the moving fuel, at loadings that are low enough to preserve the tensile elongation of the nylon. Greater tensile elongation reduces the chance of a fuel line rupture at low temperatures[451].

In body panels and other painted parts, nanotubes impart sufficient conductivity so that the part may be electrostatically spray-painted. Because the nanotube loadings are low (2% to 4%), and the nanotubes are so small, Class A surfaces are obtained. Nearly every car produced in the U.S. since the late 1990s contains some carbon nanotubes, typically blended into nylon to protect against static electricity in the fuel system[452].

Cellulose nano-fibre-reinforced bioplastics have a wide range of potential applications, including auto parts. Some industry sources believe that the first application of these nano-biocomposites will be biodegradable parts for "green vehicles"[453].

[448] Observatory Nano (2013), Nano-composite Materials, BRIEFING No.30, p.1
[449] Observatory Nano (2013), Nano-composite Materials, BRIEFING No.30, p.2
[450] Camargo, et al. (2009), Nano-composites: synthesis, structure, properties and new application opportunities, Materials Research, 12(1), p.27
[451] BCC Research (2014), Nanotechnology, a realistic market assessment, p.84
[452] Ibid
[453] Ibid

Nanocor Inc.

Nanocor, Inc. was founded in 1995 in Hoffman Estates, Illinois (US) as a wholly-owned subsidiary of AMCOL International Corporation with the specific purpose of pursuing opportunities in nanotechnology, specifically the development of nanometre-size bentonite-based composites as additives for plastics, bentonite being an absorbent aluminium phyllosilicate clay. Nanocor's first production facility was in Aberdeen, Mississippi, US. AMCOL 2014 was taken over in 2014 by Materials Technologies, a resource- and technology-based company that develops, produces and markets worldwide a broad range of specialty mineral, mineral-based and synthetic mineral products and related systems and services.

Nanocor Inc. manufactures and supplies nano-clays for plastic nano-composites, providing nano-clays as microfine powders for use in resin systems, such as polyamides, epoxy, urethanes, EPDM (ethylene propylene diene terpolymer), and engineering resins, as well as in pellet form for use in resin systems, including polypropylene homopolymers and copolymers, polyethylenes (low-density (LDPE), linear low-density (LLDPE), high-density (HDPE)), and ethylene methacrylate (EMA). The company also produces nylon concentrates for nylon pack cloth (NPC) as well as nano-composites in pellet form for injection moulding, blow moulding, and film casting. Among its products are: Imperm, a nylon that gives protection for oxygen sensitive products, and CO2 retention for carbonated soft drinks, waters, beers, and flavoured alcoholic beverages; Durethan, a nylon nano-composite for films and paper coating; Aegis NC, a nylon nano-composite for film and paper coating, and engineering applications; and Aegis OX that combines nano-composite barrier and an oxygen scavenger in one system for use in beer bottles. Other products include nanoTUFF, a nylon nano-composite for applications where high modulus and cold weather impact are required; and nanoSEAL for tank and hose fuel systems. Nanocor working areas include consumer packaging and transportation applications; and business, industrial, and general consumer applications.

http://www.nanocor.com/

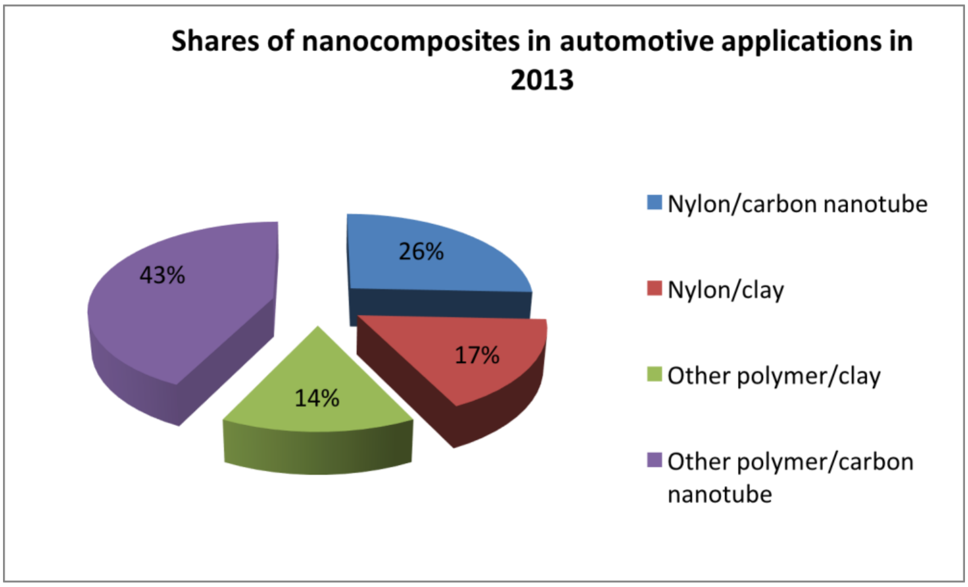
http://www.mineralstech.com/Pages/MTI/About-Us.aspx

Ref: International Directory of Company Histories, Vol.59. St. James Press, 2004.

MARKET DATA AND FORECASTS [454]

It has been estimated that the market for all types of nano-composites used in manufacturing automotive components at USD 277 million in 2013. Carbon nanotube-based nano-composites accounted for the bulk of the market.

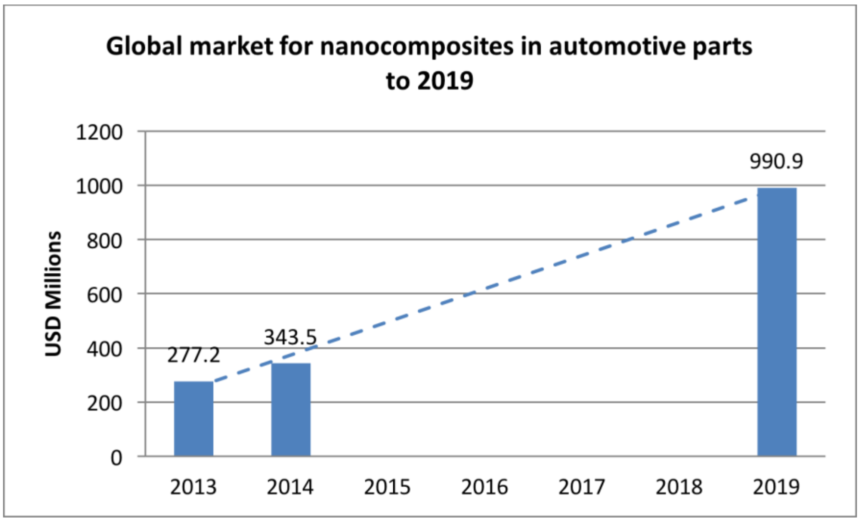
[454] BCC Research (2014), Nanotechnology, a realistic market assessment, p.175-176



Source: BCC Research, 2014

Figure 9-12: Global market for nano-composites in automotive parts in 2013 by type of composite

Factors driving the automotive nano-composite market vary by sub-segment. It is estimated that the automotive market for nano-composites will grow (in value terms) at an average annual rate of close to 24% from 2014 through 2019.



Source: BCC Research, 2014

Figure 9-13: Global market for nano-composites in automotive to 2019

A2 HYDROPHOBIC/OLEOPHOBIC NANO-COMPOSITES

TECHNOLOGY AND PRODUCTS

Hydrophobic surfaces have established themselves as candidates for various engineering applications, such as self-cleaning, anti-bio-fouling, anti-icing, anticorrosion, drag reduction at micro and macro scales and textiles to name a few. Superhydrophobicity provides a pathway toward protecting sensitive properties of the surfaces, which can be easily affected by environmental factors such as rain, dirt, etc.[455].

Nanogate GmbH has developed and markets a variety of products based on its proprietary hydrophobic/oleophobic nano-composites. Little information is available on the composition of these nano-composites. According to some published reports, Nanogate's nano-composite technology is based on a self-organising nano-composite material that is created by breaking down a composite material (consisting mainly of alcohol and sand) into nanoparticles. Some of the resulting nanoparticles are adhesive and move naturally toward the substrate surface to which they adhere, whereas other anti-adhesive nanoparticles move toward the air, where they help to prevent dirt and grease from attaching themselves to the protective film. Nanoparticles with binding qualities keep the outside and inside layers of film together, creating a surface that is both hydrophobic and oleophobic[456].

Cotec GmbH has developed a fluor-organic material which exhibits both hydrophobic and oelophobic qualities when segregated on a workpiece. The layer with a thickness of 5 to 10 nanometres results in a super-smooth surface, which is easy to clean of impurities such as water drops, oil, dust, dirt, sweat and fingerprints. Due to its good dynamic friction properties, there is only low abrasion during cleaning, which results in a longer durability of the layer. This layer consists of molecular chains that have an anchor group at one end with which the layer forms a chemical bond on the surface of the substrate and thereby "digs in". The functional group at the other end is responsible for the water-, fat- and dirt-repellent effect. The layer systems developed by Cotec are used in the automotive industry and its subcontractors for the coating of mirrors, injection -moulded components and reflectors[457].

MARKET DATA AND FORECASTS [458]

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

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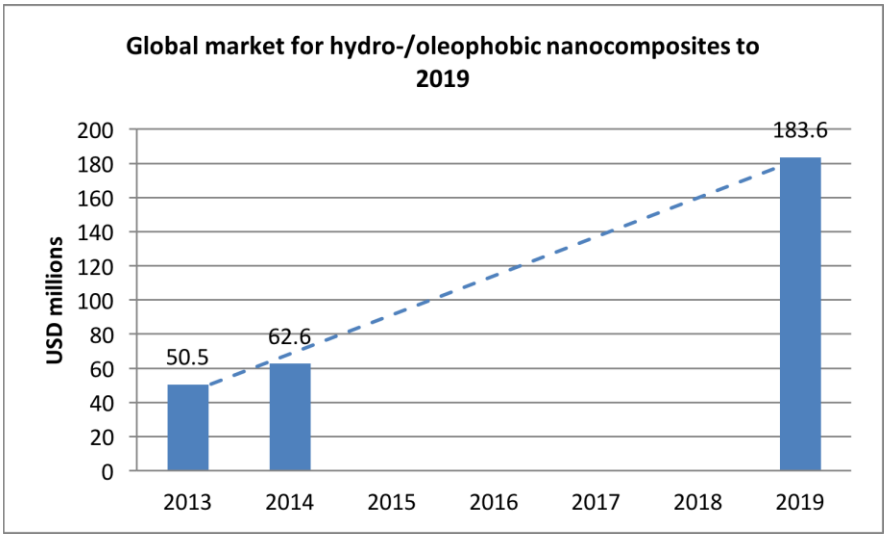
[455] Asthana et al. (2014), Multifunctional Superhydrophobic Polymer/Carbon Nano-composites: Graphene, Carbon Nanotubes, or Carbon Black? ACS Appl. Mater. Interfaces

[456] BCC Research (2015), Global Markets for Nano-composites, Nanoparticles, Nanoclays, and Nanotubes, p.66

[457] Hessian Ministry of Economy, Transport, Urban and Regional Development (2008), Nanotechnologies in Automobiles, p.13

[458] BCC Research (2014), Nanotechnology, a realistic market assessment, p.180



Source: BCC Research, 2014

Figure 9-14: Global market for hydrophobic/oleophobic nano-composites to 2019

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

The Nanogate Group

Nanogate was founded in 1999 as a spin-off from the Leibniz Institute for New Materials (INM)[459] in Saarbrücken. In 2006, it became a public limited company (Nanogate AG). Nanogate is a leading international provider of integrated systems for high-performance and multi-functional surfaces. It enables additional properties – such as non-stick, scratch-proof and anti-corrosive – to be incorporated into materials and surfaces for companies in a wide range of industries.

The Nanogate Group[460] consists of the parent company Nanogate AG (Quierschied-Göttelborn, Germany) and the consolidated portfolio companies of Nanogate Industrial Solutions GmbH (NIS) (Quierschied-Göttelborn), Gesellschaft für Oberflächentechnik AG (GfO) (Schwäbisch Gmünd, Germany), Nanogate Textile & Care Systems GmbH (NTCS) (Quierschied-Göttelborn) and Plastic-Design GmbH (Bad Salzuflen, Germany). The shares in Eurogard B.V. (Geldrop, the Netherlands) and Nanogate Glazing Systems B.V. (Geldrop), are pooled in the intermediate holding company Nanogate Nederland B.V. (Geldrop). In July 2014, the Nanogate Group also acquired all of the shares in surface specialist, Vogler, which now trades under the name Vogler GmbH (Lüdenscheid, Germany). At the end of 2015, Nanogate AG transferred all of the shares in Vogler GmbH to Nanogate Industrial Solutions GmbH. Following the end of the reporting period, the Group also acquired a 75 % stake in plastics specialist Walter Goletz GmbH.

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

459 http://www.leibniz-inm.de/en/
460 http://www.nanogate.de/en/home

Volkswagen) with several hundred projects already having gone into mass production. The company also has strategic partnerships with many international corporations.

As of 31 December 2015, the Nanogate Group had 586 employees. It increased sales in the 2015 financial year by about 30 % to over EUR 90 million (previous year: EUR 68.6 million) and overall performance exceeded EUR 94 million (previous year: EUR 71.1 million). In the expansion of its volume of business, the Group benefited from a strong demand for systems in its strategic application areas of advanced metals and advanced polymers, as well as from consolidation effects and strong end-of-year business. The operating result (consolidated earnings before interest, taxes, depreciation and amortisation, EBITDA) improved by around 35 % to over EUR 10 million (previous year: EUR 7.4 million). Consolidated earnings before interest and tax (EBIT) totalled more than EUR 2.8 million (previous year: EUR 2.5 million).

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

Nanogate remains optimistic about the current 2016 financial year. On the basis of existing projects and the acquisition of Goletz, the Group expects to see a substantial increase in sales to more than EUR 105 million. The Group would therefore exceed its medium-term sales target of EUR 100 million initially announced in 2014, reaching a significant milestone in its (Phase 5) growth strategy, having generated sales of EUR 53 million in 2013. Despite the continued expenses associated with the expansion strategy as well as one-off transaction and integration costs, the Group also expects its operating result to increase significantly in 2016 and to exceed the EUR 12 million mark. Substantial funds will continue to flow into the ongoing investment programme and international expansion. In view of the growth strategy, consolidated nett income will continue to be shaped by depreciation and amortisation as well as financing costs.

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

For reasons of efficiency, Nanogate collaborates on fundamental and applied research with several recognised research institutes, such as the Leibniz Institute for New Materials (INM)[461] in Saarbrücken, the plastics technology department of the Kaiserslautern University of Applied Sciences[462], the Öko-Institut Freiburg[463] and the Kunststoff-Institut Lüdenscheid[464]. Nanogate has also successfully participated in EU projects within FP6 and FP7.

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

[461] http://www.leibniz-inm.de/en/
[462] https://www.hs-kl.de/international/
[463] http://www.oeko.de/en/
[464] http://www.kunststoff-institut.de/inhalte/en/startseite.php

Case study: Nanocyl

Nanocyl[465] is headquartered in Belgium since it was founded as a spin-off from the Universities of Namur and Liège in 2002. The company has commercial and technical support wings in the US (Nanocyl Inc.) in Atlanta, Georgia and distributors in various Asia Pacific locations such as Korea (Seoul), Taiwan (Chinese Taipei), China (Shanghai-Guangzhou) and Singapore. Nanocyl specialises in the development and manufacturing of Nanocyl® NC7000™ carbon nanotubes, produced in multi-tons via a chemical vapour deposition (CVD) process.

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

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

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

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

- *RECYTUBE. Reutilisation of scraps containing carbon nanotubes generated during master batch, compounding or injection moulding to produce new plastic nano-composites with commercial value. (www.recytube.eu, Project Number: 256152);*
- *MULTIPLAT. Novel biomimetic selective ion-conductive thin membranes with highly ordered structure as a multipurpose platform for range of applications.(www.multiplat.net, Project Number: 228943);*
- *MARINA. Risk assessment and management of nanomaterials: Materials, Exposure, Hazard and Risk. (www.marina.eu, Project Number: 263215);*
- *IMS-CPS. Innovative Material Synergies & Composite Processing Strategies (www.imscps.eu, Project Number: 246243);*
- *LASERCELL. Novel competitive performance alkaline fuel cells and stacks that can be economically produced in volume for large scale stationary applications.(http://www.laser-cell.eu, Project Number: 278674);*
- *STORAGE. Structural lightweight composite power storage for hybrid vehicles to perform efficient propulsion and energy needs of future vehicles. (www3.imperial.ac.uk/structuralpowerstorage, Project Number: 234236);*
- *THERMONANO. Low temperature heat exchangers based on thermally conductive polymers nano-composites. (www.thermonano.org, Project Number: 227407);*
- *SARISTU. Reductions in aircraft weight and operational costs as well as an improvement in the flight profile specific aerodynamic performance. (www.saristu.eu, Project Number: 284562);*
- *DEROCA. Development of safer and more eco-friendly flame Retardant materials based on CNT co-additives for Commodity Applications. (http://www.deroca.eu, Project Number: 308391);*
- *NANOSOLUTIONS. Biology Approaches to understand interactions of engineered nanomaterials with living organisms and the environment. (http://nanosolutionsfp7.com/, Project Number: 309329);*

465 http://www.nanocyl.com/

- *INSIGHT. In-line characterisation of nanoparticles during nanomaterial manufacturing. The objective is to develop new tools to measure/evaluate the nano-engineered particles in a medium or alone. (http://www.fp7-insight.com, Project Number: 263374); and*
- *PLATFORM. Open access pilot lines development for industrial production of nano-enabled products (buckypapers, CNT treated prepreg and CNT doped non-woven veils) for applications in composite parts for sectors such as Aeronautic and Automotive. The purpose of the project is to efficiently and economically manufacture the components using novel nanomaterials at a scale suitable for industrial uptake. (website under construction, Project Number: 646307).*

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

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

B EMERGING PRODUCTS

B1 GRAPHENE POLYMER COMPOSITES

TECHNOLOGY AND PRODUCTS

Graphene is predicted to have many potential applications in the future, the most immediate being in composite materials. One example is polymer nano-composites (or polymer matrix composites), which incorporate nano-scale filler materials. Indeed, graphene-based polymers show substantial property enhancements at much lower loadings than polymer composites with conventional micron-scale fillers (such as glass or carbon fibres), which ultimately results in lower component weight and can simplify processing. Moreover, the multifunctional property enhancements made possible with nano-composites may create new applications of polymers. It has been found that by dispersing a small amount of graphene in polymers, many properties of the resulting composites (such as tensile strength and elastic modulus, electrical and thermal conductivity, thermal stability, gas barrier, and flame-retardance) can be significantly improved. These properties make graphene-based polymers and composites good candidates for structural materials for the automotive sector[466].

Various graphene-filled polymer composites have been developed, of which graphene-polystyrene composites are among the more promising. However, the list of possibilities is much longer and includes, at a minimum, alternatives to most of the carbon nanotube- and fullerene-polymer composites that have been developed or investigated. The properties of graphene-polymer composites compare favourably with those of nanotube-polymer composites. Indeed, graphene may offer some performance-related advantages over nanotubes as a filler material. Graphene-polymer composites have many of the same potential applications as carbon nanotube composites, including automotive components (e.g., fuel lines, exterior painted parts)[467].

One of the projects that was selected in 2014 for the 2nd-stage of the EU's Graphene Flagship initiative is called iGCAuto, led by the University of Sunderland (UK). In this project, partners will explore the use of graphene and graphene-composite materials in the automotive industry. The focus of the project will be to find new materials that can make vehicles lighter and safer. The partners include Fiat, the Fraunhofer ICT, Interquimica, Nanesa and Delta-Tech[468].

[466] Elmarakbi, A. et al (2015), Novel Composite Materials for Automotive Applications: Concepts and Challenges for Energy-efficient and Safe Vehicles, paper presented at the 10th International Conference on Composite Science and Technology

[467] BCC Research (2014), Nanotechnology, a realistic market assessment, p.93-94

[468] http://www.sciencecodex.com/fiat_drives_forward_wonder_material_to_revolutionize_automotive_industry-136574

MARKET DATA AND FORECASTS[469]

Although graphene composites are not yet in commercial use, it is expected that they will reach the market in the next five years and capture significant market share from competing products, especially carbon nanotube composites. The estimated global market for carbon nanotube composites is predicted to be USD 56.9 million by 2019, the point at which graphene nano-composites should be commercially available. In spite of the lead that nanotube composites have on the market, the performance and cost advantages of graphene composites may enable them to capture a significant share (e.g. 10%) of the market that would otherwise be served by nanotube composites by 2019.

Case study: Graphenea

Graphenea S.A. (www.graphenea.com) was established in 2010 in Donostia-San Sebastian, Spain, as a joint venture of private investors and the Basque nanoscience co-operative research centre CIC nanoGUNE[470]. Today, the company specialises in the production of chemical vapour deposition (CVD) graphene films and liquid exfoliated graphene oxides. The company's activities include research, development, manufacturing, and supply of graphene for industrial and research purposes. The products are used in integrated circuits, solar cells, super-capacitors, batteries, airplanes, automobiles, conductive coatings, flexible displays, and touch screens, for example. The company is active in markets throughout the world, including the United States, Japan, Korea, Taiwan, India and Europe[471].

Graphenea was founded with an initial investment of EUR 100,000 in 2010 to tap into the potential of graphene and its market opportunities. This initial amount came from the founder who remains as CEO and has control over the strategic decisions made within the company[472].

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

In 2013, Repsol, a multinational oil and gas company, and the Centre for Industrial Technology Development (CDTI), a public business entity dependent on the Spanish Ministry of Economy and Competitiveness, signed an agreement to invest EUR one million in Graphenea[473]. This co-investment was to be used to accelerate the company's business plan towards industrial uptake.

Even though the company has still a short history, it is quite a profitable one: with 14 workers and 4 patents[474] in 2015, it has achieved sales higher than EUR 1 million and exports its products to universities, research centres and industries in 53 countries[475]. It is estimated that Graphenea has 10% of the current graphene market.

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

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469 BCC Research (2014), Nanotechnology, a realistic market assessment, p.186

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

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

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

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

474 See Nanodata Landscape data collection – Patents includes the following patent of Graphenea: 46397070

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

large, high quality graphene sheets, most often useful only on insulating substrates.

Furthermore, in June 2015, Graphenea was granted EUR 2.5 million from the Horizon 2020 programme 'SME Instrument' for the construction, installation and commissioning of a new production plant. The current production capacity will expand by a factor of 200 and is estimated that the current number of employees of Graphenea will double. "It is a very important boost that will accelerate our business plan. It will allow us to grow faster and consolidate our position as the global leader in our industry"[476], said Jesus de la Fuente, Founder and CEO of Graphenea after receiving the news of the SME instrument. The construction of the new plant will take 24 months and the new facility could open in late 2017.

In addition, Graphenea is currently taking part in several FP7 projects under different programmes (NMP, ICT, People), NMP being the most important one[477]. This has provided Graphenea with the opportunity to collaborate and complement its knowledge and expertise with important European universities, research centres and companies working in the field of graphene related nanotechnology, such collaboration being one of the most important objectives when participating in a European project. Regarding the EU funding, Graphenea has received FP7 funds of more than EUR 1.1 million for research activities. Participation in H2020 is also important with two main projects and a funding of more than EUR 1.7 million.

Graphenea is also participant in the Graphene Flagship, the EU's biggest ever research initiative. The flagship was launched in 2013 with a budget of EUR 1 billion, and is a consortium of 74 partners. The Graphene Flagship aims to bring together academic and industrial researchers to take graphene from academic laboratories into European society in the space of 10 years, thus generating economic growth, new jobs and new opportunities[478].

Besides increasing its sales, Graphenea has made a continued effort to popularise the use of graphene by increasing its production capacity and reducing the prices of graphene twice at the beginning of two consecutive years[479].

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

In late 2014, Graphenea opened an Applications Laboratory at Cambridge MA, US, in order to meet the needs of the company's North American customers and due to the close relation that the company has with the Massachusetts Institute of Technology (MIT) and Harvard[480]. In September 2015, Graphenea was selected as one of Europe's top fast growing start-ups to be present at the European Innovation Day (EID) in Silicon Valley[481].

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

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

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

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

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

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

B2 Conductive fibre

Technology and products

Thread spun from polyvinyl alcohol in which single-wall nanotubes have been dispersed is a candidate to meet at least some of the growing demand for conductive fibres in smart and interactive textile applications such as automotive switches and comfort applications[482].

Market data and forecasts[483]

The global market for conductive fibre is expected to grow from approximately USD 60 million in 2013 to more than USD 3 billion in 2019. If they are commercialised, carbon nanotube fibres could compete for this market with non-nanoconductive fibre such as coated yarns and fibres made from non-composite nanotubes, potentially capturing 10% of the market for conductive fibres, worth at least USD 300 million, by 2019.

9.4.6 Other products

A Current products

This section includes diesel fuel additives and high pressure discharge lamp tubes.

A1 Diesel fuel additives

Technology and products

Efforts to reduce diesel particulate emissions include the use of:

- oxidation catalysts;
- diesel particulate filters (DPFs);
- low-sulphur diesel fuels; and
- fuel additives.

Some additives also improve fuel economy. Diesel fuel additives gaining acceptance include engineered nanomaterials composed of cerium compounds (nCe), which also reduce emissions of fine particulate matter (PM2.5, i.e. 2.5 micrometre particulate matter) and impact on the emissions of carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbon (HC) species, including several HAPs (hazardous air pollutants)[484]. For example, Envirox is a cerium oxide-based nanocatalyst for diesel fuels of Energenics Pte Ltd. (Singapore) that lowers fuel costs, by reducing fuel consumption, with a corresponding reduction in greenhouse gas emissions (CO_2) and other harmful exhaust emissions[485].

Clean Diesel Technologies, Inc.[486] has developed Platinum Plus® fuel-borne catalyst (FBC) as a diesel fuel-soluble additive, which contains minute amounts of nano-scaled organo-metallic platinum and cerium catalysts. Platinum Plus® enables rapid conversion of particulate matter (PM) from diesel engines when coupled with a diesel particulate filter (DPF). The catalytic action takes place in the engine cylinders where it improves combustion - reducing particulates, unburned hydrocarbons (HC) and carbon monoxide (CO) emissions. Platinum Plus® FBC lends itself to a wide range of applications including: diesel particulate filtration, low emission biodiesel, carbon footprint reduction and exhaust emissions reduction.

Eolys PowerFlex® is another cerium oxide-based nanocatalyst for diesel fuels (manufactured by Solvay), initially developed by Rhodia Electronics & Catalysis (now Solvay). Eolys PowerFlex® is being used with Peugeot diesel engines on the basis of a long term co-operation between Peugeot SPA and Rhodia that began in 1992.

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482 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.144
483 BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.186
484 Green Car Congress: EPA researchers find widespread use of nano cerium diesel fuel additives could have measurable impact on air quality, 21 October 2014
485 http://www.energenics.co.uk/
486 http://investor.cdti.com/

Rhodia SA

Rhodia SA was founded in 1998 and became an international chemical company. At the end of 2010, Rhodia SA had 14,130 employees and EUR 5,226 billion revenues. Operating in Asia Pacific, Europe, Latin America and North America, it was acquired by Solvay in 2011 and became part of the Solvay group, a chemical company headquartered in Brussels with about 30,000 employees spread across 53 countries. The company portfolio includes intermediates, resins, oxygenated solvents polymers and engineering plastics for use in textiles, tyres, airbags and other automotive applications including paints and inks, as well as electronics.

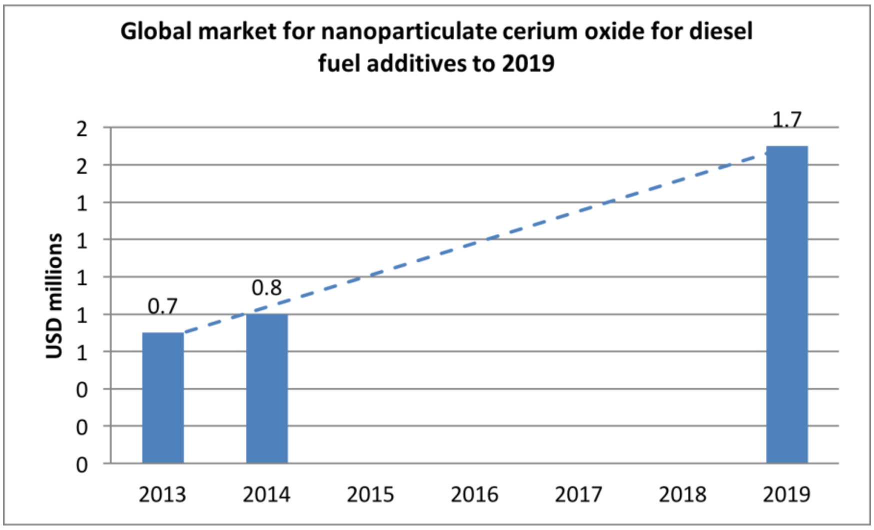
http://www.rhodia.com/en/markets_and_products/product_finder/index.tcm

http://www.solvay.com/en/about-solvay/index.html

MARKET DATA AND FORECASTS[487]

Energenics Ltd. does not publish sales data for its Envirox diesel fuel catalyst, which it acquired from Oxonica Ltd. in 2009. However, in 2008, the last full year before it sold the Envirox technology to Energenics, Oxonica purchased an estimated USD 600,000 worth of cerium oxide nanocatalyst from Advanced Nanotechnology Ltd. for use in Envirox. Sales of Envirox had been stagnant at around USD 3.6 million for two years following the loss of Oxonica's contract to supply USD 12 million worth of Envirox per year to Petrol Ofisi (the Turkish national oil and gas company).

Assuming that Energenics will by 2019 be able to restore Envirox sales to at least the level prior to the loss of that contract, the forecast is for consumption of nearly USD 1.7 million of ceria nano-powders on a proportional basis in 2019.



Source: BCC Research, 2014

Figure 9-15: Global market for nano-particulate cerium oxide for diesel fuel additives to 2019

[487] BCC Research (2014), Nanotechnology, a realistic market assessment, p.128-129

Case study: Energenics Europe Ltd

Energenics Europe Ltd, was originally a business unit of the Oxford University spin out company Oxonica plc. This unit, named Oxonica Energy, was bought in 2009 by the current owners of Energenics after a legal dispute over the intellectual property of the product; in this period, other units of Oxonica were sold to multinationals such as Croda Europe Ltd and BD (Becton Dickinson).

Energenics is now a small and stable company of 11 employees and £1.5 million turnover that produces Envirox™, a fuel borne catalyst for diesel fuel based on cerium oxide nanoparticles. The product is used for reducing fuel consumption and regenerating Diesel Particulate Filters (DPFs) and has been used nationally since 2005 by the UK's largest bus operator Stagecoach. Envirox™is also used in leading European brands of DPF Cleaner/Regenerator fuel treatments.

Framework projects of the European Commission have been seen as a way for the company to develop similar chemistry products for new markets. Energenics joined the consortium of the EU FP7-NMP project WOODLIFE (along with SP Chemistry, Materials and Surfaces, Sirris, Universidad del Pais Vasco, Paint Research Association LTD, SP Sveriges Tekniska Forskningstitut AB, Akzo Nobel Deco GmbH, Casco Adhesives AB, Laviosa Chimica Mineraria SPA, BYK Chemie GmbH, and EKA Chemicals AB) to develop nano-cerium oxide containing wood coatings for UV-absorption and the extension of the life service of the material. The project ran for two years between 2010 and 2013 and the technology that Energenics developed proved to be very effective in long term natural exposure tests. In 2015 Energenics have introduced their first commercial UV absorber additive products to the coatings industry.

Additional valuable performance data for the new UV absorber products was provided by an InnovateUK project called SENCoat which explored applications for nano cerium oxide in industrial applications including the aerospace industry.

Another experience of FP-funding was the R4-SME project ReactaFire (along with Fire Protection Coatings Limited, J.W. Ostendorf GmbH & Co. KG, Garvson AB, vanBaerle AG, PRA, SP Technical Research Institute of Sweden, and Ove Arup & Partners International Ltd). However, ReactaFire was was not a successful project for Energenics as it turned out that nano cerium oxide did not have the fire prevention properties that other project members had anticipated. ReactaFire ended in 2015.

Energenics considers that its previous engagement in projects has led to taking its UV absorber products from a technology readiness level of 3 to 6; the Horizon 2020 SME Instrument is considered to be an effective means to bring its products to the market. Energenics submitted a proposal to two Horizon2020 SME instruments calls.

With regards to regulation, Energenics is openly focussed on commercialising cerium oxide based nanomaterials including fuel additives. There have been two significant challenges:

1. *The US EPA has used its powers under the fuel additive regulations of the 1990 Clean Air Act to withhold registration of Envirox™ indefinitely despite the company having spent $0.5 million on a series of prescribed emissions tests which the EPA acknowledged were 'satisfactorily completed'. In effect this prevents sales to the 'on highway' market in the USA.*
2. *As a small company, Energenics need a REACH registration dossier by 2018. The uncertainty around REACH annexes with respect to nanomaterials has been seen as critical by the company: a specific dossier for cerium oxide nanoparticles would represent an immense challenge to the company while providing additional input to the general dossier for cerium oxide is considered to be a reasonable expectation.*

In the value chain, Energenics is a specialist supplier of novel additive products based on its core technology of commercial manufacture of cerium oxide nanoparticle systems. These additives when sold to formulators and marketers of products (fuel treatments and coatings) add value by delivering superior performance characteristics to established offerings. In some cases, Energenics sells its additive products directly to end users when commercial circumstances are appropriate.

A2 High-pressure discharge lamp tubes

Technology and products

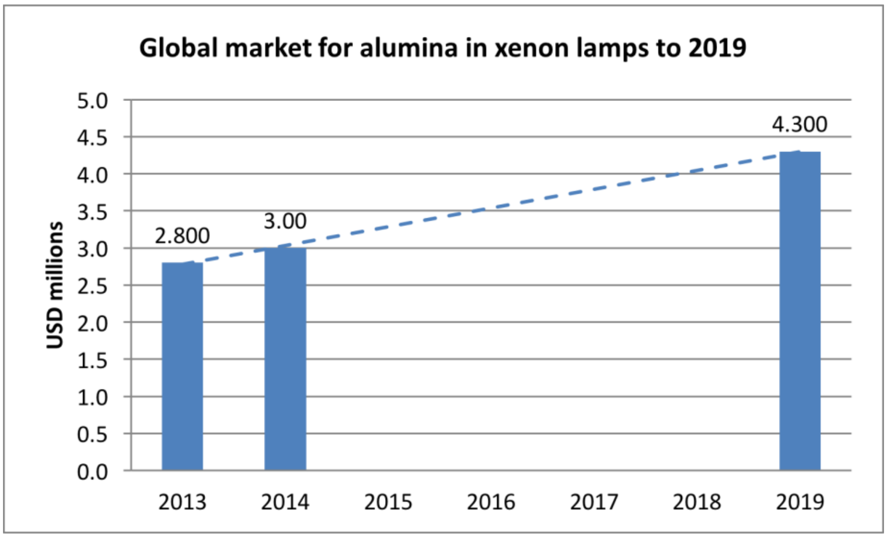
Nanostructured ceramic materials fabricated from alumina nanopowders have found commercial applications in the translucent alumina arc tubes of high-pressure discharge (xenon) lamps. In these applications, nanoparticles are normally used in conjunction with larger, submicron- or micron-scale powders to obtain the desired properties after final sintering. Each arc tube consumes about 3 to 5 grammes of alumina powder, approximately 30% of which has nanoscale dimensions[488].

> ***Company snapshot: OSRAM Licht AG***
>
> *OSRAM Licht AG is a multinational lighting manufacturer headquartered in Munich, Germany. It was founded in 1919 by the merger of the lighting businesses of Auergesellschaft, Siemens & Halske and Allgemeine Elektrizitäts-Gesellschaft (AEG). On 5 July 2013, OSRAM was spun off from Siemens. It employs around 34,000 people throughout the world and has operations in over 120 countries. The company generated a revenue of more than EUR 5.1 billion in 2014. OSRAM business activities have been focusing on light for over 100 years. The company's North American operation is Osram Sylvania, headquartered in Wilmington, Massachusetts; products sold in Canada, Mexico, United States and United States territories are sold under the Osram Sylvania brand name.*
>
> *Being one of the two leading light manufacturers in the world, the company's portfolio covers the entire value chain from components – including lamps, electronic control gear and opto semiconductors such as light-emitting diodes (LED) – as well as luminaires, light management systems and lighting solutions. With LED-based products making up a share of 36 percent of the total turnover, the company is setting significant trends with regard to technological changes in the lighting market. More than 60 percent of research & development expenditures are in the SSL area.*
>
> *See www.osram-licht.ag*

Market data and forecasts

Total consumption of nano-structured ceramic materials in high-pressure discharge (xenon) lamp tubes in 2013 was 11 metric tonnes with a value of USD 2.8 million. The forecast growth is expected to be mainly driven by the sales of vehicles equipped with these lamps. Once found only in luxury cars, xenon headlamps are available in a growing number of vehicles. The automotive market for xenon lamps is expected to grow at a CAGR of 7.5% from 2014 to 2019, assuming that alumina consumption grows proportionally[489], as shown in the figure below.

[488] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.75
[489] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.166-167



Source: BCC Research, 2014

Figure 9-16: Global market for alumina in xenon lamps to 2019

A3 Nano-enabled lubricants

Lubricants play a vital role in machine life and performance, reducing friction and wear and preventing component failure. Poor lubricant performance can cause significant energy and material losses. The already large global demand for lubricants is expected to continue to grow in the future. Engine oils account for approximately half of this demand, and industrial lubricants represent the second-largest and fastest-growing segment by volume. Performance-enhancing additives are a vital part of today's modern lubricants. The lubricant market is in need of lower-cost and higher-performing additives that meet end-user performance specifications and environmental safety requirements[490].

Nano-additives are opening up new ways to maximise lubricant performance. However, even though numerous studies have been carried out showing that nanotechnology can indeed improve the lubrication properties of oils and greases, large-scale market introduction of nano-fortified lubricants is still facing serious technical and legislative obstacles[491]. Although several nano-enabled lubricant products have been introduced to the market, there is a long way to go before balanced formulations are developed[492]. There are no market data or forecasts for this application market.

A4 Nano-enabled cleaning agents

Apart from coatings that will produce self-cleaning surfaces (using hydrophobic, oleophobic and photocatalytic effects), nanoparticles can be also used in soaps to improve their performance while producing less environmentally-harmful by-products. Both routes to cleaner surfaces can be combined. For example, Eagle One offers a car wash and wax car care product that includes nano-sized carnauba wax particles for increased surface coverage, filling even the finest microscopic scratches, maintaining a smooth surface and increasing shine, while Nanogate's Nano Gelcoat Sealer cleans, polishes and seals surfaces in one step. There are no market data or forecasts for this application market.

[490] US Department of Energy (2009), Large-Scale Manufacturing of Nanoparticulate-Based Lubrication Additives
[491] Zhmud, B. et al. (2013), Nanomaterials in Lubricants: An Industrial Perspective on Current Research, Lubricants 2013, 1, p.95
[492] Ibid

B Emerging products: Nano-sensors

Technology and products

A sensor is a device that responds to a physical, chemical, or biological parameter and converts its response into an output or signal, with complexity ranging from a door bell ringing when a button is pressed to a minute resistance change across a functionalised nanowire when a single protein attaches to it[493].

Sensors are basic components of today's mechatronic systems in automobiles used both for monitoring and for changing parameters in the vehicle. In moving systems, position and angle sensors play a key role. In order to improve the reliability of mechatronic systems, contactless magnetic field sensors are increasingly being applied that operate on the magnetoresistive principle. The measuring principle of a magnetic field sensor consists of the conversion of a position or movement information of a magnet to an electric signal, using the giant magnetoresistive effect (GMR). The GMR effect only takes place in extremely thin layers of only a few nanometres[494]. Examples of automotive applications include ABS braking, door windows, sun roofs, control of driving dynamics or steering angle sensors.

Sensitec GmbH from Lahnau in Hesse was the first European company to start series production of GMR sensors. The company has been successfully operating in the field of GMR sensors for industrial and automotive applications and owns the most extensive chip factory for magnetic sensors in Europe[495]. Among the sensor applications are electrical power control. Alps Electric Company of Japan also uses nanotechnology in its sensors and actuators for automotive applications.

Alps Electric.,Ltd

Alps Electric Co., Ltd. was established in Japan in 1948 as the Kataoka Electric Co. Ltd a manufacturer of components for radios. It expanded in the 1970s into Korea, Taiwan and other parts of Asia. In the 1980s, it increased its international reach and began to produce floppy disc drives and computer mice. It has continued to grow and adapt to technological advances and customer needs and now operates in the segments of electronic components, automotive infotainment and logistics. Alps Electric uses nanotechnology in the construction of its electronic devices, including switches, potentiometers, sensors, encoders and touchpads. Since its foundation, Alps Electric has supplied around 40,000 types of electronic components to over 2,000 manufacturers of vehicles, mobile devices, household equipment and industrial equipment worldwide. As of the end of March 2016, the company had over 39,000 employees (including part-time) and nett sales of 774 billion Japanese Yen (EUR 6.32 billion).

See: http://www.alps.com/e/about_alps/alps_view/figures.html

Market data and forecasts

The market for nanosensors is at a nascent stage, with negligible sales in 2013 and 2014 and a forecast market of USD 60 million by 2019. Companies involved include Avanzare Innovacion Tecnologica in Spain, albeit that they are also engaged in many other application areas of relevance to transport.

[493] Report of the National Nanotechnology Initiative Workshop (2009), Nanotechnology-Enabled Sensing, Arlington, Virginia, May 5–7, 2009

[494] Hessian Ministry of Economy, Transport, Urban and Regional Development (2008), Nanotechnologies in Automobiles, p.26

[495] Ibid

Avanzare Innocacion Technologica, Spain

Avanzare Innovacion Tecnologica is a Spanish SME dedicated to the production of high-performance nanomaterials (graphene, ZnO, artificial nanoclays, doped nanoparticles), dispersion of nanomaterials in different matrices, and nanotechnology- based solutions for a number of application areas. The company also produces nanosensors, sensor-based platforms and sensor/actuator systems. It was founded in Logrono in Spain in 2004.

AVANZARE focuses on meeting customer requirements by adding value to nanomaterials and nano-composites through fire resistance, anti-scratch features, enhanced conductivity and antistatic properties, improved hardness, wear resistance, anti-UV and anti-IR features, repelling harmful bacteria, and having fungicidal and anti-mould characteristics, stain resistance, superhydrophobic and superlipophobic properties, anti-odour features and last but not least, a significant improvement of polymer and rubber properties.

In most of the applications, the innovations of Avanzare offer higher cost-effectiveness compared with conventional solutions. Products range from nanomaterials in liquid or solid formulations to customised solutions for large customers. The customer base includes market participants from various sectors such as automotive, aeronautic, textile, wood, paper, plastic, rubber, paint and building industries, the wire and cable sector and manufacturers of household appliances and packaging. The company has worldwide sales for research and business activities in more than 45 counties, with significant penetration in the European market (Germany, Italy, Spain).

The company has been actively involved in various R&D projects, a number of which are a part of the EU Seventh Framework Programme (FP7) including NANOSCRATCH[496], THERMALCOND[497] and NANOMASTER[498], VINEROBOT[499], POLYGRAPH[500], BUONAPART-E[501], DIB-BIOPACK[502], BISNANO[503], SAMDOKAN[504] and BIOFIBROCAR[505]. Under Horizon 2020, the company is involved in the Graphene Flagship.

The company has also been involved in a national R&D programme (project GRAFENTEX) which it co-ordinated. Avanzare used its expertise in the manufacture of graphene and partnered with a textile company (Textil Santanderina S.A.); a national leader in the production of fabrics (Talleres Ruiz S.L. which specialises in the development and production of chemical reactors); and two research centres: CTC (Components Technology Centre) and INTERQUIMICA, in La Rioja, Spain. This initiative is funded by the Collaboration Challenges 2015 from a Ministry of Economy and Competitiveness programme and has a budget of EUR 924,713[506].

According to Dr. Gomez Cordon, "National R&D projects are not interesting for a company with a strong R&D team; the Spanish project mainly gave finance to the R&D centres and Universities. The company is just a partner which subcontracts them (similar to CRAFT projects in FP6 or Research for SME in FP7). An SME intensive in R&D such as Avanzare needs programmes supporting higher involvement in R&D. We are at the frontiers of knowledge, and it is 'high risk research' and for that some public funding is needed."

Avanzare identifies itself as having a workforce of 32 people of whom around ten work in the R&D division. The company generated a revenue of more than EUR 2.3 million in 2015, up from EUR 1.8 million in 2014 and EUR 1.4 million in 2013. In 2015, around EUR 0.6 million was dedicated to R&D. With regard to company ownership, there are eight private owners with three of these owners holding 85% of the company.

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496 http://cordis.europa.eu/project/rcn/92264_en.html
497 http://cordis.europa.eu/project/rcn/96989_en.html
498 http://www.nanomasterproject.eu/Home.aspx
499 http://cordis.europa.eu/project/rcn/111031_en.html
500 http://cordis.europa.eu/project/rcn/110823_en.html
501 http://cordis.europa.eu/result/rcn/168078_en.html
502 http://www.dibbiopack.eu/
503 http://www.bisnano.eu/
504 http://www.samdokanproject.eu/
505 http://cordis.europa.eu/result/rcn/156255_en.html
506 http://www.interquimica.org/index.php/en/

The company has filed two patents one of which has been granted and another is still in the application phase. The product portfolio of Avanzare revolves around various formulations of graphene such as pristine graphene (av-PRIST); highly reduced graphene oxide (av-70-1-2.5, av-40-1-2.5, av-70-3-3.5, av-40-3-3.5); partially reduced graphene oxide (av-70-3-8, av-40-3-8, av-70-3-20, av-40-3-20); graphene oxide (av-GOX-70, av-GOX-40); graphene/graphite nanoplatelets (av-PLAT-2, av-PLAT-7, av-PLAT-40, av-PLAT-70); anticorrosion- NR345 for the paints and varnishing applications; and many more[507]*.*

Company sources indicate that representative applications in transportation (automotive) and construction are:

- *Electrical conductive polymers;*
- *Bonding/de-bonding additives for thermoset and thermoplastics;*
- *Electrical conductive paints;*
- *Fire retardant materials;*
- *Higher fatigue resistance materials;*
- *Anti-bacterial surfaces;*
- *Anti-odour surfaces;*
- *Photocatalytic applications (road, concrete, paints and in automotive in interior pieces);*
- *Cr(VI) free plating of plastics.*

Avanzare also contributed to the manufacturing of "Cribs CDMX" through its partner Nanomaterials SA, as a part of an initiative of the Mexican Government. With the aim of reducing child mortality, a special coating with Avanzare additives was used to increase flame resistance and water repellence[508]*.*

http://www.avanzare.es/

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

507 http://www.avanzare.es/article.php?seccion=1&primernivel=PRODUCTS
508 http://www.avanzare.es/article.php?seccion=5&id=206&primernivel=NEWS&title=News

10 THE WIDER ENVIRONMENT FOR NANOTECHNOLOGY AND TRANSPORT

10.1 Regulation and standards for nanotechnology and transport

Legislation and regulation of transport is mainly based on a broad and well-established framework that covers all aspects of transportation from the manufacture of vehicles and the construction of infrastructure to the end of life of these vehicles. In this mature sector, the use of nanomaterials is not incorporated in the transport regulations of the relevant authorities. They rely rather on the adaptation of regulations for chemicals to the use of nanomaterials.

10.1.1 European regulations for nanotechnology

GENERAL REGULATIONS

Transport is one of the key policies of the European Union and is featured in *Title VI – Transport* of the *Treaty on the Functioning of the European Uni*on. The Directorate General for Mobility and Transport has the main responsibility for European transport policy, a dense package of directives and regulations. These never directly address the use of nanotechnologies in the final products.

The reuse and recycling of vehicles, for example, is mainly regulated by the *End of Life Vehicles Directive* (Directive 2000/53/EC - the "ELV Directive", amended in 2008) of the European Commission. It restricts the use of some substances and includes targets for the recycling and reuse of vehicles, but no provision in this directive targets nanomaterials. The ELV directive is supported *by Directive 2006/66/EU on Batteries and Accumulators and Waste Batteries and Accumulators*, amended in 2013, which also does not cover nanomaterials.

Nanomaterials used in transportation must comply with the overarching regulatory framework in place for chemical substances: *Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)*. Electronic items used in vehicles and incorporating nanomaterials may fall under the scope of electronics regulations, such as the *Waste Electrical and Electronic Equipment Directive (WEEE) - 2012/19/EU and* the *Directive on the restriction of the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS2) - 2011/65/EU.*

The WEEE directive refers to a 2009 Opinion of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) entitled *'Risk assessment of Products of Nanotechnologies'* stating that 'when nanomaterials are firmly embedded in large structures, for example in electronic circuits, they are less likely to escape this structure and no human or environmental exposure is likely to occur.' This directive also states that the European Commission should consider nanomaterials when reviewing Annex VII - Selective treatment for materials and components of waste electrical and electronic equipment referred to in Article 8(2) of the Directive. Currently, nanomaterials are not addressed in that annex.

The RoHS2 directive restricts the use of hazardous materials for electronic and electrical materials and mentions nanomaterials. In the absence of scientific evidence concerning any hazardous properties of nanomaterials, use can also be made of an associated annex: *Annex II – List of Restricted Substances*. Between late 2012 and June 2014, the Environment Agency of Austria (Umweltbundesamt) was tasked with formulating a methodology for the review of the *List of Restricted Substances* under RoHS2, under which methodology nanomaterials are not prioritised but assessors are still invited to be cautious when dealing with such substances.

For articles containing nanomaterials that are used in road vehicles, only electrical or electronic articles that can be bought separately and that are not specifically designed to be used in vehicles[509] would be covered by the RoHS2 Directive.

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[509] European Commission, *Frequently Asked Questions on Directive 2002/95/EC on the Restriction of the Use of certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) and Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE),* available at http://ec.europa.eu/environment/waste/pdf/faq_weee.pdf

REGULATIONS SPECIFIC TO NANOTECHNOLOGY

Nano-specific regulations may also apply. The EU is actively developing a set of regulations around nanotechnology. With the *first Regulatory Review on Nanomaterials SEC (2008) 2036* and the *Second Regulatory Review on Nanomaterials SWD (2012) 288 final*, the EC has given *Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)* a central role in regulating nanomaterials. *"There are no provisions in REACH referring explicitly to nanomaterials. However, nanomaterials are covered by the 'substance' definition in REACH",* states the 2008 Communication. A third Regulatory Review is planned in 2016.

Since the summer of 2013, there has also been ongoing work to adapt the Annexes of REACH to specifically cover nanomaterials. An impact assessment and a wide consultation process on this issue has taken place and discussions are still ongoing. However, the rules of ECHA (the European Chemicals Agency) prevent the modification of the regulation during the two years prior to the next round of deadlines for registration (June 2018). This rule also applies to guidance documents that the Agency provides to support registrants. In 2016, ECHA nevertheless announced that four guidance documents related to nanomaterials would be released in May 2017, one year prior to the next registration deadline. These are:

- Guidance on nano-forms
- Guidance on information requirements for nanomaterials for human health
- Guidance on information requirements for nanomaterials for the environment
- Guidance on read-across for nano-forms.

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

The definition is the following:

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

Developed in 2011, this definition is undergoing a review process (which was scheduled to reach its conclusion in December 2014). One outcome of this review could be a revision of the definition. The process of review of this definition is still ongoing.

While a regulatory framework has been under development for nanomaterials under REACH, some European Member States have sought to find additional ways to regulate nanotechnologies. In recent years, databases and reporting schemes for nanomaterials have been developed in Europe. Whilst these are not specific to the market sector covered by this report, they are still relevant to the regulation of nanotechnologies.

Under the Belgian Presidency of the European Union, in 2010, the European Union opened the discussion on a 'harmonised database of nanomaterials'. This was followed by a 2012 letter to the European Commission calling for a European Reporting Scheme, signed by ten European Member States, plus Croatia. The European institutions are still weighing the pros and cons of such a reporting scheme. Nevertheless, some European Member States have been moving forward on this.

In addition, as part of the electoral promises of the 2007 Presidential Elections, the 'Grenelle de l'Environnement', a large environmental debate was organised in France and resulted in major environmental acts: the *Grenelle Acts (Lois Grenelle I & II)* which enacted the future creation of a mandatory reporting scheme for nanomaterials. France hence took steps towards setting up the first registration scheme for substances at the nano-scale in Europe. In 2012, the Decree[510] on the

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[510] 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

annual declaration on substances at nano-scale - 2012-232 was published and 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 (*Koninklijk besluit betreffende het op de markt brengen van als nanodeeltjes geproduceerde stiffen* or *Arrêté royal relatif à la mise sur le marché des substances manufacturées à l'état nanoparticulaire*). The registration of substances began on 1 January 2016, while mixtures will have to be registered from 1 January 2017.

In June 2014, the Danish *Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register - BEK nr 644* came into force. Under this Order, the Ministry of the Environment is creating a national mandatory database of nanomaterial-containing products, registering the first products for the year 2014 in the year 2015.

Other EU Member States have been considering options for a registration scheme for nanomaterials e.g. Norway, 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. In the spring of 2016, KEMI declared that it aimed to establish a Swedish registry in 2019 which would register manufactured and imported quantities during 2018. Italy is also considering setting up a similar system.

With these initiatives, EU Member States have been pushing the European Commission to act; the Second Regulatory Review on Nanomaterials of 2012 included an impact assessment of potential transparency measures which include approaches similar to the reporting schemes set in action in several Member States. The *Study to Assess the Impact of Possible Legislation to Increase Transparency on Nanomaterials on the Market was led by a RPA and BiPro; three reports were published to help the EC decide on an eventual EU-wide registry of nanomaterials. Early in 2016, the European Commission has stated that it will not go forward with an EU-wide nanomaterial registry but would rather support the establishment of a knowledge base entitled the 'nanomaterials observatory' which would contain publically available information on nanomaterials and their use in Europe.*

The table below lists some key regulatory documents within the European Union as a whole and within Member States.

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.[511]

10.1.2 Nanotechnology regulation in the rest of the world

Similarly to Europe, countries across the planet have not developed nano-specific regulations in their transport policy.

The European legislation that may be applied to vehicles in Europe: the RoHS2 and WEEE directives enacting restrictions for the use of certain hazardous materials have been adapted in numerous countries outside of Europe (i.e. Argentina, China, Vietnam, the State of California, India etc.), but do not specifically target nanomaterials.

In the US, the *Toxic Substances Control Act (TSCA)* is the main chemical regulation. The US Environmental Protection Agency (EPA) is in charge of adapting this regulation to nanoscale materials (the US authorities have decided not to write a binding definition of a nanomaterial). The latest regulatory initiative was taken by US EPA in April 2015 with the publication of a proposed rule for section 8 (a) of TSCA. This proposal would introduce reporting and recordkeeping requirements for nanoscale materials as well as a 135-days pre-notification requirement for the manufacturers of 'chemical substances as discrete nanoscale materials'. The inclusion of a new rule addressing nanomaterials under TSCA is intended to be promulgated in the fall of 2016.

[511] http://www.its-nano.eu

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*).

10.1.3 Standardisation and nanotechnology

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

At the ISO level, a number of technical committees however cover areas linked to transportation. These are: ISO/TC 8 Ships and marine technology; ISO/TC 22 Road vehicles; ISO/TC 20 Aircraft and space vehicles; ISO/TC 31 Tyres, rims and valves; ISO/TC 45 Rubber and rubber products; ISO/TC 110 Industrial trucks; ISO/TC 149/SC 1 Cycles and major sub-assemblies; ISO/TC 204 Intelligent transport systems; and ISO/TC 269 Railway applications. These do not provide for the use of nanotechnologies in these products.

The use of the nanomaterial carbon black in rubber components used in transportation has been the most heavily concerned by standardisation. In ISO TC 45 ISO/TC 45/SC 3 Raw materials (including latex) for use in the rubber industry, a series on carbon black in Rubber compounding ingredients is being developed and includes the following:

- ISO 1124:1988 Rubber compounding ingredients - Carbon black shipment sampling procedures;
- ISO 1125:2015 Rubber compounding ingredients - Carbon black - Determination of ash;
- ISO 1126:2015 Rubber compounding ingredients - Carbon black - Determination of loss on heating;
- ISO 1138:2007 Rubber compounding ingredients - Carbon black - Determination of sulphur content;
- ISO 1138:2007/Amd 1:2012 Clarification of digestion temperature in Subclause 3.4.5;
- ISO 1304:2006 and ISO/FDIS 1304 Rubber compounding ingredients - Carbon black - Determination of iodine adsorption number;
- ISO 1306:1995 Rubber compounding ingredients - Carbon black (pelletised) - Determination of pour density;
- ISO 1435:1996 Rubber compounding ingredients - Carbon black (pelletised) - Determination of fines content;
- ISO/DIS 1437 and ISO 1437:2007 Rubber compounding ingredients - Carbon black - Determination of sieve residue;
- ISO 3858:2008 Rubber compounding ingredients - Carbon black - Determination of light transmittance of toluene extract;
- ISO 4652:2012 Rubber compounding ingredients - Carbon black - Determination of specific surface area by nitrogen adsorption methods - Single-point procedures;
- ISO 4656:2012 Rubber compounding ingredients - Carbon black - Determination of oil absorption number (OAN) and oil absorption number of compressed sample (COAN);
- ISO 5435:2008 Rubber compounding ingredients - Carbon black - Determination of tinting strength.

In Europe, the European Committee for Standardisation committee on nanotechnology (CEN/TC 352) has not developed standards for transport applications. Similarly to the international level, a number of technical committees address issues related to transport, these are: CEN/TC 2 Shipbuilding details; CEN/TC 22 Rubber; CEN/TC 73 Methods of test for vehicle safety glass; CEN/TC 150 Industrial Trucks – Safety; CEN/TC 245 Leisure accommodation vehicles; CEN/TC 278 Intelligent transport systems; CEN/TC 301 Road vehicles; CEN/TC 320 Transport - Logistics and services; CEN/TC 326 Gas supply for Natural Gas Vehicles (NGV); and CEN/TC 354 Non-type approved light motorised vehicles for the transportation of persons and goods and related facilities. These, however, do not deal with the use of nanotechnologies in transport.

The International Electrotechnical Commission (IEC) in IEC/TC113 – Nanotechnology standardisation for electrical and electronic products and systems, mirrored in Europe by the European Committee for Electrotechnical Standardisation (CENELEC) committee CLC/SR 113 has not produced standardisation document relating to nanotechnologies in transport.

10.2 Environment, health and safety and nanotechnology

10.2.1 Introduction

Exposure to nanomaterials in the transport sector may be quite diverse. Three categories of subsectors were identified within the NanoData project – use in infrastructure, use in vehicles and use in operations (e.g. catalysts and sensors).

This section presents an analysis of human health and safety aspects of the more commonly used materials for transport including aluminium oxide, carbon (in the form of nanotubes), cerium oxide, cobalt oxide and titanium dioxide. The selection was based on their common usage and/or likely future usage in transport. It was not intended that the review be exhaustive and more materials can be added at a later date if required and if information is available. One additional material was identified, magnesium/aluminium or magnalium in the form of nanoparticles, but there were no data available on this alloy so no assessment could be made. All other combinations of nanoparticles and sectors were evaluated.

The basis for the evaluation was "Stoffenmanager Nano" application[512, 513], a risk-banding tool developed for employers and employees and used to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios.

The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in production facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries[514]. 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[515]. However, nanoparticles as such are very unlikely to penetrate the skin[516] 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.

10.2.2 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 transport sector and their hazard bands, either taken from le Feber et al. (2014)[517] or van Duuren et al. (2012)[518] or derived in this project[519]. 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. Further information is given in the annex. The hazard banding of the nanoparticles with identified significant use in the transport

[512] 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.

[513] 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.

[514] 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.

[515] Ibid

[516] 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

[517] 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.

[518] 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.

[519] 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 .

sector is assessed below.

Table 10-2: Hazard banding of transport-related materials

Nanoparticles	Hazard band	Source
Aluminium	C	This report
Aluminium oxide/ alumina	C	Le Feber et al. (2014)
Calcium carbonate	A	EFSA (2011)
Carbon nanotubes	E	This report
Cerium oxide	C	Le Feber et al. (2014)
Cobalt oxide	E	Van Duuren et al. (2012)
Magnesium hydroxide	C	Van Duuren et al. (2012)
Nanoclays	D	Van Duuren et al. (2012)

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

Aluminium nanoparticles

Toxicity data on aluminium nanoparticles are very scarce as the focus is more usually on aluminium oxide. A SCOPUS literature search revealed one relevant toxicity study: Braydich-Stolle et al. (2010)[520] compared the *in vitro* toxicity of aluminium and aluminium oxide nanoparticles and found no significant difference between the cytotoxicity of both nanoparticles. Based on this, it may be assumed that aluminium and aluminium oxide nanoparticles are equitoxic. Therefore, aluminium nanoparticles are attributed the same hazard band as aluminium oxide nanoparticles: band C (see below).

Aluminium oxide nanoparticles

In an update on some metal oxide nanoparticles, Stoffenmanager Nano has attributed hazard band C to aluminium oxide nanoparticles[521].

Calcium carbonate

The substance calcium carbonate has been registered under REACH. The registrant has indicated that the substance has a nano-form and has provided separate information on the nano-form. Calcium carbonate, including its nano-form, has not been classified as hazardous by any route of exposure. EFSA, the European Food Safety Authority, has given a scientific opinion on re-evaluation of calcium carbonate (E 170) as a food additive. This opinion, concluded that "*the available data are sufficient to conclude that the current levels of adventitious nanoscale material within macroscale calcium carbonate would not be an additional toxicological concern"*[522]. In view of this lack of toxicity, nanocalcium carbonate is not classified and therefore assigned hazard band A.

Carbon nanotubes (CNTs), single-walled (SWCNTs) and multi-walled (MWCNTs)

Carbon nanotubes have often been demonstrated to have severe toxicity; however, this seems to be largely dependent on the dose, the degree of agglomeration and the route of administration. Differences in toxicity are also expected between single and multi-walled CNTs and are presumably dependent on their aspect ratio[523].

Upon inhalation, single walled carbon nanotubes (SWCNTs) have shown various chronic inflammatory responses in rat and mice, depending on type of exposure (inhalation, oral

[520] Braydich-Stolle, L.K., Speshock, J.L., Castle, A., Smith, M., Murdock, R.C., Hussain, S.M., 2010. Nanosized aluminium altered immune function. ACS Nano 4, 3661–70. doi:10.1021/nn9016789

[521] 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

[522] EFSA, 2011. Scientific Opinion on re-evaluation of calcium carbonate (E 170) as a food additive. EFSA J. 9, 2318. doi:10.2903/j.efsa.2011.2318.

[523] El-Ansary, A., Al-Daihan, S., Bacha, A.B., Kotb, M., 2013. Toxicity of novel nanosized formulations used in medicine. Methods Mol. Biol.

administration)[524] [525] [526]. For example, while no tumours were reported in the case of short to medium term pulmonary exposures to SWCNTs or MWCNTs in rodents, several studies have shown the potential for MWCNTs to act like the persistent fibres of asbestos, causing thoracic inflammation and fibrosis. Additionally, MWCNT have been shown to penetrate into the alveolar region of the lung and to cause inflammation. These biological events have been shown to lead to the cancer mesothelioma[527], although MWCNT have not been demonstrated to *de facto* cause mesotheliomas. Still the weight-of-evidence for certain types of MWCNT (e.g., those with high aspect ratios) is increasing. In conclusion, flexible, rigid, high-aspect-ratio MWCNT may cause cancer in a similar fashion to asbestos and may be as potent in this respect. [528]

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

CERIUM OXIDE NANOPARTICLES

In an update[529] on some metal oxide nanoparticles hazard band C was attributed to cerium oxide nanoparticles.

COBALT OXIDE NANOPARTICLES

Stoffenmanager Nano has attributed hazard band E to cobalt oxide nanoparticles[530].

MAGNESIUM HYDROXIDE NANOPARTICLES

No relevant toxicity studies on nano-magnesium hydroxide were identified in publicly-available literature. It is not very soluble in water (solubility approx. 9 mg/L) and therefore, applying the methodology of van Duuren et al. (2012)[531], the hazard characteristics of the parent material are used. Magnesium hydroxide has no harmonised classification in the EU[532] and it is also not classified by 400 notifiers[533] nor in the registration dossier[534], based on sufficient information. Based on this lack of classification, the nano-forms should be assigned hazard band C, the lowest category a nanoparticle can be assigned, based on toxicity data for its non-nano parent compound[535].

NANOCLAYS

These are classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm). Since the size distribution of the nanoclay nanoparticles used may include sizes below 50 nm, the risk band used in the risk assessment applied here is D. [536]

SILICA

Synthetic amorphous silicon dioxide nanoparticles

In an update on some oxide nanoparticles hazard band B was attributed to synthetic amorphous

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[524] Ibid
[525] Zhao, J., Castranova, V., 2011. Toxicology of nanomaterials used in nanomedicine. J. Toxicol. Environ. Heal. - Part B Crit. Rev. 14, 593–632.
[526] Yildirimer, L., Thanh, N.T.K., Loizidou, M., Seifalian, A.M., 2011. Toxicological considerations of clinically applicable nanoparticles. Nano Today 6, 585–607.
[527] http://www.mesothelioma.com/mesothelioma/
[528] For more information and additional references, see the relevant annex to this report.
[529] Le Feber, M., Kroese, E.D., Kuper, C.F., Stockmann-Juvala, H., Hyytinen, E.R., 2014. Pre-assigned hazard bands for commonly used nanoparticles.
[530] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525–541. doi:10.1093/annhyg/mer113
[531] Ibid
[532] http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/13362
[533] Companies or consortia of companies that notified that the product was being produced or imported by them.
[534] http://echa.europa.eu/registration-dossier/-/registered-dossier/16073/7/6/2
[535] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525–541. doi:10.1093/annhyg/mer113
[536] Ibid

silica nanoparticles[537].

Crystalline silicon dioxide nanoparticles

Classified by Stoffenmanager Nano in hazard band E[538].

TITANIUM DIOXIDE NANOPARTICLES

In an update on some metal oxide nanoparticles[539], hazard band C was attributed to titanium dioxide nanoparticles.

10.2.3 Exposure assessment

NANOTECHNOLOGY IN INFRASTRUCTURE

Nanomaterials (titanium dioxide) are used in/on glass and other surfaces in transport for self-cleaning and other properties and to reduce the intensity of sunlight and heat entering vehicles. If the nanomaterial is in glass, the exposure potential is low (use phase, 1). Handling powder titanium dioxide to produce the glass results in the highest exposure potential (manufacture phase, 4).

Paints or coatings are frequently used in transport to protect the surface from wear and to make the surface more attractive in appearance. Paints are composed of base; vehicle or binder; solvent or thinner; drier and colouring pigments. In addition, several nanomaterials (e.g. TiO_2, ZnO, SiO_2) are applied in coating forms for self-cleaning properties, better water resistance, etc. In the manufacturing phase, the exposure potential is relatively low (2) since the nanomaterial is dispersed in the coating, except when the coating is sprayed on a surface, then the exposure potential is high (4). If the coating is on the surface the exposure potential is again low (use phase, 1).

NANOTECHNOLOGY IN VEHICLES

Carbon nanotubes are being applied to existing materials to increase strength and to reduce weight in the structure and interior of vehicles including materials used in the aerospace sector. In addition, carbon nanotubes are used in engines to improve the heat-transferring properties which can affect the performance, emission and durability of the engine. Furthermore, nanoadditives are added to fuel to reduce the soot emissions (e.g. cerium oxide nanoparticles; aluminium nanoparticles; magnesium-aluminium (magnalium) and cobalt oxide nanoparticles).

Regarding the exposure potential, based on expert judgement we believe a relative low exposure (1) is expected for the nanomaterials in these products. However, during the vehicle manufacturing phase, when handling nanomaterials, the exposure potential can be high (4). In the end-of-life phase shredding maybe a realistic scenario to recycle the nanomaterial, resulting in a relatively low exposure potential (2).

NANOTECHNOLOGY FOR OPERATIONS

In this subsector, catalysts and sensors are predominantly represented in the products with nanomaterials that are currently available. Although some nanomaterials are widely applied (e.g. MWCNTs, TiO_2) most are only produced on a nanoscale (e.g. using lithography). Similarly to the other subsectors, a high exposure potential is expected for the occupational phase handling nanomaterials, while low exposure potential is foreseen during the use phase. In the end-of-life phase, shredding may be a realistic scenario to recycle the nanomaterial, resulting in a relatively low exposure potential (2).

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

[538] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritisation of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525–541. doi:10.1093/annhyg/mer113

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

10.2.4 Risk assessment

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table below. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures ort to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

With reference to transport infrastructure (construction of roads, etc.), roughly four phases can be discerned in the life cycle of construction materials: production, building, use and demolition. Roughly three phases can be discerned in the life cycle of transport vehicles and nano-enabled products used in operations: production, use and end-of-life. If in a phase different degrees of exposure may occur, the highest exposure scenario is taken into account in the risk assessment (worst case scenario).

Table 10-3: Priority bands in the Stoffenmanager system

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Table 10-4: Priority bands for the transport sector

		Exposure Band		
		Production/ building/ application phase	Use phase	End-of life phase
Nanoparticle	**Hazard Band**	4	1	2
Aluminium/aluminium oxide	C	1	3	2
Calcium carbonate	A	2	3	3
Carbon nanotubes, single- and multiwalled	E	1	1	1
Cerium oxide	C	1	3	2
Cobalt oxide	E	1	1	1
Magnalium	n/a	n/a	n/a	n/a
Magnesium hydroxide	C	1	3	2
Nanoclay	D	1	2	2
Silica (amorphous)	B	1	3	3
Silica (crystalline)	E	1	1	1
Titanium dioxide (titani, rutile, anatase)	C	1	3	2

As seen in the table above, due to the high expected exposure all nanomaterials reach the highest risk priority during the production phase, except calcium carbonate (intermediate priority). In the use phase, aluminium (oxide), calcium carbonate, cerium oxide, magnesium hydroxide and titanium dioxide have a low risk priority, nanoclay has an intermediate priority, while carbon nanotubes and cobalt oxide have the highest risk priority. It should be noted that in the use phase all nanomaterials are contained in a solid matrix, meaning exposure will be negligible and thus health risks will be low. In the end-of-life phase, risk management/evaluation of transport materials containing carbon nanotubes and cobalt oxide should receive the highest priority, while the materials containing the remainder of the listed nanomaterials should receive intermediate priority.

The next section looks at communications, public attitudes and societal issues.

10.3 Communication, public attitudes and societal issues

This section looks at nanotechnology and transport in printed and online media, and surveys

10.3.1 Printed and online media

A search on the web of terms related to nanotechnology and keywords related to transport[540] is summarised in the table below. News sites only were searched using the Google News search tool. While these data are approximate, they may be useful in identifying where the public can find the most information, relatively speaking, on a given nanotechnology and transport topic. The number of news items is an indication of where the media perceive that the interest of the public lies[541].

Table 10-5: Frequency of articles on the web, in the news for nanotechnology transport

Keywords category	Web, thousands	News, thousands	News / Web, %
Aeronautics	1572	2.5	<1%
Aerospace	720	20.8	3%
Aircraft	715	24.3	3%
Car	24,300	160	1%
Diesel	292	40.4	14%
GPS	16,300	86.2	1%
Traffic	1730	47.5	3%
Truck	657	21.5	3%

A second search, using Google Scholar[542], was done in order to obtain an indication of where the interests of academics lie. The ratio of news web-pages to total web-pages for each search was much lower than the ratio of scholarly to general web-pages.

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

Select transport keywords	Scholar, thousands	Scholar/Web %
Aeronautics	42.2	3%
Aerospace	92.4	13%
Aircraft	44.2	6%
Automotive	77.3	12%
Car	220	1%
Diesel	61.7	21%
GPS	25	0%
Traffic	59.1	3%
Truck	13.5	2%

[540] The search was carried out using the keywords in quotation marks, coupled with the term nano*, so all words beginning with nano are included.

[541] For the issue of nanotechnology used in transport sector we face the problem of making a distinction between transport as a sector and transport as the action of moving something from one place to another (e.g. nanotechnology used for transporting biomolecules in water). Because of the ambiguity of the term, the following tables show a number of terms which seem relevant to understand the current situation of nanotechnology for transport in online data.

[542] Google Scholar is an online database of many of the peer-reviewed online journals of Europe and the US, plus books and non-peer reviewed journals, containing an estimated 160 million documents in 2014 (Orduña-Malea, E.; Ayllón, J.M.; Martín-Martín, A.; Delgado López-Cózar, E. (2014). About the size of Google Scholar: playing the numbers. Granada: EC3 Working Papers, 18: 23 July 2014.)

More than 200 scientific journals regularly publish articles on nanotechnology[543]. For the academic community, the International Scientific Journal & Country Ranking (SJR) index provides a means of identifying which are perceived to be the most prestigious. The h-5 index is a measure of the number of highly cited articles, and is thus dependent on how many articles are published annually by the journal. The top five journals, as measured by the SJR index largely follows the metric of citations per document published, as shown in the table below.

Table 10-7: Bibliometric data for nanotechnology

Title of journal	SJR	h-5 index 2010-14	Total articles (3 years)	Citations per article (2 years)	Country
Nature Nanotechnology	17.0	140	626	23.8	UK
Nano Letters	9.4	181	2940	13.2	US
Advanced Materials	7.9	190	2511	15.2	DE
Nano Today	7.8	61	195	17.4	NL
ACS Nano	7.0	170	3387	12.0	US

Source: http://www.scimagojr.com/journalrank.php?category=2509

While it should be noted that many nanotechnology publications may not have a Facebook page, one indication of popularity of nanotechnology media can be seen in the figures for the number of "Likes" on Facebook:

Table 10-8: Facebook likes as a measure of interest in nanotechnology

Facebook page	Likes
Nanotechnology	99,000
Nanotechnology World Association	33,000
Nanotechnology Now	6,400
Nanotechnology Solutions	3,500
Nanowerk Media/News/Publishing	5,400
The International Nano Science Community	5,700
Nanobiotechnology	2,100

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

10.3.2 Surveys of the public

More rigorous measures of public awareness, attitudes and communication can be seen through surveys. Although not fully representative of the 'average' EU-citizen, the results provide some indications of trends in attitudes.

NanOpinion was an FP7 project, which ran from 2012 to 2014, focused on monitoring public opinion on nanotechnology in Europe[544]. An online hub, social media, education and information booths in public spaces and special events were used to develop a dialogue with the general public about nanotechnology. Over 1,500 questionnaires were completed in which participants answered questions designed to gauge their understanding and opinions of nanotechnology.

Analysis of the questionnaires revealed that Europeans in general have little understanding of nanotechnology but are generally interested in and positive about it. Respondents expected

[543] http://www.nanowerk.com/nanotechnology/nanotechnology_periodicals.php
[544] www.nanopinion.eu

information on nanotechnology to be honest and balanced and wished there was more information available, particularly in the popular media. Across all educational backgrounds, they would be interested in buying products, including food containers, clothing and sun cream, containing nanomaterials. However, they would like to see nano-containing products labelled with detailed information and the testing and regulation of these products carried out by independent national or international bodies rather than profit-oriented companies. Their main policy recommendations were to promote consistent and detailed product labelling carried out by an independent body, to update teachers' knowledge of nanotechnology and to encourage more interdisciplinary STEM (science, technology, engineering and mathematics) curricula.

The objectives of NanoDiode, an FP7 project running from mid-2013 to mid-2016, is to develop a co-ordinated and innovative strategy to engage EU civil society in a dialogue about responsibility around nanotechnologies[545]. 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[546]. The scope of NanoDiode is more ambitious than NanOpinion in as much as they aim to facilitate dialogue across all levels of the nanotechnology value chain, from the general public to policy makers. Through outreach, education and specific events they will involve a cross-section of researchers, industrialists, citizens, scientific advisers and policy makers with the aim of learning where and how society wish nanotechnologies to be applied. For example, they aim to bring groups of potential nanotechnology 'users' (industrial customers as well as consumers) together with researchers working on near-market products in order to facilitate discussions which could help steer the research towards social values and user needs.

In addition to these FP7 projects, two population surveys in Germany provide some data on the public's attitudes (Zimmer et al, 2009)[547], as well as a survey among young people conducted within the framework of the NANOYOU project (NANOYOU, 2010)[548] and a recent survey in the USA (Shipman, 2010)[549]. Work has also been undertaken by the OECD on public engagement with nanotechnology and a guide produced to assist policymakers in working with the public on issues related to nanotechnology (OECD, 2010)[550].

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)[551,552].

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[545] www.nanodiode.eu

[546] 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)

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

[548] Nanoyou, 2010 http://cordis.europa.eu/publication/rcn/15319_fr.html

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

[550] http://www.oecd.org/sti/biotech/49961768.pdf

[551] Böl, G.F., Epp A., Hertel, R., 2010, "Perception of nanotechnology in internet-based discussions", Bundesinstitut für Risikobewertung (BfR)

[552] Fleischer, T., Jahnel J., Seitz S.B., 2012, "NanoSafety – Risk governance of manufactured nanoparticles", European Commission

Table 10-9: Assessments by the public of various applications of nanotechnology
From German online discourses and a questionnaire survey (Böl et al. 2010)

Application	Ratio of positive to negative assessments	
	Online discourses	Population survey
Surface treatment (textile & vehicle)	67 : 33	93 : 7 (paints) 91 : 9 (textile)
Textile; other than surface treatment	56 : 44	76 : 24
Food packaging	25 : 75	81 : 19 (detection) 64 : 36 (foil quality)
Foodstuffs	10 : 90	25 : 75 (lump prevention) 10 : 90 (appearance)
Dietary supplements	0 : 100	not asked
Cancer therapies	90 : 10	(not asked)
"Other serious medical applications"	88 : 12	87 : 13
Cosmetics (excl. sunscreens)	59 : 41	51 : 49
Sunscreen products	10 : 90	78 : 22

11 CONCLUDING SUMMARY

Nanotechnology is seen to be contributing to the goals of improving the performance of vehicles and transport infrastructure by, for example, enhancing surface properties and reducing component weight, as well as sensing and monitoring.

Policy supports in Europe include the EU RTD Framework Programmes, European strategies for transport and for clean and efficient vehicles, European Technology Platforms (including ACARE) and Joint Technology Initiatives (such as Clean Sky and FHC). Member States support nanotechnology within broad science and technology initiatives (e.g. in the United Kingdom, the Netherlands) and through special initiatives such as Germany's Action Plan for Nanotechnology 2015.

The leading EU28 countries for nanotechnology and transport in the Framework Programmes (FP6 and FP7) were Germany, the United Kingdom, France, Italy, Spain and the Netherlands. In terms of individual organisations in the EU28, Germany led with almost 19% of funding going to organisations such as Fraunhofer Gesellschaft, Airbus GmbH, Infineon and the Max-Planck. Other active companies included Thales (FR) and Infineon (DE).

The strongest publishing countries in 2014 were the US and China, followed by Germany and the United Kingdom. The companies with the most nanotechnology and transport publications globally in 2014 were the Ford Motor Company and Aerodyne Research.

For patenting, the lead EU countries were Germany and France. The EU companies identified for patenting include Saab (SE), Michelin (FR), Siemens (DE), ASML (NL) and Philips (NL) although the leaders were from the US and Japan (e.g. Goodyear, Nissan and Boeing).

Global sales of nanotechnology products in the transport sector in 2013 were estimated to be under USD 8 billion and are forecast to grow to almost USD 14 billion by 2019, largely based on the growth in existing products and market areas such as nanotubes and particles (e.g. for batteries), thin films and coatings (for multiple applications) and nano-composites (e.g. for vehicle parts). Of the 385 nanotechnology products identified as commercially available for transport applications, approximately 20% are coatings (anti-scratch and anti-stick), 16% cleaning agents, and c. 10% each are lubricants, batteries and hydrophobic/oleophobic nano-composites. The use in transport of nanodevices (i.e. sensors) and nano-composites is expected to grow to three to four times their current value before the end of the decade.

The application of nanomaterials in transport is not incorporated in transport regulations but nanomaterials must comply with the overarching regulatory framework REACH[553]. Some technical committees of ISO and CEN[554] cover areas linked to transportation but have no specific standards for nanotechnology and transport.

For most of the materials examined, the highest potential health and safety risk from nanotechnology in transport is in the construction phase, due to high expected exposures. In the use phase, nanomaterials are in a solid matrix, making exposure negligible and risks low. In the end-of-life phase, risk management and evaluation of transport materials containing carbon nanotubes and cobalt oxide should receive the highest priority of the materials examined.

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

[554] ISO = International Organisation for Standardisation; CEN = European Committee for Standardisation

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[555] (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'.

[555] 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.

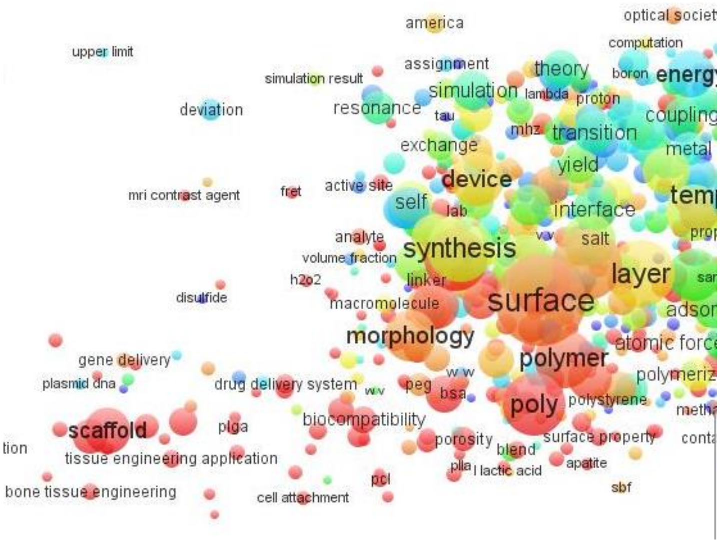

Figure A: Partial VOSViewer map for nanotechnology and health

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[556]	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[557]	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.

[556] In FP6 these were called Priorities and in FP7 Work Programmes.
[557] 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'[558] in the title or abstract of the project. 3,544 projects were selected in this way[559], 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.

[558] 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".

[559] 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[560], 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.

[560] 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)[561].

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.

[561] 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+[562].

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[563]**	United Kingdom
EL[564]	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[565].

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

[562] Data was also analysed from countries outside of the EU28 namely Iceland (IS), Israel (IL), Norway (NO), Switzerland (CH) and Turkey (TR).
[563] GB is also used
[564] GR is also used
[565] 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[566]. 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[567] 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[568] as well as existing market reports[569]. 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[570], Nanowerk[571],

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[566] 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.

[567] http://www.iso.org/iso/country_codes

[568] E.g. Nanomedicine: Nanotechnology, Biology, and Medicine 9 (2013) 1–14, Hessen Nanotech (2008) Applications of Nanotechnologies in the Energy Sector.

[569] See BCC Research www.bbcresearch.com

[570] http://www.azonano.com/

[571] http://www.nanowerk.com/

the consumer products inventory of the Project on Emerging Nanotechnologies[572], the product database of understandingnano.com[573], the Nanoinformationsportal of the Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH[574], the Danish Inventory of Nanoproducts[575] and the nanowatch.de database[576]. 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[577], 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[578], the Nano-Map of the German Federal Ministry of Research[579], the database on photonic companies compiled by EPIC, the members directory of SEMI[580], and the Nano-Bio Manufacturing Consortium (USA)[581], 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,

[572] http://www.nanotechproject.org/cpi/
[573] http://www.understandingnano.com/nanotechnology-product-suppliers.html
[574] http://nanoinformation.at/produkte.html
[575] http://nanodb.dk/
[576] http://www.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank/
[577] http://www.ema.europa.eu/
[578] http://www.nanora.eu/
[579] http://www.werkstofftechnologien.de/en/
[580] http://www.semi.org/en/Membership/MemberDirectory/
[581] http://www.nbmc.org/members-only/

and public database. European Patent Office[582], PRODCOM[583] and patentlens[584] 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[585]. 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

582 https://www.epo.org/searching.html
583 http://ec.europa.eu/eurostat/web/prodcom
584 https://www.lens.org/lens/search?n=10&q=nanotechnology&p=0
585 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: TRANSPORT KEYWORDS

Below is the list of the main keywords used in the extraction of data and the subsequent analyses.

Asterisks are used to indicate that part of a word is missing. For example, the search for "aeroplan*" would identify data related to "aeroplanes" and "aeroplane". Thus one search term was used to cover each of the words with multiple possible endings.

Aeronautic*
Airplane*
Aeroplane*
Aerospace
Aircraft
Airframe*
Automobile*
Automotive
Aviation
Avionic*
Barge*
Bicycle*
Canoe*
Car*
Cruiser*
Diesel
Electric Vehicle*
Fuel Dock
Glider*
GPS
Hatchback
Haulage
Helicopter*
Locomotive*
Lorry
Monorail
Motorcar*
Motorcycle*
Motorbike*
Moped*
Omnibus
Passenger Jet*
Railcar*
Railroad*
Rocket*
Satellite Navigation System*
Scooter*
Ship*
Spacecraft*
Spaceship*
Subway*
Metro*
SUV*
Taxi*
Taxicab*
Tram*
Trans-Shipment*
Trawler*
Tyre*
Wagon*
Windshield
Windscreen*
Yacht*

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
FP7	European Union Seventh Framework Programme for Research
FP6	European Union Sixth Framework Programme for Research
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

Abbreviation	Definition
MRAM	Magnetoresistive random access memory
MRI	Magnetic resonance imaging
MRS (MRSI)	Magnetic resonance spectroscopy (imaging)
MWCNT	Multi-walled carbon nanotubes
MX2	Metal dichalcogenides
NACE	Nomenclature statistique des activités economiques dans la communauté européenne
NEMS	Nano-electromechanical system
NGO	Non-governmental organisation
NIR	Near infrared
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 EPA	US Environmental Protection Agency
US NIOSH	US National Institute for Occupational Safety and Health
US/ USA	United States / United States of America
UV/Vis/IR	Ultraviolet / visible / infra-red
VC	Venture capital
WEEE	Waste electrical and electronic equipment

ANNEX 3: TERMINOLOGY

Word/phrase	Definition/explanation
Carbon nanotubes	Allotropes of carbon with a cylindrical nanostructure.
Dendrimers	Nanostructured synthetic molecules having evenly spread branching structure originating out of a central core.
Nanobiosensors	Biosensor at nano-scale: measurement system for detection of an analyte that combines a biological component with a physiochemical detector
Nanobiotechnology	Intersection of nanotechnology and biology, the ways that nanotechnology is used to create devices to study biological systems, this is different from bionanotechnology
Nanocapsule	Nano-scale shells made 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
Nanoindentation	Variety of indentation hardness tests applied to small volumes. For testing the mechanical properties of materials (hardness).
Nanomaterials	Materials the single units of which is sized (in at least one dimension) between 1 and 1000 nanometres (10^−9 meter) but is usually 1—100 nm (the usual definition of nano-scale).
Nanomedicine	Medical application of nanotechnology
Nanometres	One billionth of a metre
Nano-needles	Conical or tubular needles in the nanometre size range, made from silicon or boron-nitride with a central bore of sufficient size to allow the passage of large molecules
Nanoparticle	Small object that behaves as a whole unit with respect to its transport and properties, between 1 and 100 nanometres in size.
Nanopolymers	Nanostructured polymers
Nanoproducts	Any product containing nanoparticles
Nanorod	One morphology of nano-scale objects, produced by direct chemical synthesis.
Nano-scale	Refers to structures with a length scale applicable to nanotechnology, usually cited as 1–100 nanometres, also called nanoscopic scale
Nanoscience	The study of the fundamental and functional properties of matter on the nano-scale (~10^-9m).
Nanosensor (proteomic, gold)	Any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world
Nanoshells (plasmon)	This is also called nanoshell plasmon, is a type of spherical nanoparticle consisting of a dielectric core, which is covered by a thin metallic shell (usually gold).

Word/phrase	Definition/explanation
Nano-specific	Refers to a system or response that is sensitive to nanomaterials
Nanostructures	An object of intermediate size between microscopic and molecular structures
Nanosuspensions	Submicron colloidal dispersions of nanosized drug particles stabilised by surfactants. Nanosuspensions consist of the poorly water-soluble drug without any matrix material suspended in dispersion
Nanotechnologies / nanotechnology	Manipulation of matter with at least one dimension sized from 1 to 100 nanometres
Nanotechnology-based platforms	Suite of technologies using nanomaterials, structures and objects
Nanotube	Hollow nano-fibre
Quantum dots	A nanocrystal made of semiconductor materials that are small enough to exhibit quantum mechanical properties

ANNEX 5: ADDITONAL INFORMATION ON MEMBER STATE POLICIES AND PROGRAMMES

In addition to actions at the level of the whole of the European Union, many countries have developed strategies and action plans and funded programmes and projects. Some of these are identified and outlined below, by country.

The aim in this section is to give a flavour for the policies and programmes that are or have been in place for nanotechnology at Member State level, in the wider context of national strategies for science, technology, research and development. As it focusses on targeted initiatives for nanotechnology, not all EU28 countries are included.

This section has been prepared from existing data sources (e.g. Member State government and agency reports and web sites, European Commission sources (such as ERAWATCH/RIO[586]), 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)[587] and the Federal Ministry for Transport, Innovation and Technology (BMVIT)[588]. The largest share of direct support for R&D is channelled through three funding agencies: The Austrian Science Fund (FWF)[589] that focuses on funding academic research; the Austrian Research Promotion Agency (FFG)[590] specialising in funding applied industrial research and the co-operation between the higher educational sector and industry; and the Austria Economic Service (AWS)[591] 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**"[592] was adopted by the Federal Government. The NANO initiative was a response to regional activities in the Austrian Bundesländer (such as NanoNet Styria [for more information, see later in this Annex]) that sought to identify existing competences and to formulate potential themes for large-scale co-operative projects.

An important motivation in the establishment of such a national research programme was the expectation that its creation would strengthen the national research community in specific fields thereby better linking them to international communities. At that time, most Austrian peer countries (Germany, Switzerland, UK, and Finland), as well as the European Framework Programmes, were using the label nanotechnology for framing focused research programmes.

The NANO initiative aimed to address the following issues: What would be the best way for Austria to harness the opportunities in nanotechnology (for instance, in environmental and energy technology and new resource-saving products or for small- or medium-sized enterprises)? How could Austria contribute to ensuring the safety for its citizens of nanotechnology applications?

NANO had the following objectives: to increase networking among actors so as to achieve critical mass; to open up ways to exploit the benefits of nanotechnology for industry and society; and to ensure proper support for qualified personnel. To achieve these objectives it had two programme action lines:

1. National co-operative RTD Projects (Research and Technology Development in Project Clusters (RPCs) and
2. Transnational co-operative RTD Projects (Research and Technology Development in Transnational Projects).

586 https://rio.jrc.ec.europa.eu/
587 http://www.en.bmwfw.gv.at/
588 https://www.bmvit.gv.at/en/
589 https://www.fwf.ac.at/en/
590 https://www.ffg.at/en
591 http://www.awsg.at/
592 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[593], 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)[594] 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**[595]**,** 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**[596], 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)[597]**:** 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".

[593] http://www.sozialministerium.at/cms/site/attachments/6/1/7/CH2120/CMS1371046721712/umsetzungsbericht_2012_en.pdf
[594] https://www.ffg.at/en
[595] http://www.bionanonet.at/about-bionanonet
[596] http://www.bionanonet.at/about-nanotoxicology?lang=english
[597] http://www.wirtschaft.steiermark.at/cms/beitrag/10430090/12858597

BELGIUM

Since its two regions play a central role in Belgian policy making, the main nanotechnology activity in the country is carried by the regional government of Flanders, with a number of institutions working in the area of nanotechnology.

Strategische onderzoekscentra[598] (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[599] is a leading European independent research centre in micro- and nano-electronics, *nanotechnology,* design methods and technologies for ICT systems. It carries out research that runs three to ten years ahead of industrial needs. The world's top integrated device manufacturers, equipment and material suppliers, system houses and electronic design automation (EDA) vendors participate in the research conducted there. Work at Imec has a strong connection to nanotechnology given its use in electronics and as the next generation technology for electronics and ICT.
- VIB[600], 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[601], 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[602] is an independent research institute that stimulates innovation in information & communication technology (ICT) and broadband. This research is interdisciplinary and demand-driven, and takes place in close collaboration with businesses and governments, both local and international. Its aim is to provide solutions to complex problems and thus help meet society's future challenges.

In 2003, the Regional Government of Wallonia launched a nanotechnology programme in order to support research projects in that field which led to the creation of **NanoWal**[603], 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[604]. It included four different sub-programmes in the areas of: nanoparticles, nano-fibres and nano-composite 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[605], nanotechnology is addressed under the **Materials Research** priority, where it is set

598 http://www.ewi-vlaanderen.be/wat-doet-ewi/excellerend-onderzoek/strategische-onderzoekscentra
599 http://www2.imec.be/be_en/home.html
600 http://www.vib.be/en/Pages/default.aspx
601 https://vito.be/en
602 https://www.iminds.be/en
603 www.nano.be/
604 http://www.csnmt.cz/getfile.php?type=file&IDfile=24
605 http://www.vyzkum.cz/FrontClanek.aspx?idsekce=1020

as an area to be supported by national budget in order to increase the global competitiveness of the Czech economy through products with high added-value.

DENMARK

In Denmark, the Ministry of Higher Education and Science[606] 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[607]). The last phase of the foresight programme was closely linked to the establishment of the Danish National Advanced Technology Foundation[608] 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[609]** 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[610].

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

[606] http://ufm.dk/en
[607] Danish Nano-science and Nano-technology for 2025, Foresight Brief No. 032
[608] http://www.tekno.dk/about-dbt-foundation/?lang=en
[609] http://ufm.dk/en/publications/2004/technology-foresight-on-danish-nanoscience-and-nanotechnology
[610] http://www.nano-vaccine.org/

Advanced Technology Foundation, the Danish Council for Strategic Research and the Danish Council for Technology and Innovation into a new innovation foundation. Thus, the new organisation Innovation Fund Denmark[611] (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[612]. 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

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[611] 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
[612] http://www.tekes.fi/globalassets/julkaisut/research_and_technology.pdf

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[613]. 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*[614] in Grenoble (centred in Minatec);
- The *Laboratoire d'Analyses et d'Architectures des Systemes*[615] (LAAS) in Toulouse ;
- The *Laboratoire de Photonique et de Nanostructures*[616] (LPN) in Marcoussis ;
- *The Institut d'Électronique Fondamentale*[617] *(IEF) Orsay,* in Minerve; and
- The *L'Institut d'Electronique, de Microélectronique et de Nanotechnologie* [618] (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**[619]) 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**[620] (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

[613] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf
[614] http://www-leti.cea.fr/en/
[615] https://www.laas.fr/public/
[616] http://www.lpn.cnrs.fr/fr/Commun/
[617] http://www.ief.u-psud.fr/
[618] http://exploit.iemn.univ-lille1.fr/
[619] http://www.agence-nationale-recherche.fr/suivi-bilan/historique-des-appels-a-projets/appel-detail1/programme-national-en-nanosciences-et-nanotechnologies-pnano-2005/
[620] http://www.gouvernement.fr/investissements-d-avenir-cgi

a pilot stage and to consolidate knowledge about toxicology and nanomaterials, the programme is funding therapies, imaging, diagnostics and medical devices base on nanotechnology and biotechnology.

GERMANY

As far back as 1998, the Federal Ministry of Education and Research (BMBF) increased collaborative project funding for nanotechnology. In addition, an infrastructure plan was put in place in the form 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**[621]" 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**[622] in 2006. This was done through the **Nano Initiative—Action Plan 2010**[623], 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**[624], 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

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621 http://d-nb.info/97392179x/34

622 http://www.research-in-germany.org/en/research-landscape/r-and-d-policy-framework/high-tech-strategy.html

623 http://www.cleaner-production.de/fileadmin/assets/pdfs/Nano_initiative_action_plan_2010.pdf

624 http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf

support funding for strategic co-operation between industry and public research in high-potential technology areas that require high levels of funding and long lead times. Through a public-private partnership, the Federal Government provided funding for R&D and other innovation-related activities for specific, long-term co-operative R&D projects. R&D activities could range from fundamental research to prototype development. Public funds were complemented by private money from industry, typically at a proportion of 1:5 (public: private). Each innovation alliance was set up through an industry initiative, organised as a long-term co-operative research project and involving 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)[625]: The Bavarian cluster policy was initialised in 2007 and focused on 19 branches/technologies with high importance for the future of Bavaria. These were organised into five fields:
  - materials engineering (including ***nanotechnologies***, materials engineering, chemical industries);
  - mobility (including automotive, rail, logistics, aerospace and satellite navigation);
  - life sciences and environment (including biotechnology, medical technologies, energy technologies, environmental technologies, forestry and food);
  - IT and electronics (ICT, high-performance electronics, mechatronics and automation); and
  - service and media (financial services, media).

After a positive evaluation in 2010, the State Government announced some changes in the future organisation of the overall initiative: A major change is that the (nonetheless successful) clusters high-performance electronics, logistics, biotechnology and medical technologies would be restructured into networks, while future funding would be focused on the other clusters, where funding so far was most successful in generating additionality.

- Research Strategy of Thuringia (2008): Main objectives of Thuringia's research policy were to strengthen regional universities and non-university research institutes and regional companies in their research and development efforts in order to achieve scientific excellence, to initiate knowledge and technology transfer as well as innovation. The document described outstanding research areas of the state and measures to strengthen and relate the regional research

625 https://www.cluster-bayern.de/en/

landscape to target fields in the regional economy: micro and nano technologies, microelectronics; information and communication technologies; media and communication; health research and medical technology; microbiology and biotechnology; optical technologies, photonics; materials and production technologies; environmental and energy technologies, infrastructure; and cultural and social change. Main fields of activity of regional research policy were (i) to support competitiveness, (ii) to strengthen networks, (iii) to support young researchers, and (iv) to invest in infrastructure.

IRELAND

Following the establishment of Science Foundation Ireland (SFI) in 2000, public funding was made available to support many public research initiatives including the **Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN)[626]**. 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[627] 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,

[626] http://www.crann.tcd.ie/

[627] Forfás ceased to exist in 2015 and was, in part, subsumed under the Department of Jobs, Enterprise and Innovation.

nanotoxicology and nanomedicine. The group investigates molecular, cellular and physiological interactions using novel biophysical tools such as cell actuators, and magnetic and ultrasound fields. Members of the BioNano Laboratory are also members of the **Integrated Nanoscience Platform for Ireland (INSPIRE)[628],** 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)[629]** was launched. AMBER is jointly hosted in TCD by CRANN and the Trinity Centre for BioEngineering, and works in collaboration with the Royal College of Surgeons in Ireland and UCC. The centre provides a partnership between leading researchers in material science and industry to develop new materials and devices for a range of sectors, particularly the ICT, medical devices and industrial technology sectors.

THE NETHERLANDS

In the Netherlands, nanotechnology was established as a distinct field of scientific research in the early years of the 21st century. A foresight study (Ten Wolde 1998) conducted by the Dutch Study Centre for Technology Trends (STT) between 1996 and 1998 laid the foundation of a national research agenda. The study showed the importance of nanotechnology for electronics, materials, molecular engineering and instrumentation, and also recommended to pay due attention to nanosafety issues and set up research in that area.

The Netherlands hosts three dedicated nanotechnology research centres: The University of Twente (with the **Mesa+** research centre in microsystems technology and nanomaterials[630]), Delft University of Technology (with the **Else Kooi Laboratory**[631], previously called Dimes research centre on nanoelectronics) and the University of Groningen (with **BioMaDe[632]** focused on bio-nanotechnology). The early 2000s, these formed the core of **NanoNed** - the Nanotechnology R&D initiative in the Netherlands[633]. 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[634]**. 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

[628] http://www.crann.tcd.ie/Research/Academic-Partners/testt.aspx
[629] http://ambercentre.ie/
[630] https://www.utwente.nl/mesaplus/
[631] http://ekl.tudelft.nl/EKL/Home.php
[632] http://www.biomade.nl/
[633] However, four other universities, and TNO, the Netherlands Organisation for Applied Scientific Research, are also represented.
[634] http://www.rritrends.res-agora.eu/uploads/27/8079721-bijlage%281%29.pdf

"nanomedicine".

The Dutch systematic approach to nanotechnology strategy resulted in the development of stable research groups, centres, department and laboratories. On the national level, **NanoLab NL**[635] 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**[636] 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**[637], 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**"[638]. 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

[635] http://www.nanolabnl.nl/
[636] http://www.nanonextnl.nl/
[637] http://topsectoren.nl/english
[638] www.bioin.or.kr/fileDown.do?seq=5186

yearly in the specialisation of nanotechnology, building specialist laboratories, establishing co-operation networks of research and industrial units, financial institutions, etc. and integrating dispersed activity of research units in a joint programme of nanotechnology development.

In 2014, the Government approved the **National Smart Specialisation Strategy** as an integral part of the Enterprise development Programme, setting "Multifunctional materials and composites with advanced properties, including nano-processes and nano-products" as a horizontal smart specialisation area in Poland.

PORTUGAL

In 2005, the Portuguese and Spanish Governments decided to jointly create the **International Nanotechnology Laboratory (INL)[639]** 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

639 http://inl.int/

were involved in the development of many of them either on a collaborative basis, or were subcontracted by the company carrying out the project.

In 2005, the Government of Spain launched the strategic programme **INGENIO 2010[640]** 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[641]** was implemented by the Ministry of Economy and Competitiveness. This policy measure was part of the National Plan for R+D+I 2008-2011**[642]** 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[643] and in the State Plan of Scientific and Technical Research and Innovation 2013-2016[644] (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)[645]: 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

640 http://www.ingenio2010.es/
641 http://www.idi.mineco.gob.es
642 Ibid
643 http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_Strategy_Science_Technology.pdf
644 http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_RDTI_Plan_2013-2016.pdf
645 http://www.nanobasque.eu/aNBW/web/en/strategy/index.jsp

designed to develop a new economy sector enabled by nanotechnology. It was created with the purpose of covering three main areas of action, namely: company, knowledge and society. One of the objectives was to create a new model of relations to involve both national and international companies, scientific, technological, political and social agent. The expected result were targeting the efficiency and the integration of the ecosystem of innovation that was clearly aimed at the market, based on the co-operation between all parties. The launch of the nanoBasque Strategy was accompanied by the creation of a dynamic support agency, the nanoBasque Agency, with the mission of coordinating and managing the development of the Strategy. The nanoBasque Strategy strived to boost Basque the presence of companies and research agents on international nanotechnology initiatives and markets. EUR 550 million were expected to be mobilised in the 2009-2015 period, with a proportion of public funding of 52% on the total.

- Within the nanoBasque strategy and using CONSOLIDER funds, the Cooperative Research Centre 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[646]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[647] and identified future potential growth sectors. Both institutions have also developed a number of measures facilitating the knowledge exchange and technology adoption, such as: commercialisation opportunities and Knowledge Transfer Partnerships, Knowledge Transfer Networks, Technology and Innovation Centres, and Small Businesses Research Initiative.

The main interest of the UK government for nanotechnology started in 2002, when they published the **Taylor Report**[648] 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

[646] https://www.gov.uk/government/organisations/innovate-uk
[647] https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative
[648] http://webarchive.nationalarchives.gov.uk/20130221185318/http://www.innovateuk.org/_assets/pdf/taylor%20report.pdf

facilities were targeted at addressing a broad range of key application areas where micro/nano scale activity was considered key to future UK industry capability and where the UK had some strength. Micro/nano technologies were included within relevant broader collaborative R&D competitions, principally in the materials, medicine and electronics areas. In 2007 the **Nanotechnology Knowledge Transfer Network (NanoKTN)**[649] 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 nano-fabrication. 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**[650] 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**[651]", 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**[652] 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**[653]. 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)**[654] in order to facilitate discussion and engagement between Government and stakeholders in matters referred to the responsible advancement of the UK's nanotechnologies industries. The NSF is an advisory body formed by *ad hoc* expert with a membership drawn from industry, regulators, academia and NGOs (non-governmental organisations

[649] https://connect.innovateuk.org/web/nanoktn
[650] https://www.epsrc.ac.uk/newsevents/pubs/report-of-the-nanotechnology-strategy-group/
[651] https://www.epsrc.ac.uk/newsevents/pubs/nanotechnology-programme/
[652] http://www.nibec.ulster.ac.uk/uploads/documents/nanoscaletechnologiesstrategy.pdf
[653] http://www.steptoe.com/assets/htmldocuments/UK_Nanotechnologies%20Strategy_Small%20Technologies%20Great%20Opportunities_March%202010.pdf
[654] https://www.gov.uk/government/groups/nanotechnology-strategy-forum

and it is jointly chaired by the Minister of State for Universities and Science (BIS) and the Parliamentary Under-Secretary for DEFRA and is supported by a small secretariat based in DEFRA.

The UK **Enabling Technologies Strategy 2012-2015**[655] 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.

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

ANNEX 6: PRODUCTS FOR NANOTECHNOLOGY AND TRANSPORT

This Annex is divided largely into the same categories as used in the main body of the report:

- Batteries and fuel cells (e.g lithium ion batteries);
- Coatings and thin-films;
- Composites; and
- Other (lubricants, cleaning products, sensors, etc.).

1 LITHIUM ION BATTERIES

Product Name	Description	Producer
12V Engine Start Battery	A123's Nanophosphate EXT™ lithium-ion 12V starter battery sets a new performance standard for micro-hybrid vehicle applications by delivering a significant increase in cycle life, charge acceptance and a 50% weight reduction as compared to lead acid batteries.	A123 Systems LLC
AHP14 Prismatic Pouch	Nanophosphate® AHP14-M1Ultra-A: A123's AHP14 prismatic pouch cell is built to deliver very high power output with high usable energy range.	A123 Systems LLC
AHR32113 Cylindrical	Nanophosphate® AHR32113M1Ultra-B: Designed for HEV applications using our high power M1Ultra electrode design, A123's AHR32113 lithium iron phosphate cell is built to deliver high power and long life under the most demanding duty cycles.	A123 Systems LLC
AMP20 Energy Modules	Nanophosphate® AMP20 Energy Modules: Designed for plug-in hybrid and electric vehicle applications, our automotive class prismatic modules are built to deliver high energy without compromising power performance.	A123 Systems LLC
AMP20 Prismatic Pouch	Nanophosphate® AMP20M1HD-A: A123's AMP20 prismatic pouch cell is built to deliver high energy and power density combined.	A123 Systems LLC
ANR26650 Cylindrical	Nanophosphate® ANR26650M1-B: The ANR26650M1-B is the next generation of A123 Systems' pioneering 26650 cylindrical cell, now with greater power and energy density and lower impedance.	A123 Systems LLC
APR18650 Cylindrical	Nanophosphate® APR18650M1-A: Based on the same Nanophosphate LiFePO4 technology as A123 Systems' pioneering ANR26650 cell, the APR18650 is now available as a smaller form factor for design flexibility in commercial and handheld products and appliances.	A123 Systems LLC
Nanophosphate® Energy Core Pack (23kWh)	Nanophosphate® Energy Core Pack (23kWh): Designed for plug-in hybrid and electric vehicle applications, our automotive class Energy Core Packs are designed as ready-to-use sample packs for rapid deployment into powertrains for testing and development purposes.	A123 Systems LLC

Product Name	Description	Producer
Lithium-Ion Battery	Lithium-ion battery with the anode composed of lithium titanate spindle nanoparticles	Altair Nanotechnologies Inc.
Nano-structured Lithium Titanate	Nano-structured Lithium Titanate	Altair Nanotechnologies Inc.
Lithium-ion battery with Silicon anode	Lithium-ion battery with Silicon anode	Amprius
BTY-175	Blue Nano's BTY-175 is a proprietary blend of carbon nanomaterials designed specifically to extend the life of lithium-ion batteries. It features proprietary granular conductive additives to maintain dispersion, increase durability and improve discharge capacity.	BlueNano
Silicon-Graphene (SiGr) composite anode material	Anodes that use silicon nanoparticles embedded in graphene, for use in lithium-ion batteries	CalBattery
Moxie+ Prismatic Cell	Li-ion battery	ENERDEL INC.
EnerG2 nano-structured hard carbon	nano-structured hard carbon for Li-ion battery anodes	EnergG2
High Capacity Manganese Rich (HCMR™) cathodes	Envia has built on Argonne's cathode technology and developed proprietary engineered compositions (Ni, Co, Mn and Li_2MnO_3) with innovative particle morphologies (particle size, shape, distribution, tap density & porosity) and specialised dopants and nano-coatings resulting in major improvements to capacity, rate, cycle life & safety.	Envia Systems
SEPARION Ceramic Separator Membrane	SEPARION® - a new type of separator that gives lithium-ion batteries outstanding properties. This ceramic separator from Evonik is stable to temperatures of up to approx. 700 °C. SEPARION® is a combination of ceramics and polymers, two materials that are normally completely incompatible because of their differing temperature profiles.	Evonik Industries
Binder less electrodes	Binder less electrodes is a revolutionary technology Graphene Batteries (GB) is developing together with CVD Equipment Corporation. The technology will not only replace conventional binders in the battery but will also lead to the fabrication of thicker electrodes which in itself can reduce the cost of batteries per KWh by about 30%.	Graphene Batteries AS
LFP/Graphene	A composite LFP/Graphene material with significantly higher conductivity than the reference industrial material. The material shows higher volumetric and gravimetric energy densities at all discharge rates than the reference material. Additionally the final material has potentially high thermal diffusivity which would further improve battery safety.	Graphene Batteries AS
Silicon/Graphene	Silicon is the next generation of anode material with ten times the theoretical capacity of currently used graphite. The	Graphene Batteries AS

Product Name	Description	Producer
	flexibility and conductivity of graphene makes it an ideal material to be used with silicon in the anodes.	
ToBox	Lithium titanite oxide battery	Leclanché
Smart NanoBattery (SNB)	Battery with chemicals isolated from electrode by "nanograss" when the battery is not in use	mPhase Technologies, Inc.
Tin Nanode™	Tin Nanode™ has applications as a tin anode for lithium-ion batteries. Commercial lithium-ion batteries currently use graphite as the active material on the anode, and research and development worldwide is focused on high energy anode materials such as silicon and tin. Tin and its alloys offer high energy materials for the use in lithium-ion batteries with more than twice the energy density of commercial graphite electrodes.	Nano-Nouvelle
CNTs for Li-ion batteries	Nanotube based additive for use in lithium-ion electrodes	NanoAmor
3rd Generation Cathode Materials	Lithium-ion battery using nano-composite electrodes using technology developed at Argonne National Laboratory	NanoeXa Corporation
NANOMYTE® Battery Material	Nanomaterials for lithium-ion battery electrodes	NEI Corporation
Li-ion batteries	Nexeon has patented a unique way of structuring silicon so that it delivers extended cycle life and significantly increases battery capacity. In contrast to carbon, Nexeon's silicon anode materials have a much higher capacity for lithium and as a result are capable of almost ten times the energy capacity per gram (mAh/g).	Nexeon Limited
YB-LITE2344	Lithium titanite oxide battery	Shenzhen Yabopower Technology Co., Ltd.
Super Charge Ion Battery (SCiBTM)	Lithium titanite oxide battery	Toshiba
ZPower	Silver-zinc battery using nanoparticles in the silver cathode	ZPower LLC

2 SUPER CAPACITORS

Product Name	Description	Producer
NanoCap	NanoCap energy storage application. The NanoCap ultra-capacitor stores energy by functioning both like a battery and a capacitor. NanoCap has the potential to offer game-changing advances, ranging from power grids to consumer electronics and transportation.	Dais Analytic
PowerStor Aerogel Capacitors	PowerStor / Eaton XL60 Series is a large format, high capacity supercapacitor. The 2.7V, 3000F cells combine electrochemical double layer capacitor (EDLC) construction with new, high-performance materials. These factors allow the series to provide high energy for backup applications and high power for cycling applications and engine starting. Operating temperature is range is -40ºC to 65ºC (up to 85ºC with voltage derating to 2.3V).	Eaton
Graphene Hexagonal Supercapacitor.	Graphene-based supercapacitor	Graphenex Ltd
Human Gait Energy Scavenger	Nanostructured devices that generate electricity during walking	nStep NanoPower, LLC
PowerResponder™	Hybrid Supercapacitor	Paper Battery Company
PowerWrapper™	The PowerWrapper™ products are thin, patternable supercapacitor devices operating at voltages designed to match battery and system operating voltages.	Paper Battery Company
Skelcap High Energy Ultra-capacitor	High energy density ultra-capacitors providing up to 10 Wh/kg. Intended for longer application times and higher energy requirements without sacrificing power performance.	Skeleton Technologies
Skelcap High Power Ultra-capacitor	High power density ultra-capacitors with up to 60 kW/kg and 101 kW/L for unprecedented power delivery. Low ESR of 0.12 mOhm minimises overheating issues.	Skeleton Technologies

3A Fuel cells

Product Name	Description	Producer
BEI Cathode	Manufactured with a patented process and the latest in nanotechnology advancements. BEI cathodes provide outstanding performance and achieve new level of value. BEI cathodes are unique and utilise a patented construction to minimize the amount of Platinum required while improving the overall power output and durability.	Bing Energy
Membrane Assembly Material	Bing's Membrane Electrode Assemblies (MEAs) are made with DuPont Nafion and Bing's patented cathode technology. The standard size is 4 cm x 4 cm. Other sizes are available upon request.	Bing Energy
CAT-110 Fuel Cell Catalyst	Blue Nano's porous catalyst technology increases reactive surface area, minimizing expensive material usage and increasing power density for both fuel cells and other chemical catalysts. The CAT-110 series represents Blue Nano's flagship fuel cell catalyst technology.	BlueNano
Dynalene FC	Dynalene FC is a nanoparticle and water-based coolant with extremely low electrical conductivity (less than 1.0 µSiemens/cm). It has been specifically designed to maintain a low level of electrical conductivity for at least two years while providing excellent heat transfer properties similar to a water-based fluid. This coolant is primarily used for cooling PEM (polymer electrolyte membrane) fuel cell stacks and liquid cooled computers. The low electrical conductivity of the coolant enables the fuel cell to work efficiently (without "short-circuiting" the cells) and safely (without electrical shock hazards).	Dynalene
PowerBox180	eZelleron's fuel cells can be driven gas directly (Hydrogen, Methane, LPG, ...) or even with liquid fuels (diesel, JP8, kerosene).	eZelleron GmbH
Solvicore	SolviCore develops and supplies products for four different applications: hydrogen- and reformate- fuel cells as well as for PEM-water-electrolysis. These components for fuel cells are manufactured on specially developed or adapted pilot production lines.	Greenerity®
HiSPEC® Catalyst	HiSPEC® Catalysts product range includes single component, alloy, supported and unsupported catalysts. All are manufactured to a consistently high standard in our quality approved, high volume facility.	Johnson Matthey Fuel cell
Mobion® off-the-grid portable power solution	Mobion® is a proprietary direct methanol micro fuel cell power system and a number of system prototypes demonstrating size reductions and performance improvements; and related intellectual property.	MeOH Power

Product Name	Description	Producer
HionicTM	Fuel cell	Nexceris, LLC.
Catalysts for fuel cells	Catalysts for fuel cells	Solvay/ Rhodia SA
Graphene Anode Active Material	Targray offers 2 types of Ultra High Performance Graphene: Vor-charge Anode-HC: High Current, Short recharge, Extended life, Improved safety, Good temperature range. Vor-charge Anode-HE: High energy storage capacity, Short recharge times, Good cycle life.	Targray
Solid Oxide Fuel Cell Materials	Fuel cell materials	U.S. Nanocorp Inc.
ELAT fuel cell line	Fuel cell	Uhde Chlorine Engineers (Italia) Srl
XX55™ reformed methanol fuel cell	The XX55™ reformed methanol fuel cell is an ultra- compact and highly portable fuel cell. The XX55 is designed to meet the rugged off-grid power needs of performance-demanding military and commercial users.	UltraCell

3B FUEL CELL MEMBRANES

Product Name	Description	Producer
Membrane Assembly Material	Bing's Membrane Electrode Assemblies (MEAs) are made with DuPont Nafion and Bing's patented cathode technology. The standard size is 4 cm x 4 cm. Other sizes are available upon request. Bing Energy MEAs are made with our patented proprietary cathodes and anodes and Dupont Nafion.	Bing Energy
Nafion	Nanoporous fuel cell membranes	E. I. Dupont de Nemours and Co.
SiMION	SiMION: is a new generation of composite and nano-composite ion exchange materials. Thanks to exclusive composite knowledge and years of research & development, SiM Composites has created by an exclusive method, unprecedented proton (H+) exchange materials.	SiM Composites

4 ANTI-STICK/ANTI-SCRATCH COATINGS

Product Name	Description	Producer
Hybrid EX7	This extremely tough coating does not peel, crack or flake and enhances the substrate with its own glossy finish. It generates a thin, transparent coating with extremely high impact strength, is resistant to alkali, abrasion, corrosion and a host more.	Advanced Nano Coating
Advanced Coatings	The advanced vacuum and polymer coatings offer a wide range of characteristics: signature management, selective electromagnetic filtering, high-speed rain erosion resistance, precipitation static abatement. The aircraft transparency coating systems have proven superior in providing longer life-cycle efficiencies.	AIP Aerospace
EternAloy® TCHP	This coating can be applied easily by any HVOF process for superior sliding wear performance compared to leading aerospace coatings. High durability and performance.	Allomet Corp.
4K Nano Paint Sealant	4K is a paint sealant designed using aerospace technology, formulated to produce a gloss and protection.	Autobright
Wheel Seal - Nano Wheel Sealant 250ml	Nano Wheel Sealant has been formulated using polymers and cross linking anti-corrosion amino-functional silicones to deliver superior protection to wheels.	Autobright
Nanotol car paint protection kit	The complete overhaul of all older lacquers. Professional package for car care.	CeNano
Nanotol Combi Set	Hitech nano-polymer sealant for glass, metal and plastic. Set with pre-cleaner and microfibre cloths.	CeNano
Diamon-Fusion®	Diamon-Fusion® forms a covalent bond, creating an ultra-thin, clear protective layer which makes the surface significantly easier to clean and more resistant to soap scum, bacteria, dirt, grime, weathering and more.	Diamon-Fusion International
Diamon-Fusion® ULTRA™	Diamon-Fusion® ULTRA™ makes surfaces easier to clean and harder to pit and scratch, extending the life of all surfaces. Independent laboratory test show that it is the most durable protective nano-coating available on the market.	Diamon-Fusion International
BETAPRIME	BETAPRIME™ glass and body primers promote adhesion to vehicle bodies and inhibit rust in small nicks and scratches.	Dow Chemical Company
Surface Restoration Bundle	A product bundle to remove contaminants, fill in microscopic scratches, create a smooth surface and maintain a long-lasting, professional quality shine.	Eagle One
Toughseal Step 1 Pre Treat	A 2-part process that gives all paintwork a diamond-hard shine and offers protection from most harmful elements including: ultra violet rays, fading, acid	Eurochem Group chemicals

Product Name	Description	Producer
	rain, peeling, frost, tree sap, insect acid, bird droppings, oxidation (chalking), petrol and diesel fumes. Toughseal nanoplate is a highly researched complex blend of PTFE and polysilazanes particle displacement protection package for the exterior of cars, boats, caravans and aircraft.	
DEGALAN® LP 64/11	High solids coatings for universal application	Evonik Industries
DEGALAN® LP 64/12	Bead polymer for manufacturing weather-resistant marine paints, metal coatings, exterior paints and concrete coatings	Evonik Industries
DEGALAN® PM 381 N	CDP™ polymer for universal applications for metal coatings and exterior paints	Evonik Industries
DEGALAN® PM 709	Solution polymer for universal coatings such as metal coatings, exterior paints and concrete coatings	Evonik Industries
POLYVEST®	The hydroxyl-terminated product is an alpha-omega-terminated diol of polybutadiene manufactured by radical polymerisation process. POLYVEST® grades are used in adhesives and sealants for automotive applications.	Evonik Industries
G-Clean Interior Protectant	G-CLEAN Protectant shines and shields; protecting the interior surface of vehicles against harmful UVA and UVB sun rays while leaving a lasting shine.	GClean
G-Clean Rain Repellent	G-CLEAN Rain Repellent's nano-sized particles penetrates deep into the windscreen and forms a chemical bond, repelling rain, ice, snow, bugs and road grime for months.	GClean
NF1206 Car Glass Special Fluid	F1206 Carglass Special fluid is a NANO-technology product that causes a long lasting repellent effect against aqueous liquids. Rainwater on the windscreen is taken away by the airstream.	Nadico Technologie
NF1207 Car Paint Fluid	NF1207 Car Paint fluid is an innovative paint sealing which is based on the chemical nanotechnology. The product is water-based and creates a transparent, ultra-thin layer which refreshes and protects paint colour and shine permanently.	Nadico Technologie
Nano Coating For Car Glass	This is a new windscreen coating based on nanotechnology. This coating improves the drivers vision by 50%. The coating is based on nanotechnology. Rainstop removes rain, snow, dirt and insects from car windscreens and keeps ice from building up on the surface. Windscreen wipers suffer less wear-and-tear and confusing reflections are reduced to a minimum.	Nano Acceleration Network
Nano Repair & Restoration Compound	Anti-wear anti-friction repair & restoration compound for repairing cars or other equipment with moving parts subject to friction.	Nano Acceleration Network

Product Name	Description	Producer
Water repellent nanotechnology coating for outdoor textile and fabric	The coating for car upholstery. Thanks to this ultra-thin water-repellent layer, dirt can no longer penetrate into the fibres of the upholstery. This means that spilt soft drinks or other kinds of dirt can be conveniently removed with a cloth.	Nano Acceleration Network
NanoX150 Antifog	Moisture is another problem solved by this anti-fogging liquid, which does not modify the appearance of the surfaces it is applied on, such as glasses, and thus there are no visibility problems.	Nano Soluciones
NanoX150 Glass	There are many uses that can be given to the anti-adherent effect in glass, because it also provides savings in cleaning maintenance. The improvement in visibility has been used by companies such as the ETN bus line, the second largest in Mexico, which implements it in its units.	Nano Soluciones
Nano-coatings based on silicon dioxide for glass and glazed ceramic	These non-stick coatings were designed to enable smooth, glass-like surfaces to have less contact with dirt particles. The hydro- and oleophobic effects cause particles of contamination such as grease, oil , lime and materials from environmental pollution to adhere less to the substrates, and allow them to be easily removed from the water repellent coating, i.e. without applying abrasive agents ("Easy-clean" effect).	Nano-Care Deutschland
Nano-coatings, based on silicon dioxide for plastics, painted surfaces and precious metals	The hydro- and oleophobic effect causes the particles of contamination such as grease and oil, lime-scale and materials from environmental pollution to adhere less to the substrates or and allow them to be easily removed from the nano-coating, i.e. without applying abrasive agents ("Easy-clean" effect).	Nano-Care Deutschland
Nano-coatings, based on silicon dioxide for textiles	This innovative water repellent nano-coating for textiles protects almost any type of textile from water, dirt, contamination and stains – whilst remaining totally invisible! It will not affect the appearance, its ability to breath, its colour or handle and is easy to maintain.	Nano-Care Deutschland
NanoCover Marine Sealant	NanoCover Marine Sealant is easy to apply, durable and efficient. On the freeboard and other fibreglass surfaces above the waterline prevents the seals, black stripes , pollen, seagull droppings etc.	Nanobiz ApS
NanoCover MultiCover Marine	NanoCover MultiCover is a product for sealing which is based on chemical nanotechnology. NanoCover MultiCover cleans, preserves and protects the treated parts with a permanent seal that works dust and water resistant.	Nanobiz ApS
NanoCover® Antimist Glass	NanoCover® Antimist Glass is an alcohol-based, nanochemical glass seal that prevents glass surfaces from misting up dirty in places such as internal panes in homes, cars, greenhouses, ships and	Nanobiz ApS

Product Name	Description	Producer
	other places where condensation is a problem.	
NanoConcept Lacquer Fit Sealing	NanoConcept Lacquer Fit Sealing (1 Component System 100 ml) offers a surpassing grade of brilliance and sleekness as well as protection against alkali, car wash brushes, abrasive environmental impacts, uv-radiation and road salt.	NanoConcept
NanoConcept Pane Fit Sealing	Water rolls off a car window already by a speed of 60 till 70 km/ h after using the sealing. Therefore using the windscreen wiper is not necessary.	NanoConcept
nanodeck Car Glass	Instantly repels water from all car windows and removes the dirt with it (lotus effect).	nanodeck®
nanodeck Car paint	Paint is protected from dirt and other environmental influences in a lasting way.	nanodeck®
nanodeck Car rims	Self-organising, microscopically small nanoparticles provide rims with a lasting protection with dirt-repellent features.	nanodeck®
Clarity Defender® PLUS Marine Windshield Treatment	Clarity Defender PLUS Marine Windshield Treatment is a self-assembling thin-film that coats glass with an invisible, water-repellent nano-barrier that improves vision and adds reaction time for a boat captain.	Nanofilm
Clarity Defender™ Automotive Windshield Treatment	Clarity Defender® PLUS Automotive Windshield Treatment is a self-assembling thin-film that coats automotive glass and mirrors with an invisible, water-repellent nano-barrier.	Nanofilm
Nanolex Premium Glass Sealant	An ethanol-based sealant which forms a chemical bond with glass to provide a hydrophobic barrier, encouraging water to bead and sheet off the wind screen whilst driving.	Nanolex
Rim Refinement	The ultra-thin and super durable layer of DIE NANO EXPERTEN® Rim refinement protects alloy wheels against general soiling and the "burning in" of hot brake dust.	nanopool
Textile	TEXTILE protects your textiles with an ultra-thin nano refinement. It is a ready to use product and can be sprayed directly on the surface.	nanopool
2C Auto Sealant PRO	This two-component sealant is comprised solely of nano-particles and - unlike most products on the market - does not contain any wax, silicone or Teflon, which can all do more harm to auto paint than good.	NanoSafeguard
Auto Glass Treatment Kit	Nanosafeguard repels water so well that above speeds of 45 mph wiper blades are not needed: the water blows off.	NanoSafeguard
Auto Rim Treatment Kit	Nanosafeguard repels water, dirt, brake dust, road grime and other pollutants, and contaminants that are not completely repelled are easily removed	NanoSafeguard

Product Name	Description	Producer
	later on with a damp cloth and mild cleanser!	
Fast Seal	This easy-to-apply sealant uses custom nano-particles to provide superior protection in very few steps.	NanoSafeguard
Nanosafeguard Auto Glass Treatment	NanoSafeguard Auto Glass Treatment forms an invisible protective coating on windscreens, greatly enhancing driver visibility and safety in bad weather conditions.	NanoSafeguard
Nanosafeguard Marine Treatment Kit	By creating a hydrophobic surface Nanosafeguard reduces friction, allowing your boat to slide across the water much easier and faster.	NanoSafeguard
nanoShell Glass	A non-stick, easy to clean, alcohol based protective coating, containing silane based nano-particles for glass and glazed ceramic surfaces.	nanoShell
Vision Protect	Vision Protect™ is a special nanotechnology product with an extremely durable, water and dirt repellent effect on glass surfaces.	Nanoshop
Vision Protect Glass Coating kit for Marine Glass	Vision Protect is a special nanotechnology product with an extremely durable, water and dirt repellent effect on glass surfaces. It represents the latest technology for driving safety.	Nanoshop
Vision Protect ™ 8 kits	Vision Protect™ is a special nanotechnology product with an extremely durable, water and dirt repellent effect on glass surfaces.	Nanoshop
NANOMYTE® PC-10	Specially formulated for aqueous fluoropolymer coatings, NANOMYTE® PC-10 is easily incorporated into commercial coating formulations. Wear resistance is dramatically improved with only a small additive loading. Ideal for demanding applications and severe environments.	NEI Corp.
NANOMYTE® PC-10	PC-10 nanomaterials are specially designed additives for thermoset coatings (e.g., polyurethane, nitrocellulose and epoxy).	NEI Corp.
NANOMYTE® UV-100 Hardcoat	NANOMYTE® UV-100 provides both scratch resistance and UV protection to plastic substrates. UV radiation at wavelengths below 350 nm is cut to almost 100% with the coating, leading to improved weatherability and suppression of discoloration of the substrate.	NEI Corp.
Guard NanoTech 2 - Glass & Solar	Makes windscreens easy to clean - you can just use water to wipe away any dirt, bird foul etc. with windscreen wipers.	New Guard Coatings Ltd
Guard NanoTech 2 - Glass & Solar	Highly effective against ice-build up. Application onto smooth, glass surfaces.	New Guard Coatings Ltd
Guard NanoTech 2 - Marine, Plastic & Paint	Can be used on the bodywork and bumpers of vehicles – offering improved protection against corrosion and reduces cleaning times.	New Guard Coatings Ltd

Product Name	Description	Producer
Guard NanoTech 2 - Metal	Can be used on alloy wheels, offering an extremely durable coating and therefore extending the life of the alloys.	New Guard Coatings Ltd
Guard NanoTech SV - Fabric	Can be applied onto the internal leather/fabric of a car, offering water, stain and oil resistance.	New Guard Coatings Ltd
NanoTec Upholstery Sealant	Upholstery and textiles sealed with the Nigrin NanoTec formula are water and dirt-repellent. Dirt and liquids can no longer penetrate into the upholstery	Nigrin
NIGRIN Windshield Frost Protection Turbo - 60°C	Ensure clear, glare-free visibility and improved driving safety in winter and on long drives.	Nigrin
Antifreeze	Percenta Nano Antifreeze is especially designed for glass surfaces, which have been treated with the Percenta nano sealant.	Percenta
Nano Coating for Lacquer Car Paint	Percenta Nano Coating for Lacquer Car Paint is a 2-component concentrate for impregnation which protects the surface from dirt, oil and dust residues. At the same time it makes the treated lacquer paint shiny and resistant to the negative influence of dust, dirt, acids, alkali, dissolving agents etc. Afterwards, the treated surface could be cleaned only with water, with no additional chemical detergents.	Percenta Nanotechnology
Nano Coating for Wheel Rims	Percenta Nano Coating for Wheel Rims is a concentrate for impregnation which forms a transparent coating, protecting the surfaces from dirt, colour impairment and brake dust. The product forms a transparent film on the surfaces which has a self-cleaning effect.	Percenta Nanotechnology
Nano Coating for Windscreens	Percenta Nano Coating for Windscreens is a concentrate for impregnation forming a transparent coating which: is water-repellent, reduces dirt and dust adherence, improves the visibility, solves the problem with the freezing windscreens at wintertime.	Percenta Nanotechnology
Windscreens Set	Percenta Nano Coating for Windscreens is a concentrate for impregnation forming a transparent coating.	Percenta Nanotechnology
SUPER MATT	The product contains silicon in an aqueous solution. It provides matt finish and is UVA & UVB protection. It does not form a chemical bond with the plastic film. It can be used in rally cars and show vehicles.	Permanon
Hi Shine Polymer Sealant Kit	The resins and cross linked polymers protect paint and metal from UV damage while leaving an impermeable shine.	Sonax GmbH
SONAX Plastic Restorer Gel	SONAX Plastic Restorer Gel contains microscopic nanoparticles that penetrate deeply into grained and structured surfaces, thereby providing long-lasting protection and long-term conservation.	Sonax GmbH
SONAX Polymer Net Shield	SONAX Polymer Net Shield performance car care.	Sonax GmbH

Product Name	Description	Producer
SONAX XTREME Antifreeze & clear view concentrate	Antifreeze and cleaning concentrate for windscreen washer units. Prevents ice formation in the washer unit tank, hoses and nozzles.	Sonax GmbH
SONAX XTREME Wheel rim coating	Protects the wheel rims against renewed soiling. Alleviates and simplifies cleaning.	Sonax GmbH
Rollex NANO	Ready to use polishing polymer for the maintenance of car bodies. Addition nano-formulation protects the surface of varnish. Protection against pollutants and weather conditions. Road pollution, bird excrement, pitch, resin, insects are removed without additional cleaning agents apart from water. Accelerates the drying process	Tenzi Sp. z o.o.
Transparencies	We have integrated state-of-the-art nanotechnologies and proven process methods for fifth-generation coating systems. These tie directly to a complementary core competency of Texstars, the lamination and forming of high-optical transparent sheet materials into the most advanced aircraft transparencies in military defence.	Texstars
tripleO coating	The 'nano-technology' in tripleO is a polymer that enables this high performance solution to cross link and bond with the surface materials - such as paint work, bare metal, leading edges and even rivets - to which it is being applied. tripleO contains hard, durable acrylic elements and creates a perfectly smooth finish, filling the 'pores' of a surface with a unique resin. This forms a barrier to prevent penetration by contaminants.	TripleO Performance Solution

5 Photocatalytic Coatings

Product Name	Description	Producer
Fog Protect	DryWired® Fog Protect nano-coating technology enables transfer from different temperature environments without condensation issues. Fog Protect is ideal for application on work goggles, dive masks, car windows, mirrors, visors, ski goggles and many other transparent hard surfaces. Application can be done manually with a wipe or by liquid spray.	DryWired
Anti Fog	G-CLEAN Anti Fog's nano-sized particles penetrate deep inside the windscreen's interior side and forms a chemical bond, preventing fog build-up inside the vehicle.	Green Earth Technologies
TA2219 Indoor / Air Purification	TA2219 is photocatalytically-active product for the coating of surfaces. The coating is able to decompose organic compounds on a molecular level just by means of light.	Nadico Technologie
Water Repellent Anti-Fog Spray	Anti-Fog Spray leaves an ultra-thin coating preventing condensation from forming. Unlike other similar products, this coating does not leave a greasy mist residue that is then difficult to remove. Available for glass and plastic. Suitable for helmet visors.	Nano Acceleration Network
Top CLEAR NANO	Agent creates protective titanium nano elements layer. Protects from grease, dirt, drops, dust, insects, mineral contaminations, weather conditions and strongly pushes liquid away ("lotus effect") and improves safety and driving comfort, visibility in case of shower.	Tenzi Sp. z o.o.
Top Glass NANO	Ready-to-use agent maintains glass surfaces, makes thin protective anti-static layer (titanium nano-elements). Efficiently removes finger prints, grease stains, natural dirt and dust, recommended for: home, office and car equipment. Does not leave streaks and has citrus aroma.	Tenzi Sp. z o.o.

6 Thermal spray coatings

Product Name	Description	Producer
SURPREX CNC20	The SURPREX CNC20 series of thermal spray materials, developed by Fujimi, is a chromium carbide (CrC) and 20% nichrome (NiCr) compound cermet. This material is used for wear resistance at high-temperatures and for oxidation resistance.	Fujimi
SURPREX WC17	Thermal spray materials with application in jet engine parts, fretting parts, aircraft parts, fan blades and internal combustion engine parts.	Fujimi

7 NANO-COMPOSITES

Product Name	Description	Producer
HYBTONITE® G4	The resin is a low viscosity solvent-free 100% reactive CNT-modified epoxy resin for use in automotive components.	Amroy Europe Oy
CNTstix™ adhesive	CNTstix™ is an ultra-strong carbon-nanotube reinforced adhesive for structural applications in the transportation industry.	Applied Nanotech, Inc.
MIXINO + AERO SHELL VD2.0	Mixino with Graphene and Aero Shell VD 2.0 are the perfect aerodynamic couple. The design of Mixino has an excellent aerodynamic performance.	Catlike Sport Components S.L.U
MIXINO MTB	Mixino MTB helmet that adapts itself to almost any cycling modality. Mountain bikers are protected and equipped by a helmet with inner aramid skeleton with graphene, in a super-light helmet.	Catlike Sport Components S.L.U
MIXINO ROAD	Cycling road helmet incorporating graphene nano-fibres on its inner aramid skeleton. A super-light helmet.	Catlike Sport Components S.L.U
MIXINO VD2.0	Mixino VD2.0 for track and chrono stages. Mixino VD2.0 maintains all Mixino's technical features adding a fixed aerodynamic shell as requested from UCI's rules.	Catlike Sport Components S.L.U
DOLAN TUONO SL CARBON ROAD BIKE	The Dolan Tuono SL. The super stiff, lightweight carbon fibre road frame with race geometry is a perfect all round racer. With seven sizes available, the frame has been designed with internal cable routing and is electronic groupset ready.	Dolan Bikes
DOLAN TUONO SL CARBON ROAD BIKE - SHIMANO ULTEGRA 6800	The Dolan Tuono SL is now available complete with full Shimano 6800 Ultegra 11 speed groupset, Mavic Cosmic Pro Carbone Clincher wheels, Deda finishing kit and Sella Italia saddle.	Dolan Bikes
BETAFORCE	For high-performance bonding in lightweight multi-material vehicles, BETAFORCE™ composite bonding adhesives enable significant weight reduction plus improved acoustic performance and better corrosion protection.	Dow Chemical Company
EP113	Master Bond EP113 is a two component, nanosilica filled epoxy system for potting, coating and sealing. The addition of the nano-particles enhances the dimensional stability and the already exceptionally low shrinkage upon curing. EP113 has a 100 to 80 mix ratio by weight. It has an unusually low viscosity along with an especially long open time of 2-4 days. Requires oven curing, typically 2-3 hours at 250°F followed by 5-8 hours at 300°F with a 2-hour or longer post cure at 350°F.	Master Bond Inc.
Nanosilica Reinforced Polymer System UV22	Master Bond Polymer System UV22 represents a remarkable technological breakthrough in the utilisation of	Master Bond Inc.

Product Name	Description	Producer
	nanotechnology in the formulation of a one component UV curable epoxy for coating, sealing and encapsulation applications. This nanosilica-filled system features superior physical properties, enhanced abrasion resistance and excellent optical clarity along with significantly reduced shrinkage after curing.	
UV22DC80	Master Bond UV22DC80 is a nano-silica filled, dual cure epoxy-based system. It is formulated to cure readily upon exposure to UV light and will crosslink in shadowed out areas with the addition of heat. The UV-curables will crosslink rapidly and thoroughly upon exposure to the light, but it will not cure in areas where the material is not exposed to the light. The thermal part of the cure is achieved at 80°C. Dual cure systems are particularly useful for rapidly fixing parts with the UV portion of the cure and then finishing the process by heating.	Master Bond Inc.
jERCURE	jERCURE™ curing agents for epoxy resins that cover the full range from low to high curing temperature with functional groups ranging from amine, mercaptan, and phenol to Lewis acid complex compounds.	Mitsubishi Chemical Corporation
jER™	jER™ (formerly Epikote™ *) epoxy resin	Mitsubishi Chemical Corporation
SUNPRENE	SUNPRENE™ is a vinyl chloride-based thermoplastic elastomer in which much-desired rubber-like elasticity has been engineered into the versatile soft polyvinyl chloride while maintaining the good workability of a soft polyvinyl chloride compound.	Mitsubishi Chemical Corporation
THERMORUN™	THERMORUN™ is widely used for air bag covers, weather strips, various protectors, hoses, moulded parts, packing, auto parts, household appliance parts, and common industrial components.	Mitsubishi Chemical Corporation
ExoShield	Multi-layer nano-composites sandwiched into a thin, transparent film slightly more thicker than human hair. ExoShield absorbs the impact energy from stones hitting your windscreen to prevent stone chips and windscreen breakage.	Neverfrost, Inc.
Ecobarrier®	Noble Polymers' Ecobarrier® Thermoplastics PolyOlefin (TPO) series of products represent the highest level of performance and functionality in applications that require superior acoustical management.	Noble Polymers
FivePlus™	FivePlus compounds are used in automotive, heavy truck, consumer goods, building and construction and many other industries for applications such as brackets, housings, trim panels and other applications that require a balance of durability, dimensional	Noble Polymers

Product Name	Description	Producer
	stability and processability. Noble Polymers FivePlus™ series of filled polypropylene compounds offers processors a wide range of filler and physical properties options. Five Plus compounds are available with your choice of mineral fillers.	
DOGMA 65.1 - Carbon Torayca® 65HM1K - 833 Giallo Nero	The DOGMA uses Torayca 65Ton HM 1K with Nanoalloy technology, exclusively from Toray the Japanese carbon company and only available to Pinarello	Pinarello
DOGMA 65.1 Think 2	Nanoalloy in bicycle frames. Torayca 65Ton HM 1K Nanoalloy technology, exclusively from Toray the Japanese carbon company	Pinarello
reSound™ NF Natural Fiber Reinforced Thermoplastic Composites	Highly engineered, strong and sustainable alternative to glass fibre-reinforced formulations, with densities 5-10 percent less than comparable glass fibber formulations. The combination of superior performance and low density makes reSound NF solutions an excellent choice for technical applications in many industries. In automotive, PolyOne has identified more than 15 potential applications in passenger vehicles for these formulations.	Polyone Corporation
Nano Molecular Bonding	Vindicoat's nanomolecular bonding technology can be used in aircraft and helicopter airframes, It is a super hybrid composite material enabling lighter, thinner and stronger materials tailored to the aerospace industry.	Vindicoat, LLC
NanoXcelTM	A proprietary nano-engineered material called NanoXcel(TM) that significantly increases performance by decreasing weight by 25 percent.	Yamaha Motor
Arovex®	350°F curing carbon fibre composite variant of Arovex®, the class-leading prepreg enhanced with nano-materials.	Zyvex

8 HYDROPHOBIC/OLEOPHOBIC NANO-COMPOSITES

Product Name	Description	Producer
Hybrid EX6	Hybrid EX6 has much higher high water repellency (hydrophobic) than EX3 and can be applied direct to glass, metal, plastic, powder for a brilliant finish.	Advanded Nanocoating
AUTO WINDSCREEN COATING	AquaShield Clear solution for car windscreens is superhydrophobic and designed to keep visibility at a maximum (up to 30% improvement) regardless of rainfall or the accumulation of environmental debris. The molecular coating is formed from next-generation inorganic sol-gel technology utilising liquid state silica, an inorganic compound also providing a high level of UV protection and scratch resistance.	AquaShield
Boora Permaseal	PermaSeal is a 'two-step' product for car bodywork. Step 1 is a liquid that lines the surface of the car with a preliminary reactive pre-treatment. It conditions the paint surface in readiness for Step 2.	Boora
Nanotol 250ml Nanocoating Car Care Combi Set plus Car glass coating	Nanotol superhydrophobic automotive glass coating 50 ml in car care set with three microfibre cloths. Nanotol for all surfaces on the car plus disc seal for extra water-repellent effect of the windscreen.	CeNano GmbH
Special sealant for windscreens	Ultra-hydrophobic sealant for all windscreens. Good visibility even in bad weather.	CeNano GmbH
Perma-Clean Glass | Hydrophilic/Anti-Static Coating	Perma-Clean Glass is a self-cleaning anti-static coating for glass surfaces. This coating prevents dust and other pollutants from contaminating glass thereby reducing maintenance cycles. Perma-Clean Glass is easily applied and dries in seconds.	DryWired LLC
Super Hydrophobic Coating	DryWired™ SHC (Super Hydrophobic Coating) is a superhydrophobic aerosol coating formulated to repel rain, snow, and ice. Packaged conveniently in an aerosol can, this easy-to-apply single-step spray dispenses solution that forms a superhydrophobic film to repel the most harsh weather conditions.	DryWired LLC
Nano8 Wax	Nano8 wax contains eight nano-formulated waxes and resins to bond and protect surfaces from road grime, salts, tree sap, bird droppings, etc.	Eagle One
Toughseal Step 2 Acrylic Sealant	A 2-part process that gives all paintwork a diamond-hard shine and offers protection from most harmful elements including: ultraviolet rays, fading, acid rain, peeling, frost, tree sap, insect acid, bird droppings, oxidation (chalking), petrol and diesel fumes. Toughseal Step 2 will react with Step 1 pre-treat EC289 and produce a second protective layer on the paintwork. Toughseal nanoplate is a highly researched complex blend of PTFE and polysilazanes particle displacement	Eurochem

Product Name	Description	Producer
	protection package for the exterior of cars, boats, caravans and aircraft.	
Aviation Coatings	The aviation coatings that are currently developed by Glonatech and its partners are practically nanostructured hydrophobic topcoats, which exhibit improved aerodynamic efficiency, by reducing turbulent skin-friction, and decrease ice formation rate on the surface of the aircraft. This in turns leads to significant reduction in fuel consumption and carbon dioxide emissions. Concurrently, the topcoat is characterised by excellent durability and mechanical properties.	Glonatech SA
Auto Body Care	The Liquid Crystal nano-coating for automotive body care utilises ultra-thin coating nano-polymers that create a superior hydrophobic surface which causes water to wash dirt and dust away from the surface without scrubbing or hands-on labour. In addition the coating provides a high level of hardness, preventing most scratches and scrapes.	Green Earth Technologies
Lotos Best Of Nature	MacBRITE's lotos autopolish combines nanoparticles with hydrophobic polymers such as polypropylene, polyethylene and waxes.	MacBRITE
Aluminium Rim set	NanoCover® Aluminium Rim is a sealing product based on chemical nanotechnology. Water and oil-based liquids easily run off, and the product facilitates the removal of dirt, brake dust and oil from untreated or lacquered aluminium rims.	Nanobiz ApS
NanoCover Aluminium Rim set	NanoCover Aluminium Rim set is a nano-coating which is chemically related to the surface and forms a protective film. It causes the water and oily liquids are very light beads, and makes the removal of dirt, brake dust and oil on untreated or coated aluminium / chrome rims easier.	Nanobiz ApS
NanoCover Car Glass set	Coating & hydrophobic treatment: rain beads very easily and it makes the removal of dirt and insect residue from the windscreen easier. Significantly improved vision is achieved in the rain.	Nanobiz ApS
Rim Sealing 100 ml	The rim sealing is a coating material based on chemical Nanotechnology and creates a very good good pearl off behaviour of washy and oily liquids.	NanoConcept
Nanodeck Yacht & boats	Yacht & Boat is a 2-component-mixture based on chemical nanotechnology, which provides a very good repelling effect of aqueous and oily liquids on the strained surfaces.	Nanodeck
Nanoproofed® Camping Reiniger Konzentrat (cleaning concentrate)	Nanoproofed® Camping Reiniger is an alkaline high performance cleaner, specially designed for the cleaning of caravans, boats and camping furniture.	Nanoproofed GmbH

Product Name	Description	Producer
Nanoproofed® protection Anti-Fingerprint	Nanoproofed® protection Anti-Finger-Print is a solvent based system on the basis of the chemical nanotechnology containing abrasive components. It is designed for an effective cleaning of chrome- and stainless steel surfaces. nanoproofed® protection Anti-Finger-Print provides an additional protection against dirt and fingerprints on stainless steel surfaces.	Nanoproofed GmbH
Nanoproofed® protection Antibeschlag Kunststoff & Glas	Nanoproofed® protection Antibeschlag Kunststoff & Glas creates a hydrophilic layer on plastic or glass surfaces which prevents the clouding of the material. Suitable substrates: Glass, PET, PC, PMMA and all solvent resistant plastics.	Nanoproofed GmbH
Nanoproofed® protection Chrom & Edelstahl	Nanoproofed® protection Chrom & Edelstahl is a semi-permanent system based on the nano technology for the maintenance of metal and plastics surfaces. Nanoproofed® protection for chrome and stainless steel has a water, oil and dirt repellent effect leading to easier cleaning of the treated substrates.	Nanoproofed GmbH
Nanoproofed® protection Elektronik	Nanoproofed® protection protects electronic devices and installations from humidity and wet conditions of all kinds.	Nanoproofed GmbH
Nanoproofed® protection Glas & Keramik	The Nanoproofed® protection Glas & Keramik for glass and ceramics is an alcohol based system, which generates an easy-to-clean effect on glass and ceramic surfaces. On the surface a thin hydro- and oleophobe- film is created, which prevents the sticking of dirt, limescale and impurities and increase the rolling off of water.	Nanoproofed GmbH
Nanoproofed® protection Glas & Keramik Set	Nanoproofed ® protection for glass and ceramics is an alcohol-based system, which generates on glass and ceramic surfaces, an easy-to-clean effect. On the surface, a thin hydro-and oleophobic layer is created which prevents the adhesion of dirt, chalk and other foreign matter and water will be repelled.	Nanoproofed GmbH
Nanoproofed® protection Glas&Keramik Visier Sachet	The sealant for glass and ceramics protects pores from dirt recording, by a roll-off effect on the surface. It protects against dirt, water, oil and lime cannot settle easily. The easy-clean uses from car windows at 60km / h.	Nanoproofed GmbH
Nanoproofed® protection Glasversiegelung Photokat exklusiv	Nanoproofed(R) glass seal is a product based on the chemical nanotechnology, which protects transparent substrates in the outskirt area against clouding and soil. Due to the super-hydrophilic film dirt is scoured by rain and washed away.	Nanoproofed GmbH
Nanoproofed® protection KlarSicht Set	Nanoproofed ® ClearView creates a set of water- and oil-repellent layer leads to the front and side windows of your vehicle and a greatly improved visibility in wet conditions. Our product provides a	Nanoproofed GmbH

Product Name	Description	Producer
	significantly easier removal of dirt, snow and ice.	
Nanoproofed® protection Kunstglasversiegelung	Nanoproofed® protection glass sealant creates a water and oil repellent layer on glass and plastic surfaces. Therefore, the removal of dirt and lime residuals is easier and the surface is protected against long-term damage by incorporation of insoluble residuals. The coating exhibits a high abrasion resistance.	Nanoproofed GmbH
Nanoproofed® protection Lack & Felge	Nanoproofed® protection for paint and rims is a solvent based semi-permanent system based on the nano technology for the maintenance of metal and plastics surfaces. Nanoproofed® protection Lack & Felge has a water, oil and dirt repellent effect leading to easier cleaning of the treated substrates.	Nanoproofed GmbH
Nanoproofed® protection Lack & Felgen Set	Nanoproofed® protection for paint and rims is a solvent based semi-permanent system based on the nano technology for the maintenance of metal and plastics surfaces. Nanoproofed® protection Lack & Felge has a water, oil and dirt repellent effect leading to easier cleaning of the treated substrates.	Nanoproofed GmbH
Nanoproofed® protection Lack Pearl	Nanoproofed® protection Lack Pearl is a solvent containing varnish sealing based on the chemical nano technology specially made for varnish surfaces in mint condition or conditioned. The coating creates an ultra-thin, transparent layer which protects the varnish, recovers colour and shine and produces a water repulsive effect.	Nanoproofed GmbH
Nanoproofed® protection Lackfinish	Nanoproofed® protection Lackfinish is an aqueous polish which protects varnished surfaces from stone chipping and environmental influences. The sealing based on the chemical nano technology creates an ultra-thin, transparent layer with long-lasting shine and water repulsive attributes.	Nanoproofed GmbH
Signo Glassguard	The coating is crystal clear, UV stable, chemically inert and extremely durable, having both hydrophobic and oleophobic capabilities.	Signo Ltd

9 Fuel Additives

Product Name	Description	Producer
Platinum Plus®	Platinum Plus® fuel borne catalyst (FBC) is a diesel fuel-soluble additive, which contains minute amounts of nano-scaled organo-metallic platinum and cerium catalysts.	Clean Diesel Technologies, Inc.
Evirox	Cerium oxide-based nanocatalyst for diesel fuels	Energenics Pte Ltd.
Eolys PowerFlex®	Cerium oxide-based nanocatalyst for diesel fuels	Solvay

10 Lubricants

Product Name	Description	Producer
Nano-Engine Oil Additive And Lube	AquaShield NanoLub® Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on the innovative "IF-WS2" technology. A fully synthetic carrier oil concentrate mixed with a proprietary super strong tungsten disulfide (WS2) multi-layered nano fullerene-like particles. These multi-layered particles are extremely thermal- and pressure-resistant	AquaShield Technologies
Nanoskin Nano Shock Instant Lubricant Sealant 128 oz.	Nanoskin Nano Shock AutoScrub Lubricant & Sealant uses advanced nano-sized polymers to create a lubricant and polymer sealant combined in one product.	Autopia-CarCare
Nanoskin Nano Shock Instant Lubricant Sealant 16 oz.	This polymer sealant dries clear on the paint, repels water, enhances gloss, dissipates the static charge attracts dust, and adds additional gloss and protection.	Autopia-CarCare
CerMet Nano-Particle Ceramic Conditioner	CERMET hardens the metal's crystal lattice at the surface up to 30 microns. This new hardened surface emulates the properties of pure ceramic, hence the name CerMet (Ceramic-Metal), and will reduce friction up 100-300% CERMET will also reduce surface roughness up to 10 times. Unlike typical ceramic coatings that become brittle, the stronger CERMET surface is actually an extremely integrated structure inside the metals surface	CerMet Lab Company
Mobil 1™ Advanced Fuel Economy	These specially formulated synthetic oils can help increase engine efficiency, saving money over the lifetime of the vehicle.	ExxonMobil
DRY LUBRICANT (NDT11D)	NCT11D point-of-use lubricate with moisture-displacing formula reduces friction and wear, preventing fretting and galling even in extreme pressure and high temperature applications.	NanoProMT
Gear Oil	Specially designed for conventional and high performance applications: auto, truck, marine, racing and heavy	NanoProMT

Product Name	Description	Producer
	equipment axles where factory-fill or drain-and-fill levels of limited slip performance are required.	
High Temp EP Grease	Multi-purpose lubricant with lithium complex that withstands the heat and pressures of high performance equipment.	NanoProMT
Marine Grease	Designed for highly corrosive marine environments, NDT14MGs water insoluble formula provides long lasting protection from friction, corrosion, rust and wear, over a broad temperature range.	NanoProMT
OIL STABILIZER	Protects vital engine components against friction and engine wear: reducing oil temperature 60% faster than standard lubricants, dry starts and viscosity breakdown for improved horsepower and oil pressure, and extended oil life by 100%.	NanoProMT
PENETRATING Lubricant	Goes deeply into spaces between metal to metal rusted mechanical parts, such as nuts and bolts to decrease maintenance, reduce wear and friction, and prevent future corrosion.	NanoProMT
ChainSpray	With its special formulation, it is highly adhesive and thus prevents spinning off through centrifugal forces.	REWITEC GmbH
G5	The product G5 is a coating concentrate for vehicle gearboxes and is mainly used in switching, automatic and axle drives of cars and commercial vehicles.	REWITEC GmbH
GR400	The high-temperature special grease can be used in all kinds of bearings, including ball, roller and plain bearings or main, generator, pitch bearings in wind turbines.	REWITEC GmbH
REWITEC G5 - For Gears and Differentials up to 5 Litres	REWITEC® G5 reduces friction in manual and automatic gearboxes and also differentials, more precisely on rubbing metal parts, due to grading of the surface and therefore protects them from wear.	REWITEC GmbH
REWITEC Powershot S	Basic treatment for motorbikes and - boats (1 bottle per 600cm³ engine capacity) resp. yearly after-treatment for „M" and „L" for passenger cars (1 bottle per 1.000cm³ engine capacity) resp. with every oil change	REWITEC GmbH
REWITEC® PowerShot	Coating Concentrate for Combustion Engines: REWITEC® PowerShot® reduces friction in engines (on rubbing metal parts) and protects them from wear. Applied into warm engine oil, it works within a few hundred kilometres. The REWITEC® technology operates using innovative silicate particles, which are implemented in the metallurgical surface in a physico-chemical process under certain circumstances, such as wear, temperature and pressure. Small microscopic damages will be repaired and surfaces can be rebuilt, leading to	REWITEC GmbH

Product Name	Description	Producer
	noticeable reduction of friction and wear and optimisation of the efficiency factor of the engine.	
NANO-ENGINE OIL ADDITIVE AND LUBE	AquaShield NanoLub® Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on the innovative "IF-WS2" technology. A fully synthetic carrier oil concentrate mixed with a proprietary super strong tungsten disulfide (WS2) multi-layered nano fullerene-like particles. These multi-layered particles are extremely thermal- and pressure-resistant	TMC Industries Inc.
NanoLub® DE-M4600 Heavy Duty Diesel Engine Oil Additive	NanoLub® DE-M6000 Marine Diesel Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on formulated Mineral Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide (WS_2) multi-layered nano-fullerene particles.	TMC Industries Inc.
NanoLub® DE-M4600 Heavy Duty Diesel Engine Oil Additive	It is a nano lubricant engine oil based on formulated mineral oil concentrate mixed with tungsten disulfide particles. It is mainly used in large diesel 4-stroke engines.	TMC Industries Inc.
NanoLub® DE-M5000 Power Generation Diesel Engine Oil Additive	The product is a surface-reconditioning nano lubricant based on mineral oil mixed with tungsten disulfide multi-layered nano-fullerene particles.	TMC Industries Inc.
NanoLub® DE-M6000 Marine Diesel Engine Oil Additive	NanoLub® DE-M6000 Marine Diesel Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on formulated Mineral Oil concentrate.	TMC Industries Inc.
NanoLub® DE-M6000 Marine Diesel Engine Oil Additive	Surface-reconditioning nano lubricant for engine oil, based on formulated Mineral Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide WS_2 multi-layered nano-fullerene particles	TMC Industries Inc.
NanoLub® DE-S4100 Classic Diesel Engine Oil Additive	Surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide WS_2 multi-layered nano fullerene-like particles	TMC Industries Inc.
NanoLub® DE-S4400 SUV & Light Truck Diesel Engine Oil Additive	NanoLub® DE-S4400 SUV & Light Truck Diesel Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide (WS_2) multi-layered nano-fullerene particles.	TMC Industries Inc.
NanoLub® DE-S4400 SUV & Light Truck Diesel Engine Oil Additive	Surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide WS_2 multi-layered nano-fullerene particles	TMC Industries Inc.

Product Name	Description	Producer
NanoLub® DE-S4500 Buses & Big Trucks Diesel Engine Oil Additive	NanoLub® DE-S4500 Buses & Big Trucks Diesel Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide (WS_2) multi-layered nano-fullerene particles.	TMC Industries Inc.
NanoLub® DE-S4500 Buses & Big Trucks Diesel Engine Oil Additive	Surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide WS_2 multi-layered nano-fullerene particles	TMC Industries Inc.
NanoLub® EM-X EP Grease Additive	Surfacing-reconditioning nano lubricant additive for grease based on NIS's proprietary super strong tungsten disulfide (WS_2) multi-layered nano-fullerene particles	TMC Industries Inc.
NanoLub® GE-M6000 Marine Gasoline Engine Oil Additive	NanoLub® GE-M6000 Marine Gasoline Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on formulated Mineral Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide (WS_2) multi-layered nano-fullerene particles.	TMC Industries Inc.
NanoLub® GE-M6000 Marine Gasoline Engine Oil Additive	Surface-reconditioning nano lubricant for engine oil, based on formulated Mineral Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide WS_2 multi-layered nano-fullerene particles	TMC Industries Inc.
NanoLub® GE-S4100 Classic Gasoline Engine Oil Additive	NanoLub® GE-S4100 Classic Gasoline Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide (WS_2) multi-layered nano fullerene-like particles.	TMC Industries Inc.
NanoLub® GE-S4200 Sport Gasoline Engine Oil Additive	Surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide WS_2 multi-layered nano-fullerene particles	TMC Industries Inc.
NanoLub® GE-S4300 Bike Gasoline Engine Oil Additive	Surface-reconditioning nano lubricant for engine oil, based on d Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide WS_2 multi-layered nano-fullerene particles	TMC Industries Inc.
NanoLub® GE-S4400 SUV & Light Truck Gasoline Engine Oil Additive	NanoLub® GE-S4400 SUV & Light Truck Gasoline Engine Oil Additive is a new generation surface-reconditioning nano lubricant for engine oil, based on Synthetic Oil concentrate mixed with NIS's proprietary super strong tungsten disulfide (WS_2) multi-layered nano-fullerene particles.	TMC Industries Inc.
NanoLub® ISO-220EP Industrial Gear Oil	NanoLub® ISO-220EP is a blend of solid IF-WS2 nanoparticles and other high-quality multifunctional lubricant additives dispersed in a premium grade mineral oil	TMC Industries Inc.

Product Name	Description	Producer
	designed for heavy industrial enclosed gear systems.	
NanoLub® LiX #2 EP Grease	A super strong, multipurpose solution for a wide range of EP applications. Based on our proprietary IF-WS2 formulated technology of super strong tungsten disulfide multi-layered nano-fullerene like particles	TMC Industries Inc.

11 Cleaning Agents

Product Name	Description	Producer
Hybrid EX1	Hybrid EX1 is an automotive cleaner based on nanomaterials which cleans by super hydrophobicity and nano-treatment.	Advanced NANO Coating
Hybrid EX3	An emulsion coating that can be used as a car polish.	Advanced NANO Coating
Nanoskin Autoscrub Towel PRO Starter Kit – Fine Grade	By utilising a rubber-polymer coated material, the Nanoskin Autoscrub System removes contaminant build up quickly.	Autopia-CarCare
ACS DryGloss	Special drying super-concentrate for use in WashTec ACS gantry car washes.	AUWA-Chemie GmbH
ACS Foam	Special active foam super-concentrate for use in WashTec ACS gantry car washes.	AUWA-Chemie GmbH
ACS FoamWax	Special foam wax super-concentrate for use in WashTec ACS gantry car washes.	AUWA-Chemie GmbH
ACS PreLavan	Special pre-cleaner super-concentrate for use in WashTec ACS gantry car washes.	AUWA-Chemie GmbH
ACS Shampoo	Special shampoo super-concentrate for use in WashTec ACS gantry car washes.	AUWA-Chemie GmbH
ACS ShineWax	Special wax care super-concentrate for use in WashTec ACS gantry car washes.	AUWA-Chemie GmbH
ACS Wheel	Special rim cleaner super-concentrate for use in WashTec ACS gantry car washes.	AUWA-Chemie GmbH
DryGloss TruckBus	Effektiv run-off effect shampoo for commercial car washes without blow dryer.	AUWA-Chemie GmbH
Nanotol automotive coating	Nanotol Universal nano-coating Combo Set plus Carshampoo Refresher and microfibre glove for refreshing the coating during normal car wash	CeNano
Nanotol car shampoo	Clean and renew car sealant with nanotol car shampoo.	CeNano
20/20™ Auto Glass Cleaner	A streak-free glass cleaner that sets the bar in performance. Easily remove tough dirt, grime, fog and film. Ammonia-free formula, safe for tinted windows and mirrors.	Eagle One
A2Z™ All Wheel & Tire Cleaner	The thick acid-free foam is safe for any type of wheel, hubcap or tire, making for a risk-free clean.	Eagle One

Product Name	Description	Producer
Evolution™ Car Wash	The Evolution™ Foaming Car Wash makes the wash process quicker to allow you more time for the details.	Eagle One
Interior Detailer	The vapour interior detailer formula reaches small interior crevices that a regular spray nozzles miss, while concealing scratches and scuffs.	Eagle One
Nano Waterless Car Wash	AquaShield Platinum Nano Waterless Car Wash is an innovation in eco-responsibility, but maintains industry leading results leaving the surface of a car body absolutely spotless and conserves 20-100 gallons of water per wash.	Eagle One
NanoWax As-U-Wash™	The nano-sized Carnauba wax particles in our car wash and wax car care product provide more surface coverage, filling even the finest microscopic scratches, maintaining a smooth surface and creating more shine.	Eagle One
Tire And Plastic Cleaner And Rejuvinator	AquaShield Tyre Shine combines a blend of glossing agents and emollient cleaning compounds to scrub and leave tires with a long lasting satin finish. Unlike traditional tire cleaners Tyre Shine is a non-grease formula and can also be used on plastic interior and exterior surfaces of the car body revitalising their appearance and significantly increasing colour and tone density.	Eagle One
Wax As-U-Dry	Carnauba wax is a naturally-occurring substance found on palm tree leaves. This wax is known for its durability, providing a barrier on car paint that lasts for months.	Eagle One
Chrome Polish	Chrome Polish imparts a long lasting finish on all types of polishable metal including chrome, stainless steel, copper, brass, aluminium and alloys. Designed using super fine mono-beads and graded diamond tipped abrasives.	Eurochem Group chemicals
Marine Boat Cleaner (MBC)	Removes oily grime, embedded stains, salt residues, bird lime and marine scum leaving the whole boat sparklingly clean.	Eurochem Group chemicals
V-Clean Cationic Car Shampoo	Modern advanced car shampoo formulation. Deposits cationic film to protect paint and repel water. Promotes fast streak free drying. Affords “just polished” water beading properties to forecourt cars. Dries faster than a regular car shampoo enabling car to be quickly polished.	Eurochem Group chemicals
Brake Dust Shield	G-CLEAN Brake Dust Shield SHIELDS against the toughest baked on brake dust and dirt build-up while leaving a shiny protective INVISIBLE nano-coating that repels brake dust re-coating for up to 30 days.	GClean
Car Wash	G-CLEAN Car Wash is a hydrophobic solution that causes water to "bead up" and "roll off", leaving NO SPOTS. It penetrates into dirt and oils, then breaks	GClean

Product Name	Description	Producer
	them into billions of little particles that constantly repel each other. This prevents the particles from sticking, resulting in a spot-free shine on your vehicle's surface.	
Car Wash Pouch	G-CLEAN Car Wash is a hydrophobic solution that causes water to "bead up" and "roll off", leaving NO SPOTS. It penetrates into dirt and oils, then breaks them into billions of little particles that constantly repel each other.	GClean
Glass Cleaner	G-GLASS keeps surfaces cleaner much longer than other products by creating an invisible anti-static residue that reduces future dust and dirt build-up.	GClean
Tire Shine	G-CLEAN Ultimate Tire Shine removes the toughest dirt and road grime from the tire, while leaving a lasting shine that also protects the rubber surface.	GClean
Wheel Cleaner	G-CLEAN™ Wheel Cleaner is a proprietary formulated wheel cleaner that is made with American grown base oils that now puts the power of nanotechnology into the hands of the consumer. G-CLEAN Wheel Cleaner removes the toughest baked on brake dust and dirt build-up while leaving an incredible shine. Safe for ALL WHEEL STYLES & SURFACES.	GClean
Multipurpose Enzyme Surface Treatment	BRITOL interacts chemically when it comes in contact with the car paintwork creating an optically perfect, flat bond between paint and polish.	MacBRITE
NANO Gloss	NANO Gloss conceals swirl marks and hairline scratches. The result is a deep, glossy shine.	MacBRITE
NR1301 Basic Cleaner	NR1301 Basic-Cleaner is a product which has extraordinary cleaning properties. This cleaner is suitable for the preparation of surfaces with are to be coated with NADICO-Products.	Nadico Technologie GmbH
NR1302 Rim Cleaner	NR1302 Rim Cleaner is a product, which shows very good cleaning action on almost all kinds of vehicle rims. Brake dust and dirt can easily be removed with minor efforts.	NADICO Technologie GmbH
NR1305 Car Paint Cleaner	NR1305 Car Paint Cleaner is a special cleaner for professional car painters. The Cleaner removes sealings, waxes, polymers, silicones and car-polish deposits quickly and securely.	NADICO Technologie GmbH
Coating For Automotive Paint	This unique product polishes, cleans, cares for and protects car paint like no other. Provides a permanent and invisible thin surface effect. It is quick and easy to apply leaving a water-repellent coating.	Nano Acceleration Network
Coating For Automotive Wheels	Wheel rim cleaner.	Nano Acceleration Network

Product Name	Description	Producer
Cleaner With Semi-Permanent Anti-Fog Properties	This cleaner was designed to give smooth and non-absorbent surfaces semi-permanent anti-fogging properties after cleaning.	Nano-Care Deutschland
NanoCover A/C Cleaner	NanoCover A / C Cleaner cleans air conditioning. Bad odours and bacteria, mould and fungi are removed from the cabin.	Nanobiz ApS
NanoConcept Anti Fog Glass 100 ml	NanoConcept anti-fog glass is a highly efficient developed anti-fogging and cleaning agent which is based on a nano chemical surfactant.	NanoConcept
Rim Cleaner 100 ml	NanoConcept rim cleaner, a very strong high active cleaner. The cleaner removes brake dust and crusted contaminations of all rims without any difficulties.	NanoConcept
Nano Gelcoat Sealer	Nano Gelcoat Sealer cleans, polishes & seals all gelcoat surfaces above the waterline in one step.	Nanogate
CHROME & STAINLESS STEEL TREATMENT	NanoSafeguard Chrome & Stainless Steel Treatment helps keep stainless steel and chrome looking new and clean for months.	NanoSafeguard
WNS-Cleaner	WNS-Cleaner is a new technology that cleans with an improved micro-fluid formulation that penetrates dirt layers, down to the nano- scale of the surface structure.	Nanoshop
CL 40 abrasive cleaner 60 g	CL 40 removes hard water stains, salt spots, render and cement stains, soap scum and other pollutions from glass surfaces.	Nanovations Pty Ltd
CL 40 abrasive glass cleaner	CL 40 Abrasive Glass Cleaner is a water based, abrasive cleaner for glass, ceramic and sanitary surfaces. It is also the recommended surface preparation for Nanotechnology treatments like NG 1010.	Nanovations Pty Ltd
CL 50 Abrasive spray and wipe glass surface preparation	CL 50 is using a technology from the semiconductor manufacturing to provide an extremely deep clean down to the micro-structured surface details of substrates.	Nanovations Pty Ltd
Nanoprotect Marine Polish	Nanoprotect® Marine Polish is a care and maintenance product for all gelcoat surfaces above the water line.	Nanovations Pty Ltd
Marine Wax As-U-Wash™	Combining nano-size carnauba wax particles with QUAT silicone delivers an incredible shine and protective barrier against UV and prevents adhesion of grime and lake scum.	Nigrin
Nano Tec Cleaning Polish	The NanoTec formula polishes and seals the surface of paintwork with a microstructure of nano-scopic waxes in a single process.	Nigrin
NanoTec Hard Wax Polish	The NanoTec formula polishes - and seals the surface of paintwork with a nanoscopic wax layer.	Nigrin
Aircraft Supershine	Supershine provides very small air resistance and hence it is used in	Permanon GmbH

Product Name	Description	Producer
	helicopters, gliders, propeller and jet aircraft. It also has a very good disinfectant and germ-inhibiting properties	
PowerSpray	PowerSpray acts as a rust remover with tight screw and metal connections, as a cleaning agent dissolves encrusted and gummy lubricant residues and leaves a very thin, antistatic protective film.	REWITEC GmbH
SONAX Profiline Nano Polish	SONAX Profiline Nano Polish agents for new and slightly weathered paintwork.	Sonax GmbH
Sonax Profiline Nano Polish 3/6 1000 ml.	Sonax Profiline Nano Polishes uses nano polishing agents that gently work against the paint, eliminating paint defects such as swirl marks, towel marks, and mild oxidation, while burnishing the paint to a high gloss finish.	Sonax GmbH
Shampoo Neutro NANO	Concentrated, foaming shampoo recommended for hand car wash does not contain phosphates and aggressive chemical substances. Nano element of silver and titanium improves non-visible cracks. Leaves shiny protective self-drying surfaces.	Tenzi Sp. z o.o.
Top Efekt KOK NANO	Anti-reflecting cleaning agent recommended for cockpits and other plastic surface. Makes thin anti-static silver nano protective layer, removes contaminations, stains and greasy sediment, absorbs UV radiation. Refreshes cleaning surface and brightens up colour.	Tenzi Sp. z o.o.
POWERnANO car protect	StayClean POWERnANO will facilitate better cleaning results in many areas of vehicle care.	Vadlau GmbH
StayClean Auto	StayClean nanotechnology product for cars.	Vadlau GmbH
StayClean Boat	StayClean nanotechnology product for boats.	Vadlau GmbH
StayClean Glass	StayClean POWERnANO technology for glass cleaning.	Vadlau GmbH

12 Sensors

Product Name	Description	Producer
Incremental Encode Output Type HGP*D Series	Magnetic Sensor: Built-in 2-phase output in a small sized package. Contributes to making the encoder system smaller and to increasing the design flexibility.	Alps Electric Co
Switching Output Type HGDE*/HGDF* Series	High precision, compact and low-profile product based on magnetic sensing devices technologies.	Alps Electric Co
Latch Output Type HGP*P Series	Magnetic Sensor: Best suited for rotation mechanism using the small size and high precision latch output type.	Alps Electric Co
Analog Linear Output Type HGAR Series	This high output analogue output sensor is suited for high resolution detection of absolute angle and position.	Alps Electric Co
Force Sensor HSFPAR Series	High-sensitivity load detection with a compact package.	Alps Electric Co
Linear Type RDC10 Series	Resistive position sensor: The high accuracy space saving design contributes to reduced weight and size of sets.	Alps Electric Co
Linear Type RD7 Series	Resistive position sensor: Exclusive for head light angle detection with high accuracy and space-saving design.	Alps Electric Co
Rotary Type RDC40 Series	Resistive position sensor: Compatible with multi-rotational position tracking.	Alps Electric Co
Rotary Type RDC50 Series	Compact, high precision, high heat resistant rotary sensors, meet various needs in position detection.	Alps Electric Co
Compact Long-life Rotary Type RDC90 Series	Resistive position sensor: Allows position tracking over an extremely long life.	Alps Electric Co
Rotary Type RD6R1A Series	Long-life sensor supporting absolute linearity.	Alps Electric Co

13 Other products

Product Name	Description	Producer
ADMAFINE	ADMAFINE consists of nano-sized spherical oxide which has high moisture content with low surface porosity. It has good dispersibility and very strong adhesion.	Admatechs
Protective Coatings	Colloidal silica can be used as a binder in zinc-rich coatings to produce hard, durable, protective coatings that shield steel and prevent corrosion in construction environments.	AkzoNobel Pulp and Performance Chemicals AB
PowerCard-γ	Thermoelectric device used for power generation. It is one of the most efficient thermoelectric devices for exhaust-gas waste-heat recovery.	Alphabet Energy
Amsoil® Ea Air Filters	The revolutionary nano-fibre technology used in AMSOIL Ea Filters captures more dirt, holds more dirt and allows better air flow than conventional air filters.	AMSOIL

Product Name	Description	Producer
Amsoil® Ea Air Filters	The nano-fibre technology used in AMSOIL Ea Filters captures more dirt, holds more dirt and allows better air flow than conventional air filters.	Amsoil
Baikalox B-Series BA15	Especially developed for specialty ceramics, UV-reflective coatings and precision polishing applications, Baikalox B-Series "High Crystallinity" alumina powders are produced with high control of crystallite-size and homogeneity.	Baikowski
Baikalox B-Series BA20	Especially developed for specialty ceramics, UV-reflective coatings and precision polishing applications, Baikalox B-Series "High Crystallinity" alumina powders are produced with high control of crystallite-size and homogeneity.	Baikowski
Baikalox Regular GE30	The consistency of Baikalox Regular alumina powders is ensured by a rigorous quality control procedure throughout the entire production process. To be used for car polishing.	Baikowski
Genantin HQ CORROSION INHIBITOR	Genantin HQ is a car coolant based on organic acids.	Baikowski
Malakoff CB20CR	Malakoff materials are the result of two highly controlled processes: Bayer modified & aluminium hydrolysis (SA). Application areas include polishing of cars.	Baikowski
Malakoff PA	Malakoff materials are the result of two highly controlled processes: Bayer modified & aluminium hydrolysis (SA). Application areas include polishing of cars.	Baikowski
Instant Cooling System Stop Leak w/Nanotechnology	Using nanotechnology, this product fills in cracks & crevices making a strong, more solid bond.	CRC Industries
Permanent Head Gasket & Block Repair with Nanotechnology	Using nanotechnology, this product fills in cracks & crevices in car motor parts making a stronger, more solid bond permanently hardened to the surface.	CRC Industries
BETAFOAM™ Polyurethane Foams	Engineered to provide barrier protection against airborne noise, BETAFOAM™ polyurethane foams also can be useful in NVH (noise, vibration and harshness), stiffness and energy management applications.	Dow Chemical Company
BETASEAL	BETASEAL formulations provide a wide range of mechanical properties to suit all vehicle requirements and are compatible with all vehicle production processes, including cold- and warm-applied systems.	Dow Chemical Company
Dow Brake Fluids	Automotive brake fluids.	Dow Chemical Company
SPECFLEX	SPECFLEX polyurethane components for automotive moulders.	Dow Chemical Company
Exxtral™	Exxtral polyolefins are designed to replace higher-cost, heavier and hard-to-recycle materials traditionally used in appliances and automobile parts.	ExxonMobil

Product Name	Description	Producer
Vistalon™ ethylene propylene diene	ExxonMobil Chemical's broad range of Vistalon™ ethylene propylene diene (EPDM) rubber grades are used in a wide variety of applications in the automotive, consumer, and industrial sectors. They deliver heat-resistant part performance and processing benefits that exceed those provided by natural and general-purpose rubbers.	ExxonMobil
SURPREX W1004	Excellent corrosion resistance is exhibited in both dry and wet environments with a great deal of improvements made on poor corrosion resistant WC/Co-type cermets.	Fujimi Corporation
Heat Shield™ EPX4	Heat Shield™ EPX4 is a powerful two-part thermal insulation coating for applications where superior performance is needed. EPX4 is also splash resistant to: 98% sulphuric acid, ammonia, bleach, and other acids, bases and fuels.	Industrial Nanotech
Nansulate® Translucent PT	A clear, nanotechnology-based insulation and corrosion prevention coating that is designed for metal substrates, allows visual inspections of equipment.	Industrial Nanotech
Innlay™ silver nanowire	Innova Dynamics has produced a TCE (transparent conductive electrode) films and touch sensors with the aid of silver nanowire. The silver nanowire embedded transparent conductors have found applications in replacing ITO coatings for aerospace and automotive.	Innova Dynamics
DIACARNA	DIACARNA™ is a synthetic wax copolymer of α-olefin and maleic anhydride. It serves a wide variety of applications including use as resin moulding lubricants, mould release agents, compatibility agents, binders for thermal-printing inks, etc.	Mitsubishi Chemical Corporation
Xanoxx Electronic	Xanoxx Electronics contains a mixture of corrosion inhibitors, repellent agents and additives that prevent wear in metal and electric surfaces. Good repellent capacity and its nanotechnology structure produces a high degree of dry protection against corrosion. The invisible layer created by the Xanoxx Electronics dielectric protects circuit boards and several electric devices even when exposed to water.	Nano Soluciones
Xanoxx Marine	Xanoxx Marine was created as an electrical insulator for extreme conditions. It is ideal in regions with high marine humidity, protecting any coated surface from the abrasive effects of salt.	Nano Soluciones
nanoShell Metal	A hydrophobic, easy to clean friction reducing protective coating, containing silane based nano-particles for metal lacquer and plastic surfaces.	nanoShell
NH 2015 Metal Care Nanoprotect	NH 2015 is a special product with a long-term effect on stainless steel, silver and other metal surfaces. NH 2015 is a combination nanotechnology hybrid	Nanoshop

Product Name	Description	Producer
	product where the surface preparation is included in the protective solution.	
NANOMYTE® PT-20	Coating: Replacement for the conventional surface preparation for painting steel that involves near white blast cleaning according to procedure SSPC SP-10. This level of grit blasting is costly, time consuming and is an environmental issue because of the large amount of hazardous waste produced.	NEI Corp.
NANOMYTE® PT-60	NANOMYTE® PT-60, a patent-pending conversion coating with active corrosion protection functionality, presents an alternative where the cost associated with spacers can be avoided without sacrificing performance.	NEI Corp.
NANOMYTE® TC-1001	NANOMYTE® TC-1001 can be used as a complete coating solution or as an additive for other coating formulations. Achieves self-healing of coating surface and subsurface damage.	NEI Corp.
NANOMYTE® TC-4001	NANOMYTE® TC-4001 is a one component protective coating to prevent metals, such as galvanised steel, from corroding.	NEI Corp.
NANOMYTE® TC-5001	TC-5001 is applied on top of the galvanised steel to act as a dense, hard and durable coating to eliminate contact between metal and moisture.	NEI Corp.
Flexible Side Emitting Light Guide	Light guides made of glass fibres in conjunction with modern LED light sources support the trends in the area of interior design. Glass fibres are composed of a natural material.	Schott AG
Flexible Solutions(SCHOTT® Automotive Exterior Lighting)	The lighting systems make it possible to separate the light source spatially from the light output to create high-performance illumination in restricted spaces.	Schott AG
Rigid Solutions (SCHOTT® Automotive Exterior Lighting)	Without specific cladding or sheathing, the light guides make it possible to separate the light source spatially from the light output to create high-performance illumination in restricted spaces.	Schott AG
SCHOTT® Automotive Datacom (flexible solutions)	With different sheathing materials, the optical glass fibre cable may be used in challenging environments and high temperature ranges like in engine compartments or chassis areas.	Schott AG
SCHOTT® Automotive Datacom (rigid solutions)	Due to their physical characteristics, the glass components may be used in challenging environments and high temperature ranges like in engine compartments or chassis areas.	Schott AG
V-KOOL® 30	For applications requiring lesser visibility and maximum solar control, V-KOOL® 30 anti-glare films deliver the ideal superior heat reducing and fuel capabilities.	V-KOOL

Product Name	Description	Producer
V-KOOL® 40	V-KOOL uses a patented nanotechnology process to embed a metallic coating only a few hundred atoms thick onto an optically clear and durable polyester film. Leading technological expertise has allowed the scientists who created V-KOOL® to configure visible light transmission and infra-red rejection attributes of the coating to suit different market needs.	V-KOOL
V-KOOL® 55	V-KOOL® 55 provides a modest level of tinting that delivers a controlled balance between personal privacy, and light transmission ability for traffic regulatory requirements.	V-KOOL
V-KOOL® 70	V-KOOL® 70 is a transparent, infra-red reflective polyester film which can be bonded to glass surfaces. The polyester is coated on one side with multi-layers of microscopic metal particles and a pressure sensitive adhesive on the underside.	V-KOOL
V-KOOL® V6 Signature A-Series	For customers who are looking for a product with high solar energy rejection, glare and fade control, the A-Series would be an ideal choice.	V-KOOL
V-KOOL® V6 Signature G-Series	For customers who require maximum privacy with optimal balance of glare reduction and solar control, G-Series fits the bill perfectly.	V-KOOL
V-KOOL® V6 Signature H-Series	V-KOOL uses a patented nanotechnology process to embed a metallic coating only a few hundred atoms thick onto an optically clear and durable polyester film. A fusion of metal and tint produces an unyielding result in terms of good looks, privacy and heat protection. Whether it is on cars, trucks, MPVs and SUVs, commercial or residential buildings, H-Series deflects up to 63% of solar heat and offers strong protection against the harmful UV.	V-KOOL
V-KOOL® V6 Signature J-Series	J-Series high clarity superior heat-rejection films. See also V-KOOL® V6 Signature H-Series.	V-KOOL
V-KOOL® V6 Signature K-Series	K-Series solar control films with low reflectivity. V-KOOL® V6 Signature H-Series.	V-KOOL
V-KOOL® V6 Signature T-Series	V-KOOL uses a patented nanotechnology process to embed a metallic coating only a few hundred atoms thick onto an optically clear and durable polyester film, for a solar heat reflective surface.	V-KOOL
X68	X68 was created to offer customers a choice of having a moderately spectrally selective film at a cost-effective price. X68 offers an edge over conventional film in its ability to reject more infra-red and ultra-violet radiation for a similar amount of visible light transmission. Coupled with a light gold sheen, the films have an added aesthetic dimension that offers	V-KOOL

Product Name	Description	Producer
	heat control with a visible touch of class. X68 is usually applied on residential and commercial buildings, with a requirement for solar control as well as moderate visibility. In some countries, the films can be applied to the side windows and rear windscreens of cars.	
X75	While looking deceptively clear, X75 is a full-fledge, spectrally selective coating with good solar heat rejection properties. The performance behind X75 lies in its complex multi-layer thin coatings of metallic substances such as silver. Typical applications for X75 range from automobile, retail shopfronts, restaurants and art galleries to residential glass with very high light transmission requirements.	V-KOOL
EMPEROR® 1800	High colour black pigment for automotive and other deep black water-based masstone coatings.	Worlée-Chemie GmbH
EMPEROR® 2000	A pigment carbon black that is especially designed to provide excellent performance in waterborne automotive coatings. Employing a proprietary chemical surface treatment, the product imparts very high 'jetness', blue undertone, gloss and DOI. Also, unlike traditional high colour carbon blacks, the unique surface treatment allows for easier dispersion, enhanced coatings stability and improved weatherability	Worlée-Chemie GmbH
WorléeKyd B 845	Fast drying radiator paints, automotive and machinery refinishing enamels with good gloss. "Laroflex" (BASF) compatibility.	Worlée-Chemie GmbH
WorléeKyd S 549	Fast drying automotive and machinery refinishing enamels.	Worlée-Chemie GmbH
WorléePol 6756	W´Pol 6756 is a saturated, hydroxy functional polyester resin for the manufacture of solvent based "ultra high solids" 2 component PUR systems for industrial and automotive repair paints with good mechanical properties and excellent chemical and weather resistance.	Worlée-Chemie GmbH

ANNEX 7: HUMAN HEALTH AND SAFETY

INTRODUCTION

Exposure to nanomaterials in the transport sector may be quite diverse. Three categories of subsectors were identified within the NanoData project. All combinations of nanoparticles and sectors were evaluated. A risk-banding tool called Stoffenmanager Nano (Le Feber et al., 2014; Marquart et al., 2008; Van Duuren-Stuurman et al., 2012) was used to prioritize health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios.

The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries (ECHA, 2012). In view of the nature of the products in this sector, oral exposure of consumers is also considered to be minor.

The dermal route may be the main route of exposure for some substances or exposure situations, and cause local effects on the skin or systemic effects after absorption into the body (ECHA, 2012). However, nanoparticles as such are very unlikely to penetrate the skin (Watkinson et al., 2013), and consequently nanospecific systemic toxicity via the dermal route is improbable. Therefore, when evaluating nanorisks for the respiratory route, the most important aspects of occupational and consumer safety are covered.

HAZARD ASSESSMENT OF NANOPARTICLES NOT ASSESSED IN STOFFENMANAGER NANO

INTRODUCTION

In "Stoffenmanager Nano" the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). For nanomaterials of importance for the ICT sector (listed in the table), hazard banding has been performed within the context of Stoffenmanager Nano. For those nanoparticles toxicity data have been collected and hazard bands are derived according to the methodology described for "Stoffenmanager Nano" in van Duuren-Stuurman et al. (2012). In essence, it applies the toxicity classification rules of EU Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures. The method is summarised in the figure.

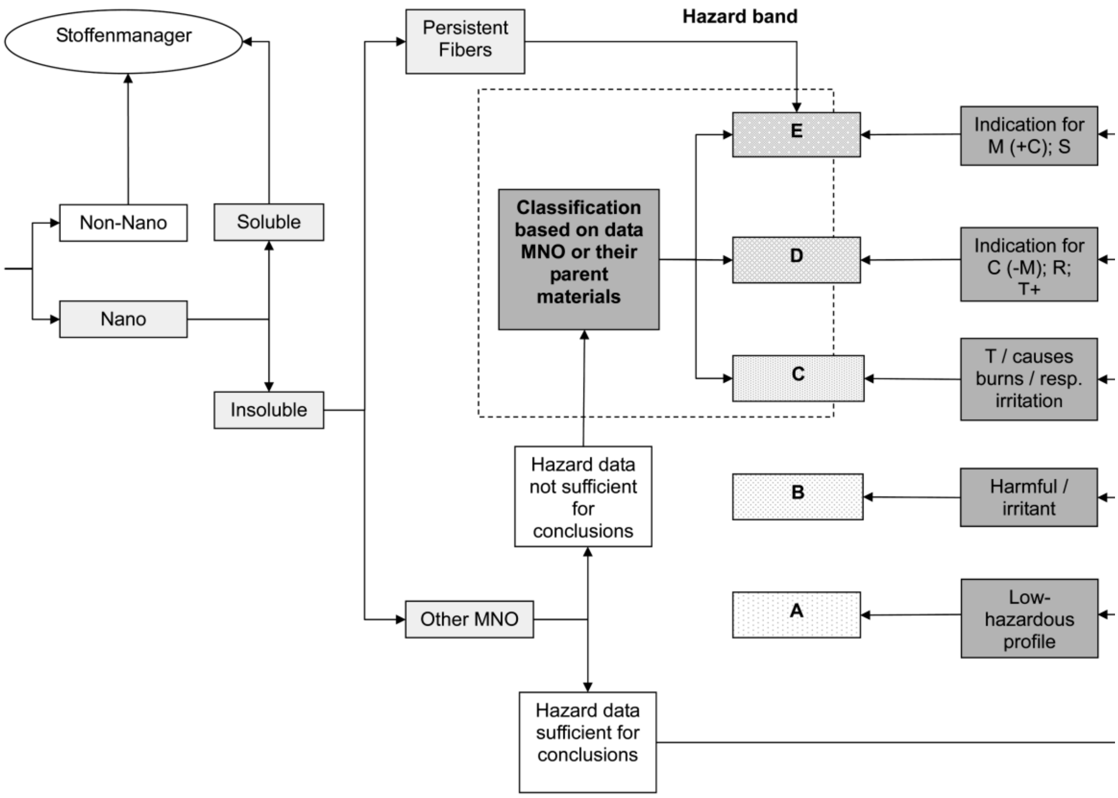

Figure 1: The stepwise approach of hazard banding of Stoffenmanager Nano (Van Duuren-Stuurman, et al. 2012)

C = carcinogenic, +C = and carcinogenic, M = mutagenic, -M = and not mutagenic, MNO = manufactured nanoparticle, R = reprotoxic, resp. = respiratory, T = toxic, T+ = very toxic
Stoffenmanager refers to the non-nano version of Stoffenmanager as described by Marquart et al. (2008).

Aluminium nanoparticles

Most public (toxicological) literature addresses aluminium oxide nanoparticles and toxicity data on aluminium nanoparticles are very scarce. A SCOPUS literature search only revealed one relevant toxicity study: Braydich-Stolle et al. (2010) compared the in vitro toxicity of aluminium and aluminium oxide nanoparticles using human alveolar macrophages (U937) and human type II pneumocytes (A549), which are the pulmonary cell lines. When cocultures of U937 and A549 were exposed to either type of nanoparticle, only slight cytotoxicity was observed at unrealistically high concentrations (up to 500 µg/mL). In monocultures, only A549 cells proved to be really sensitive to aluminium and aluminium oxide nanoparticles: 24-h exposure to 25 µg/mL caused a decrease in cell viability of approx. 60%. There was no significant difference between the cytotoxicity of both nanoparticles

Based on this very scant evidence, it may be assumed that aluminium and aluminium oxide nanoparticles are equitoxic. Therefore aluminium nanoparticles are attributed the same hazard band as aluminium oxide nanoparticles: band C (see below).

Aluminium oxide nanoparticles

In an update on some metal oxide nanoparticles, Stoffenmanager Nano has attributed hazard band C to aluminium oxide nanoparticles (Le Feber et al., 2014).

Calcium Carbonate

The substance calcium carbonate has been registered under REACH. The registrant has indicated that the substance has a nano-form and has provided separate information on the nano-form. Calcium carbonate, including its nano-form, has not been classified as hazardous by any route of exposure. EFSA has recently given a scientific opinion on re-evaluation of calcium carbonate (E 170) as a food additive. This opinion, concluded that "the available data are sufficient to conclude that the current levels of adventitious nanoscale material within macroscale calcium carbonate would not be an additional toxicological concern" (EFSA, 2011). In view of this lack of toxicity, nanocalcium carbonate is not classified and therefore assigned hazard band A.

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

Carbon nanotubes have often been demonstrated to have severe toxicity; however, this seems to be largely dependent on the dose, the degree of agglomeration and the route of administration. Differences in toxicity are also expected between single and multi-walled CNTs and are presumably dependent on their aspect ratio (El-Ansary, et al. 2013).

Upon inhalation, single walled carbon nanotubes (SWCNTs) have shown various chronic inflammatory responses in rat and mice (El-Ansary, et al. 2013, Zhao and Castranova 2011). SWCNTs have been shown to be genotoxic in mice after inhalation exposure as well as in mouse lung epithelial cells and lung fibroblasts (El-Ansary, et al. 2013, Zhao and Castranova 2011). SWCNTs have shown to be genotoxic in rats after oral administration (Zhao and Castranova 2011). Multiwalled carbon nanotubes (MWCNTs) have shown systemic immunological and inflammatory responses after short-term inhalation exposure (El-Ansary, et al. 2013, Yildirimer, et al. 2011). In the case of short to medium term pulmonary exposures to SWCNTs or MWCNTs in rodents, no tumours were reported. Cellular responses and gene expressions in these studies showed significant effects associated with lung cancer (Zhao and Castranova 2011).

Several studies have shown the potential for MWCNTs to act like the persistent fibres of asbestos, causing thoracic inflammation and fibrosis. Additionally, MWCNT have been shown to penetrate into the alveolar region of the lung and to cause inflammation due to accumulation of alveolar macrophages. These biological events have been shown to lead to mesothelioma, although MWCNT have not been demonstrated to de facto cause mesotheliomas. Still the weight-of-evidence for certain types of MWCNT (e.g., those with high aspect ratios) is increasing: mice injected with long (> 15 μm) MWCNT or asbestos showed significantly increased granulocytes in the pleural lavage, compared with the vehicle control at 24 hours post exposure. Long MWCNT caused rapid inflammation and persistent inflammation, fibrotic lesions, and mesothelial cell proliferation at the parietal pleural surface at 24 weeks post exposure. Chronic in vitro exposure (4 months) of human mesothelial cells to MWCNT induced proliferation, migration and invasion of the cells similar to those observed with crocidolite asbestos as well as a similar up-regulation of a key gene involved in the process of cell invasion (matrix metalloproteinase-2) (Lohcharoenkal, et al. 2013). As a matter of fact, at the same mass exposure (0.02 μg/cm2) MWCNT caused a higher fold increase in cell migration and invasion than crocidolite asbestos (c. 3- and 2-fold, respectively). Also asbestos and rigid, high-aspect-ratio CNT activated the NLRP3 inflammasome to the same extent (Palomäki, et al. 2011). The NLRP3 believed to play a central role in inflammatory diseases (Abderrazak, et al. 2015). Frustrated phagocytosis is believed to be the trigger for the chain of events leading to mesotheliomas; in order to be able to cause this phenomenon, fibres need to be biopersistent and longer than 5 μm (Donaldson, et al. 2013). Concluding, flexible, rigid, high-aspect-ratio MWCNT may cause cancer in a similar fashion as asbestos and may be as potent in this respect.

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

CERIUM OXIDE NANOPARTICLES

In an update on some metal oxide nanoparticles hazard band C was attributed to cerium oxide nanoparticles (Le Feber et al., 2014).

COBALT OXIDE NANOPARTICLES

Stoffenmanager Nano has attributed hazard band E to cobalt oxide nanoparticles (Van Duuren-Stuurman et al., 2012).

MAGNESIUM-ALUMINIUM (MAGNALIUM) NANOPARTICLES

Magnalium is an ally of magnesium and aluminium. No toxicity data are available on either the nano or the bulk material. Consequently, no hazard band can be attributed.

MAGNESIUM HYDROXIDE NANOPARTICLES

No relevant toxicity studies on nano-magnesium hydroxide were encountered in public literature. It is not very soluble in water (solubility approx. 9 mg/L) and therefore, applying the methodology of van Duuren et al. (2012), the hazard characteristics of the parent material are used. Magnesium hydroxide has no harmonised classification in the EU[656] and it is also not classified by 400 notifiers nor in the registration dossier[657], based on sufficient information. Based on this lack of classification, the nano-forms should be assigned hazard band C, the lowest category a nanoparticle can be assigned just based on toxicity data for is non-nano parent compound (Van Duuren-Stuurman et al., 2012).

MWCNTS

See Carbon nanotubes (CNTs), single- and multi-walled.

NANOCLAY

Classified by Stoffenmanager Nano in hazard band D for sizes ≤50 nm (C for sizes >50 nm) (Van Duuren-Stuurman et al., 2012). Since the size distribution of the iron oxide nanoparticles used may include sizes below 50 nm, the highest risk band is used in the risk assessment applied here.

TITANIUM DIOXIDE NANOPARTICLES

In an update on some metal oxide nanoparticles hazard band C was attributed to titanium dioxide nanoparticles (Le Feber et al., 2014).

EXPOSURE ASSESSMENT

Nanotechnology in infrastructure

Nanoclays, carbon nanotubes (CNT), silica, aluminium oxide, magnesium hydroxide, calcium carbonate, and titanium dioxide (TiO2) nanoparticles may be used as components of asphalt, while nanoTiO2 may also be used in coatings on e.g. concrete structures. In the building/application phase, the exposure potential is relatively low (2) since the nanomaterial is dispersed in the asphalt mixture or coating, except in the case when a coating is sprayed on a surface, then the exposure potential is high (4). If the asphalt has hardened or the coating has been applied on the surface, the exposure potential is low (use phase, 1). In the end-of-life phase, abrasive activities (demolition) executed with the concrete or asphalt may expose the worker to nanomaterials, but the exposure potential is still relatively low (2).

Nanotechnology in vehicles

Carbon nanotubes are applied to existing materials to increase strength and to reduce weight in the structure and interior of vehicles including materials used in the aerospace sector. In addition, carbon nanotubes are used in engines to improve the heat-transferring properties which can affect the performance, emission and durability of the engine. Furthermore, nanoadditives are added to fuel to reduce the soot emissions (e.g. cerium oxide nanoparticles; aluminium nanoparticles; magnesium-aluminium (magnalium) and cobalt oxide nanoparticles).

Regarding the exposure potential, based on expert judgement we believe a relative low exposure (1) is expected for the nanomaterials in these products. However, during the vehicle manufacturing phase, when handling nanomaterials, the exposure potential can be high (4). In the end-of-life phase shredding maybe a realistic scenario to recycle the nanomaterial, resulting in a relatively low exposure potential (2).

Nanotechnology for operations

In this subsector catalysts and sensors are predominantly represented in the available products with nanomaterials. Although some nanomaterials are applied (e.g. MWCNTs, TiO_2) most of the products are only produced on a nanoscale (e.g. lithography). Similar as for the other subsectors, a high exposure potential is expected for the occupational phase handling nanomaterials, while low

[656] http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/13362
[657] http://echa.europa.eu/registrati `1on-dossier/-/registered-dossier/16073/7/6/2

exposure potential is foreseen during the use phase. In the end-of-life phase shredding maybe a realistic scenario to recycle the nanomaterial, resulting in a relatively low exposure potential (2).

RISK ASSESSMENT

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table *Priority bands in the Stoffenmanager*. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures or to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 2: Priority bands in the Stoffenmanager

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Roughly four phases can be discerned in the life cycle of construction materials: production, building, use and demolition. In principle, production is covered in the sector report on manufacturing, consequently this report is limited to the building, use and demolition phases. If in a phase different degrees of exposure may occur, the highest exposure scenario is taken into account in the risk assessment (worst case scenario).

Since the transport subsector "infrastructure" is included in the sector constructions with respect to materials and technologies applied, the reader is referred to the report on that sector.

Roughly three phases can be discerned in the life cycle of transport vehicles and nano-enabled products used in operations: production, use and end-of-life. If in a phase different degrees of exposure may occur, the highest exposure scenario is taken into account in the risk assessment (worst case scenario).

As shown in the table below, due to the high expected exposure all nanomaterials reach the highest risk priority during the production phase, except calcium carbonate (intermediate priority). In the use phase, aluminium (oxide), calcium carbonate, cerium oxide, magnesium hydroxide and titanium dioxide have a low risk priority, nanoclay has an intermediate priority, while carbon nanotubes and cobalt oxide have the highest risk priority. It should be noted that in the use phase all nanomaterials are contained in a solid matrix, meaning exposure will be negligible and thus health risks will be low. In the end-of-life phase, risk management/evaluation of transport materials containing carbon nanotubes and cobalt oxide should receive the highest priority, while the materials containing the remainder of the listed nanomaterials should receive intermediate priority.

Table 3: Priority bands for the transport sector

		Exposure Band		
		Production/ building/ application phase	Use Phase	End-of-life phase
Nanoparticle	Hazard Band	4	1	2
Aluminium/aluminium oxide	C	1	3	2
Calcium carbonate	A	2	3	3
Carbon nanotubes, single- and multiwalled	E	1	1	1
Cerium oxide	C	1	3	2
Cobalt oxide	E	1	1	1
Magnesium hydroxide	C	1	3	2
Nanocly	D	1	2	2
Titanium dioxide(titania, rutile, anatase)	C	1	3	2

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This report offers a snapshot of the environment for nanotechnology in the context of transport. It gives an overview of policies and programmes for nanotechnology and transport in the EU (and wider), publications, patenting, research & innovation, industry, products and markets, and the wider environment. The report is part of a series of eight NanoData Landscape Compilation studies covering the application of nanotechnology in the fields of construction, energy, environment, health, ICT, manufacturing, photonics and transport.

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