European Commission

NanoData Landscape Compilation

Energy

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EXECUTIVE SUMMARY

Background

Nanotechnology has the potential to contribute to energy sustainability by reducing consumption, improving the infrastructure for energy generation, transmission and use, and offering new methods for energy production. To achieve this, the field of nanotechnology and energy needs to have a solid research base; routes for new developments in energy technology to be further advanced and commercialised; and a market open to nanotechnology energy products, in the context of appropriate regulation and standards.

Energy sustainability is one of the main global challenges facing the world today. The European Energy Strategy is seeking to tackle that challenge through measures to improve energy efficiency, increase the share of renewable energy and reduce greenhouse gases. This report looks, from a research, development and deployment (market) perspective, at the role of nanotechnology in achieving those energy goals and at the overall landscape in Europe for nanotechnology and energy.

Role of nanotechnology

Nanotechnology is being applied to improve energy sustainability at levels from the research bench to the production line.

In solar energy, work is underway to make existing systems for the conversion of light to electricity more efficient, to find new and improved methods of conversion using novel materials such as quantum dots and nanowires, and to better connect energy capture from the sun to the grid. Developments in nanotechnology are also focused on enabling more efficient production of hydrogen from water and on improving its storage. Nanotechnology is providing solutions to the high cost and short running times of batteries for electric vehicles and consumer electronics through new materials and their application. Carbon nanotubes are being viewed as high-strength, lightweight materials for the rotor blades of wind and other turbines. Nanomaterials can also be used to lubricate bearings, reduce heating of components and provide enhanced wear resistance, thereby increasing energy efficiency. Biological processes often operate at the nanoscale and nanotechnology has a role to play in optimising the conversion of biomass, including algae, into energy.

Policies

National policies to support energy nanotechnology in Europe are largely generic at Member State level in that they support nanotechnology within broad science and technology initiatives or support it as a designated priority but usually do not single out energy specifically. Examples of nanotechnology initiatives in which energy is specified include: the Dutch NanoNextNL, where programmes are clustered in ten themes, one of which is energy; the Spanish Strategic Action for Nanoscience and Nanotechnology, New Materials and New Industrial Processes (SANSNT); the French Agence National de la Recherche (ANR) with P2N (nanotechnologies for sustainable development) and Sustainable Electricity Production and Management (PROGELEC); the German Action Plan Nanotechnology 2015 with its proposals to develop nanotechnology in five main areas including energy; and the United Kingdom in its Nanotechnologies Strategy (addressing energy generation through solar technology) and the Enabling Strategy 2012-2015 of Innovate UK (formerly the Technology Strategy Board), with advanced materials for energy as a priority.

At European level, the Strategic Energy Technology Plan (SET-Plan) was adopted by the European Union in 2008 to establish an energy technology policy for Europe. In addition, European policies are being implemented in the EU RTD Framework Programmes, those Programmes being responsible for the largest amount of EU funding of nanotechnology research and development (R&D). Other policies focus on the need for scrutiny of the use of nanotechnologies, in manufacturing and in consumer goods, including developing strategies to test the safety of engineered nanomaterials.

There are several significant initiatives in the European context including

- The ERA-NETs, SOLAR-ERANET and M-ERA.NET;
- Research infrastructures including H2FC, SFERA and SOPHIA;
- European Technology Platforms, such as EuMAT, the European Photovoltaic Platform, RHC-Platform and TPWind;
- Joint Technology Initiatives and Joint Undertakings such as FHC Hydrogen and Fuel Cells;
- Contractual public-private partnerships (PPPS) on energy efficient buildings (EeB), green vehicles (EGVI) and sustainable process industry (SPIRE);

- KIC InnoEnergy, one of the first Knowledge and Innovation Communities (KICs) established under the European Institute of Innovation and Technology; and
- Networks of Excellence (NoEs) in energy-related areas such as INSIDE-PORES and NANOMEMPRO.

Globally outside of the EU, countries that have specified nanotechnology and energy as a priority within their policies and programmes at some point in the recent past include Russia (solar energy and energy saving cluster within RUSNANO); the United States (particularly activities at the Department of Energy on solar energy, storage and alternative fuels); and Australia (under its National Nanotechnology Research Strategy it included nanostructured materials for clean energy). Other countries include nanotechnology and energy as means of achieving national goals (e.g. Japan (which, in its Fourth S&T Basic Plan 2011-2015, moved away from designated priority technology areas to solution-oriented programmes, but these include Green Innovation)).

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

EU R&D projects

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

The number of projects in FP6 and FP7 together that were related to both energy and nanotechnology was 389, approximately 11% of the NT total. The percentage of energy nanotechnology projects was higher in FP7 (12.6%) than it was in FP6 (6.3%). Projects in FP7 comprised over 85% of all energy nanotechnology with less than 15% of projects being in FP6. The proportion of FP7 energy NT projects was higher than for either nanotechnology projects in general (74%) or FP projects overall (72%).

The 389 nanotechnology energy projects received an EC contribution of EUR 731 million, EUR 136 million (19%) in FP6 and EUR 595 million (81%) in FP7. In FP6, the EC contribution for nanotechnology and energy represented 8% of the total nanotechnology EC contribution, whereas in FP7 it was almost 13%.

In FP6, the Thematic Priorities of NMP, Sustainable Development, IST[2] and Aeronautics and Space were the recipients together of over 80% of the funding for energy nanotechnology. The Specific Activity of Horizontal Research involving SMEs received almost 3% of funding (EUR 3.9 million) and 22 projects for Human Resources and Mobility received almost 15% (EUR 20 million) of total energy NT EC funding.

In FP7, the largest amount of funding for energy nanotechnology (45%) was for NMP[3] with almost EUR 270 million for 66 projects. ERC had the next highest funding (17.7%, EUR 105 million) followed by Energy (10.8%), ICT (8.4%) and Marie Curie Actions (12.3%).

Throughout FP6 and FP7, the same five countries (DE, UK, FR, IT and NL) received the highest proportions of energy nanotechnology funding and together were successful in securing over half of the total funding, although 58 countries engaged in some way.

Higher education institutes received close to half (47%) of the EU funding of nanotechnology and energy under the FPs, followed by research organisations (28%), small and medium-sized companies (15%), large companies (9%) and other organisations (1%).

The organisations receiving the largest amounts of funding for energy nanotechnology activities were Fraunhofer Gesellschaft[4] (DE), the CEA[5] (FR), the University of Cambridge (UK) and the CNRS[6]

[1] Nanotechnologies and nanosciences, knowledge-based multi-functional materials and new production processes and devices
[2] Information Society Technologies
[3] Nanosciences, Nanotechnologies, Materials and new Production Technologies
[4] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[5] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[6] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr

(FR). Johnson Matthey Plc. (UK) was the most active company in terms of funding, followed by two SMEs, BioGasol APS in Denmark and B.T.G. (Biomass Technology Group BV) in the Netherlands. A Swiss SME, Solaronix SA, was the most active company as measured by numbers of projects, participating in seven.

Publications

Publication data for energy nanotechnology revealed that, of 1.8 million publications globally with content pertaining to nanoscience and nanotechnology between 2000 and 2014, over 140,000 mentioned or were about nanotechnology and energy. Almost 46% related to solar energy and nanotechnology, 29% to storage applications of nanotechnology and 14% to hydrogen energy and nanotechnology. In terms of geography, the most prolific publishers were in China and the US, followed by Korea, Japan, India and Germany.

Within the EU28, researchers in Germany, the United Kingdom and France generated the largest number of publications in 2014, followed by Italy and Spain. The top ten publishing institutions in the EU28 & EFTA for nanotechnology and energy were Imperial College (UK), the École Polytechnique Fédérale de Lausanne (EPFL, CH), the Technical University of Denmark (DK) and the University of Cambridge (UK), each with over 100 publications in 2014. Three of the top six are the United Kingdom, while Germany hosts four of the top ten. There was, however, no normalisation of the data to take into account factors influencing publication output, such as the number of research personnel or the research budgets in those institutions.

Publishing at a much lower level also takes place in companies, those with the most nanotechnology energy publications globally in 2014 being Polyera, IBM and Samsung.

Patenting

The same countries, Germany, the United Kingdom and France, continue to lead as patenting patterns in the EU28 are reviewed, using patent families as the measure, although patenting globally is largely dominated by the US, Japan and Korea. In the EU28, Austria performed strongly in patents also. The same top eleven countries led the ranking by number of applications as by patents granted, for EU and EFTA countries.

In patent applications by universities and public research organisations in the EU28 & EFTA, French organisations perform the most strongly (as the top two and with five in the top 20), followed by Germany (five of the top ten) and the United Kingdom (seven in the top 20). For patents granted, of the top 15 universities and research organisations, three are from the EU28/EFTA countries (CNRS (FR), CEA (FR) and Fraunhofer (DE)). Six of the top fifteen are in the US, three in Japan and one each in China and Korea.

For companies with the highest number applications by patent families, three are in Germany, three in Japan and two in Korea. In the EU28 and EFTA, of the top 20, seven are in Germany. In the top ten for patents granted, there are six US companies and two from Japan, the only EU country being Germany (Merck).

Products and markets for energy through nanotechnology

Global sales of nanotechnology products in the energy sector in 2013 were estimated to be USD 584 million and are forecast to grow to USD 3 billion in 2019.[7]

The main areas where nanotechnology is applied to energy are solar cells and storage (e.g. lithium-ion batteries). Growth is also expected in new areas including storage solutions using carbon nanotubes. There are many energy-saving applications of nanotechnology, using coatings and sensors as well as insulation applications, which are only touched on in this report but will be addressed in greater detail in future NanoData reports.

Of almost 170 products identified here as being currently on sale, almost half (46%) are in the areas of photovoltaics (coatings and conductive inks, in particular). Lithium-ion batteries account for almost one fifth of the products identified (18%) another 5% of products being other forms of energy storage. Fuel cells and membranes for fuel cells are included in both storage and hydrogen applications, where overlap occurs. Other applications of nanotechnology in energy are energy recovery ventilators, wind turbines, diesel fuel additives, petroleum refining, production of synthetic

[7] BCC Research

fuels and building insulation.

By type of nanomaterial, the largest market growth is expected in thin films (a three-fold increase between 2013 and 2019) and nano-composites. Carbon nanotubes are expected to play just a small role on the market in the next five years.

There is very high predicted growth in areas such solid-state thin film batteries (CAGR 90%) and photovoltaics (CAGR 86-123%) as well as lithium-ion batteries (CAGR 36-37%). Materials for energy applications also show high growth (CAGR 41%).[8] One indication of the uncertainty in the market is the CAGR forecast for energy and nanotechnology overall at global level which, at 20%, is lower than the estimated CAGR for any of the application areas in which forecasts have been made. It is clearly hard to predict what share nanotechnology products will capture of the energy market.

Regulation and standards

Legislative frameworks for energy production and storage do not currently include nano-specific provisions. Nanomaterials used in energy production are nevertheless regulated similarly to other chemical substances in most countries. Nanomaterials may also require registration in a country with a nanomaterial reporting scheme.

Standards development on nano-enabled energy applications is mostly done via the International Electrotechnical Commission (IEC) technical committee IEC/TC 113 Nanotechnology standardisation for electrical and electronic products and systems. In addition, ISO has technical committees dedicated to different types of energy production (e.g. ISO/TC 28 Petroleum and petroleum products, ISO/TC 180 Solar energy and ISO/TC 203 Technical energy systems).

The European Standardisation Committee (CEN) has a dedicated technical committee for nanotechnologies, addressing energy, safety and environmental aspects of relevance to this and other areas.

Environmental health and safety

The risk-banding tool Stoffenmanager Nano was used to rank the uses of nanotechnology in energy according to the health risks occurring as a result of respiratory exposure to nanoparticles of workers and consumers.

The respiratory route is the main one for exposure for many occupational scenarios. Nano-specific systemic toxicity via the dermal route is considered to be improbable in this sector as the nanoparticles as are very unlikely to penetrate the skin. The oral exposure route is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices.

Safety aspects for copper oxide, graphene, MWCNTs and nickel monoxide were identified as being particularly important in production and use for energy applications, indicating the need to apply exposure control methods or to assess risks precisely. Gold is slightly lower priority (except in solar energy production where it is high priority) while zirconium dioxide showed the lowest priority profile of the materials considered, being in the lowest hazard band and at the lower end of the exposure band (except for solar energy applications). No risk estimates were presented for the sub-sectors “Hydrogen” and “Others” due to lack of data.

[8] BCC Research

1 BACKGROUND

The World Energy Council defines energy sustainability as being based on three core dimensions:[9]

- Energy security: the effective management of primary energy[10] supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand.
- Energy equity: the accessibility and affordability of energy supply across the population; and
- Environmental sustainability: the achievement of supply- and demand-side energy efficiencies and the development of energy supply from renewable and other low-carbon sources.

These are also, broadly, the goals of policy-makers in Europe and many other countries. Nanotechnology has the potential to contribute to achieving these goals by reducing energy consumption, improving energy infrastructure (thereby increasing efficiency and the ability to meet energy needs) and offering new ways of producing energy.

This report examines and reports on the use of nanotechnology for energy from the perspectives of:

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

Given the universal use of energy throughout manufacturing and the wide range of sectors on which it impacts, there will be some overlap with other sectors considered within the NanoData project, for example, health, transport and ICT.

Unless otherwise stated in the text, the data has been extracted[11] from the NanoData project data system compiled from a wide range of statistical sources (e.g. publications databases, patent office databases, European Commission databases, Eurostat, OECD, etc.) and primary research via literature review and other data collection methods (e.g. interviews).

Nanotechnology and energy, or energy nanotechnology, are frequently abbreviated in this report to EN, and the abbreviation NT is used for nanotechnology.

1.1 Introduction to energy issues

The three goals of the World Energy Council (WEC) - energy security, energy equity and environmental sustainability – are described by the WEC as a 'trilemma', with complex interwoven links between public and private actors, governments and regulators, economic and social factors, national resources, environmental concerns and individual behaviours. To achieve the three goals, the WEC has developed a ten-point agenda including the need to connect energy to broader agendas; provide leadership and build consensus; and improve policymaker dialogue and engagement with other stakeholders. It also addresses pricing and financial incentives. In the context of this report, however, its most relevant goals are:

1. To meet the need for more research, development & demonstration (RD&D);
2. To encourage joint pre-commercial industry initiatives, including early large-scale demonstration and deployment; and
3. To minimise policy and regulatory risk and ensure optimal risk allocation.

This report will touch on each of these topics in its reporting on outputs of research and development; on the industry and its products and markets; and on regulation, standards and environmental health and safety. First, it will put energy in context, looking at production, imports and the key

[9] https://www.worldenergy.org/work-programme/strategic-insight/assessment-of-energy-climate-change-policy/

[10] Primary energy can be defined as coming from natural sources (e.g. coal, oil, gas, peat) and includes renewable energies (e.g. solar, wind). Secondary energy is energy coming from a source that has been processed or converted in some way (e.g. charcoal, refined fuels, electrical energy).

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

challenges for the EU.

Primary energy production in the EU[12]

In 2013, the highest level of primary energy[13] production among the EU Member States was in France, with a 17.1% share of the EU28 total, followed by Germany (15.3%) and the United Kingdom (13.9%). Compared with a decade earlier, the main change is the decreased share of the United Kingdom, down from 26.2%.

Production of primary energy in the EU28 totalled 790 million tonnes of oil equivalent (toe) in 2013. There has been a generally downward trend in production in the EU over recent years, with production of primary energy 15.4 % lower in 2013 than it had been a decade earlier. This trend may be attributed, at least in part, to the exhaustion of supplies of raw materials and/or producers considering the exploitation of limited resources to be uneconomical.

Nuclear energy is the most important source of primary energy production in the EU, making up 28.7% of the total for the EU28 and much higher proportions in some countries, such as France and Belgium where it accounts for about 80% and 75% respectively of national production of primary energy.

Close to one quarter of the EU28's total production of primary energy is from renewable energy sources (24.3%) and just under one fifth from solid fuels (19.7%, largely coal). Natural gas accounts for 16.7%, and crude oil, the only other major source, 9.1%. Renewable energy production has grown significantly between 2003 and 2013, at a rate of almost 90%, while crude oil production has dropped 54%, natural gas has dropped 35%, solid fuels 25% and nuclear energy 12%.

Imported energy in the EU

More than half of the energy used in the EU28 is imported (e.g. as oil from Saudi Arabia and natural gas from Norway) and this proportion has been generally on the rise over the decade to 2013. EU28 imports of primary energy exceeded exports by 909 million tonnes of oil equivalent (toe) in 2013, the largest nett importers being the most populous countries, with the exception of coal-rich Poland. Until 2013, Denmark was a nett exporter of energy but in that year it joined the rest of the EU28 in becoming a nett importer.

Security of energy supply is a concern for countries and regions if a small number of other countries are responsible for the majority of their energy supply, as in the EU. In 2013, more than two thirds (69%) of natural gas imports came from Russia or Norway, over half of crude oil (54%) from Russia, Norway and Saudi Arabia, and almost three-quarters (73%) of coal from Russia, Colombia and the United States.

Of particular concern at present is the EU's dependency for energy on the Russian Federation, the established main supplier to the EU28 of crude oil and natural gas and now also, more recently, the leading supplier of solid fuels, given both the issues around safety of pipelines and the overall stability of, and Russia's relationship with, neighbouring countries.

The next section will consider how nanotechnology could make its contribution to energy sustainability.

1.2 Role of nanotechnology

Four sub-sectors were identified for the NanoData project:

- Solar energy (Solar);
- Storage, batteries and capacitors (Storage);
- Hydrogen energy and storage (Hydrogen); and
- Alternative power generation technologies (Alternatives).

Nanotechnology has the potential to contribute in each of these areas as outlined below. There are potential applications of nanotechnology to other sectors not specifically examined here[14].

[12] http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_production_and_imports
[13] Primary energy and secondary energy as defined previously in this document
[14] For example, the applications of nanotechnology in the oil and gas industries are not included within a sub-sector although, inter alia shale gas applications show promising potential for the use of nanotechnology.

Solar

Nanotechnology can be used to make solar cells more efficient and reduce their cost. Silicon is the main raw material for most photovoltaics (PV) and comprises 10-20% of their cost.

When photons impact n-type silicon (excess of conductive electrons), they cause atoms to lose electrons which then transfer to an adjacent electron deficient area of the silicon (p-type) creating a current and thereby generating electricity. The best commercial versions of solar cells are around 22% efficient at converting sunlight into electricity. By reducing the thickness of the silicon from the typical 200 micrometres to dimensions of nanometres, material costs are significantly reduced but to the detriment of the efficiency of the cell for the simple fact that there is less material, thus electrons, for the photons to interact with. To counteract the sacrifice in efficiency caused by thinning out the costly silicon, nanotechnology can be used to maximise the light entering the solar cell, through anti-reflective coatings; to minimise light escaping the solar cell, through nanostructured photonic waveguides; and to improve light absorption, through integrating plasmonic components.

In addition to crystalline silicon PV cells, nanotechnology is being used in the development of thin film photovoltaics (e.g. based on amorphous silicon, copper indium gallium selenide (CIGS) or cadmium telluride); in third generation PVs (using quantum dots, nanowires, organic and dye-sensitised solar cells); in concentrator PV cells using optical tracking and optical concentration; and in connecting PV cells to the grid.

Nanoscale roughening of the silicon surface can drastically reduce the light reflected from the surface. One example, inspired by the structure of moths' eyes, used an ordered array of nano-sized posts fabricated on silicon using block copolymer patterning templates to decrease reflection. Most commercial strategies, however, employ multi-layered thin films and achieve similar efficiencies to the nano-pillar array.[15]

Once the light enters the active part of the solar cell, it should be prevented from escaping in order to maximise the probability of interaction with the electrons in the material. Resonant cavities and waveguides are used for this purpose along with plasmonic nanoparticles on the surface to scatter the light back into the active material. These plasmonic nanoparticles also enhance local electromagnetic fields and can improve the optical properties of the material when their resonance peak matches that of the incident light.

Another potential benefit of thinner solar-cells (developed through a combination of nanotechnology, material and fabrication advances) is that they would be more flexible and amenable to cheaper production techniques such as printing. They would also be easier to transport, possibly even rolled up, and to install, and can potentially be shaped to suit a variety of geometries.

Storage

Nanotechnology is providing potential solutions to the high cost and short running times of batteries for electric vehicles[16] and consumer electronics.

Lithium (Li) ion batteries are in common use today in consumer electronics such as mobile phones and laptops. Nanotechnology offers the potential to improve the performance of Li-ion batteries by increasing their capacity and their lifetime (enabling more charge and discharge cycles to take place) and reducing their weight. Nanoparticles coated onto electrolytes dramatically increase the surface area over which current can flow without using any more material. This translates to savings in the weight of the battery.

European battery manufacturers are currently working toward the use of carbon nanotechnologies in new types of additives to improve the conductivity of active materials in lead-based batteries.[17]

Super-capacitors are commonly used in commercial power storage applications such as light-rail, electric vehicles and power grids. Carbon nanotubes (CNTs) are being used to improve their performance in terms of capacitance, charge and discharge rates, lifetime and cost.

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[15] https://www.bnl.gov/newsroom/news.php?a=11685

[16] 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

[17] http://www.eurobat.org/sites/default/files/rev_of_battery_executive_web_1.pdf

Graphene aerogel processes are being researched with potential future applications in energy storage. The materials produced are ultralight and porous with good insulating properties. Graphene aerogel lattices have been produced using 3D printing and have high surface area, good electrical conductivity, low density and good mechanical stiffness, suitable for energy and other applications.

Hydrogen

Hydrogen is a very attractive potential source of energy storage as the process by which it releases energy is very efficient and its waste product is water. It can be produced from natural gas (by steam reformation) or from water (by electrolysis), the latter being the cleaner method as steam reformation involves the consumption of the non-renewable gas and the process emits carbon dioxide. Hydrogen can be used as a fuel by direct burning (as in aerospace where it is a main fuel for rockets) but it can also be used to produce electricity via hydrogen fuel cells. The drawbacks to hydrogen as a fuel are the high cost of producing it, that the main fuels for producing it are fossil-based (making it no longer a clean energy source) and that it is highly flammable and thus difficult to store and transport.

Developments in nanotechnology are targeted at enabling more efficient production of hydrogen from water and at improving its storage. Some nanomaterials are very effective in the decomposition of water molecules into hydrogen and oxygen through photocatalysis (e.g. titanium dioxide). Others can absorb hydrogen and store it at high densities ready to be released when and where it is to be used.

Alternatives

This sub-sector includes the non-fossil fuel energy sources: wind and wave energy, marine, ocean and tidal energy, geothermal energy, hydroelectricity and biofuels, inter alia, wherever they can benefit from the use of nanotechnology (with solar energy and hydrogen energy excluded as they are addressed as separate sub-sectors).

Nanotechnology (e.g. in the form of carbon nanotubes) can be applied as high-strength, lightweight materials for the rotor blades of wind and other turbines. They can also be used to lubricate bearings, to reduce heating and to provide enhanced wear resistance in turbine applications. Nanostructured materials could also help in countering eddy-effects and improving the effectiveness of the blades as they move through the air. Nanotechnology can be used in a similar way in river and ocean environments, where nano-textured surfaces can, in addition, reduce bio-fouling of blades by making it difficult for contaminants to become attached.

Nanotechnology is being researched with the aim of optimising the conversion of biomass into energy. It is also already being applied as sensor technology in agriculture and manufacturing (e.g. in optimising biofuel processing and in limiting the use of pesticides and fertilisers in the production of biomass). Algal biomass is being seen as a vast, untapped source of energy from the sea that will not take from food production. Nanotechnology research is looking to address the challenges of effectively harvesting algae (e.g. using clay and sand nanoparticles to extract the oil content without damaging the algae, making the resource a renewable one) and as a catalyst in the processing of the crop to be used as algal biofuels.

The next section reviews the policies that are in place at European Union and Member State levels for nanotechnology and energy.

2 EU POLICIES AND PROGRAMMES FOR NANOTECHNOLOGY AND ENERGY

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

EU funds for research and innovation are provided through dedicated programmes. In 2014-2020, these include the Framework Programmes (formerly the Seventh Framework Programme (FP7), currently Horizon 2020), covering all research fields and fully dedicated to funding research and innovation activities; sectoral research programmes (nuclear energy, coal and steel, space); and the European Structural and Investment Funds. These programmes are complemented by five other EU programmes with links to research and innovation activities: the Connecting Europe Facility (including infrastructure for energy)[18], the Third Health Programme[19], Life[20], Erasmus+[21] and COSME[22].

This section will first examine the EU Framework Programmes.

2.1 The EU Framework Programmes: supports for nanotechnology

The Framework Programmes, being the largest source of EU funds for R&D, have the greatest role in EU funding of nanotechnology R&D. Support specifically named as being for nanosciences and nanotechnologies was first provided at a significant level in the Sixth Framework Programme (FP6, 2002-2006) 23. NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had the largest amount of nanotechnology energy funding at over 54% of the total.

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

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

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

There are many other initiatives under FP7 that can fund research and development (R&D) on nanosciences and nanotechnologies including those for ICT, health, energy, transport and the environment. For example, ICT Challenge 3 (Alternative Paths to Components and Systems) also

[18] Improving trans-European infrastructure for transport, energy and telecommunications.
[19] Preventing diseases, protecting EU citizens from cross-border health threats, contributing to innovative health systems, and facilitating better access to healthcare.
[20] For environment, biodiversity and climate change.
[21] Supporting relocation for education and training purposes.
[22] Supporting the creation and expansion of companies, especially by expanding their research and innovation activities.
[23] 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.

addresses energy, resource and cost efficiency including recycling and end-of-life issues. One of the aims of the Challenge is to '*enable further integration and cross-fertilisation of key enabling technologies towards building energy- and resource-efficient components and systems'*.

Energy topics are also funded under other programmes within the EU but the Framework Programme remains the largest designated source of R&D funding.

Within FP7, non-specific basic research, People and Capacities are funded (in addition to the Co-operation Programme) and each of these provides potential funding for nanoscience and technology. Significant examples of these are:

- The European Research Council (ERC) funding of up to EUR 7.5 billion in FP7 (and EUR 13.1 billion in 2014-2020 under Horizon 2020[24]) for investigator-driven, bottom-up research ideas in science, engineering and interdisciplinary research, awarded through open competition;
- The Marie Curie Actions[25], with funding of up to EUR 4.7 billion FP7 in 2007-2013 (and EUR 6.16 billion Horizon 2020 funding in 2014-2020) for training, mobility and career development of researchers; and
- The Capacities Programme[26], with a budget of EUR 4.1 billion, funding for research infrastructures; for research for the benefit of SMEs; for regions of knowledge and support for regional research-driven clusters; for research potential of Convergence Regions; for science in society; for support to the coherent development of research policies; and for international co-operation.

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

The ERA-NET scheme began under FP6 to support collaboration between and co-ordination of national research programmes. ERA-NET was continued under FP7 and there is a network on nanotechnology and energy: SOLAR-ERANET. This is an FP7-funded European network of national and regional funding organisations and RTD (research and technological development) and innovation programmes in the field of solar electricity generation, i.e. photovoltaics (PV) and concentrating solar power (CSP) / solar thermal electricity (STE). SOLAR-ERANET has 20 partners from 15 countries and aims to help in co-ordinating and supporting joint action through national and regional RTD and innovation programmes thereby helping to reach the objectives of the Solar Europe Industry Initiative[27] (SEII).

In addition, attention was directed to nanotechnology and energy by the M-ERA.NET, another FP7-funded network, the goal of which was to improve the coordination of European research programmes and related funding in materials science and engineering[28]. Established in 2012, M-ERA.NET acts as a single innovative and flexible network of public funding organisations (29 national and 8 regional), supporting the exploitation of knowledge along the whole innovation chain from basic research to applied research and innovation. M-ERA.NET develops long-term cooperation between funding organisations across the EU as well as connections with partners outside Europe. Furthermore, it promotes transnational networking of clusters and competence centres and open access to research facilities[29]. Between 2012 and 2016, the consortium is expected to mobilise EUR 150 million.

The ERA-NET scheme 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.

Networks of Excellence (NoE) were introduced in the Sixth Framework Programme (FP6) with the objective of combating fragmentation in the European Research Area by integrating the critical mass of resources and expertise needed to enhance Europe's global competitiveness in key areas relevant

[24] http://erc.europa.eu/
[25] http://ec.europa.eu/research/mariecurieactions/ Marie Curie Actions became Marie Skłodowska-Curie Actions under Horizon 2020.
[26] http://ec.europa.eu/research/fp7/index_en.cfm?pg=capacities
[27] http://www.eupvplatform.org/seii.html
[28] http://www.m-era.net/about-m-eranet
[29] https://www.m-era.net/article/other-joint-activities

to a knowledge-based economy. These bottom-up initiatives are led by consortia targeting specific research or technological challenges. Examples related to nanotechnology and energy are INSIDE-PORES and NANOMEMPRO[30].

- INSIDE-PORES (with 17 partners from 9 Members States receiving EU funding of EUR 6.8 million over 4 years) focused on nano-porous catalyst and membrane materials for applications including energy storage, high-temperature molecular sieve separation (e.g. hydrogen purification) and low-temperature sorption separation (e.g. CO2 removal).
- The NANOMEMPRO consortium (with 13 organisations from 13 Members States receiving EU funding of EUR 6.4 million over four years) focused on membrane materials. Its scientific objective was to research the synthesis of nanostructured artificial membranes to mimic the functions of naturally occurring cellular membranes that control many functions of life, membranes used industries including energy, water treatment, electronics, healthcare and agribusiness.

European research is also being strengthened through collaboration on the development, establishment and running of large research infrastructures, so large that they cannot easily be funded by one agency or country alone. Under the auspices of the European Strategic Forum on Research Infrastructures (ESFRI)[31], Member States are coming together to fund infrastructures related to energy, ICT, health, marine and other fields. EU grants support the preparatory phases of all selected projects and assist in implementation and operation of prioritised projects. The EU funding was EUR 1.85 billion in FP7 and is about EUR 2.5 billion in Horizon 2020. Research infrastructures relevant to energy include the project on Integrating European infrastructure to support science and development of Hydrogen and Fuel Cell technologies (H2FC)[32]; Solar Facilities for the European Research Area — second phase (SFERA-II)[33]; and Solar Photovoltaic European Research Infrastructure (SOPHIA)[34], which all form part of the infrastructure needed to enable energy applications of nanotechnology.

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

[30] https://ec.europa.eu/research/industrial_technologies/pdf/noes-122007_en.pdf
[31] http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=home
[32] http://www.h2fc.eu/
[33] http://sfera.sollab.eu/
[34] http://www.sophia-ri.eu/

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

2.2.1 Overview

Project-related data was extracted from the eCorda database for the EU Sixth Framework Programme (FP6) and the EU Seventh Framework Programme (FP7)[35]. 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"[36] in the title or abstract of the project. Thus, nanotechnology projects form approximately 10% of the total FP projects. The share of nanotechnology projects increased slightly between FP6 (9.1%) and FP7 (10.4%).

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

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

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

Number and share of energy nanotechnology projects

The number of projects (in FP6 and FP7 together) that were related to both energy and nanotechnology was determined, using a keyword search[37], to be 389, approximately 11% of the total number of projects related to nanotechnology. The percentage of energy nanotechnology projects was higher in FP7 (12.6%) than it was in FP6 (6.3%) an indication that the relevance of energy has increased within nanotechnology FP-activities from FP6 to FP7.

[35] Extraction of data from eCorda January 2015.

[36] 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".

[37] See Annex for details

Table 2-2: Number of projects and shares for nanotechnology and energy 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
Energy nanotechnology FP projects	389	332	57
	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%
Energy NT FP projects	100%	85.3%	14.7%
Energy NT projects as % of all NT projects	11.0%	12.6%	6.3%
Energy NT projects as % of all FP projects	1.1%	1.3%	0.6%

Projects in FP7 comprised over 85% of all energy nanotechnology with less than 15% of projects being in FP6. The proportion of FP7 projects is higher than for either nanotechnology projects (74%) or FP projects (72%).

Funding of energy nanotechnology projects

The 389 nanotechnology energy projects received an EC contribution of EUR 730 million. The EC contribution for EN projects was EUR 136 million (19%) in FP6 and EUR 595 million (81%) in FP7. In FP6, the EC contribution for nanotechnology and energy represented 8% of the total nanotechnology EC contribution, whereas in FP7 it was 12.8% indicating an increase of energy-related funding within nanotechnology funding, as shown in the figure below.

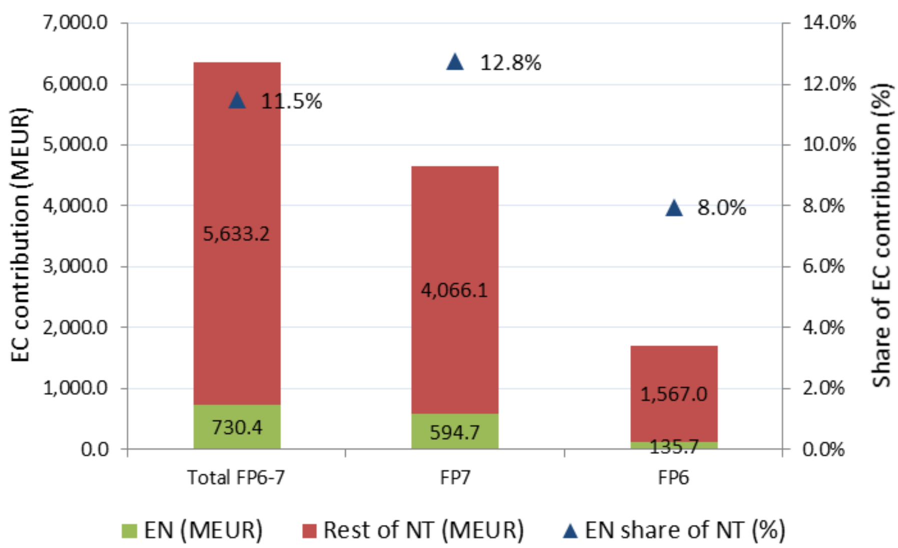

Figure 2-1: Funding of energy nanotechnology for FP6 and FP7 together, for FP7 and for FP6

2.2.2 Activities by programme and sub-programme

2.2.2.1 FP6 energy nanotechnology activities

There were 908 nanotechnology projects in FP6, approximately 9% of the total number of projects in FP6. Of those, 57 were energy-related, 6.3% 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 energy made up approximately 8% of all nanotechnology activities as measured by EC funding allocation. They took place mainly under the two priorities of (i) Focusing and integrating the ERA and (ii) Structuring the ERA.

Within the Thematic Priorities of the former:

- NMP (Nanotechnologies and nanosciences, knowledge based multi-functional materials and new production processes and devices) had the largest amount of nanotechnology energy funding at over 54% of the total (EUR 73.8 million) for 20 projects;
- Sustainable development had almost a fifth of the funding (EUR 26.2 million, 19%) for 7 projects;
- Information Society Technologies (IST) had two projects and EUR 8.3 million of EC funding (6% of total); and
- Aeronautics and space had one project with EUR 2.1 million (1.6% of total).

These Thematic Priorities together were therefore the recipients of over 80% of the funding for energy nanotechnology in FP6. The Specific Activity of Horizontal research involving SMEs received EUR 3.9 million (3% of funding).

Within the priority of Structuring the ERA, 22 projects for Human Resources and Mobility received EUR 20 million (15% of total energy nanotechnology EC funding).

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

FP6 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP6	FP6 NT	FP6 EN	FP6	FP6 NT	FP6 EN	FP6	FP6 NT	FP6 EN
I Focusing and Integrating ERA	4,735	455	35	13,445.0	1,383.6	115.7	80.5%	81.3%	85.3%
Thematic Priorities	3,374	389	30	12,027.5	1,314.8	110.4	72.1%	77.2%	81.4%
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	2	3,798.9	346.1	8.3	22.8%	20.3%	6.1%
3. NMP	444	271	20	1,534.2	870.1	73.8	9.2%	51.1%	54.4%
4. Aeronautics and Space	241	5	1	1,066.1	11.6	2.1	6.4%	0.7%	1.6%
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	7	2,300.9	30.5	26.2	13.8%	1.8%	19.3%
7. Citizens and Governance	143	3	0	236.6	2.4	0.0	1.4%	0.1%	0.0%
Specific Activities	1,361	66	5	1,417.5	68.8	5.3	8.5%	4.0%	3.9%
Policy Support	520	29	1	604.2	40.7	1.4	3.6%	2.4%	1.1%
Horizontal Research Involving SMEs	490	29	4	463.1	24.7	3.9	2.8%	1.4%	2.9%
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	22	2,744.2	303.1	20.0	16.4%	17.8%	14.7%
Research and Innovation	240	3	0	224.0	3.9	0.0	1.3%	0.2%	0.0%
Human Resources and Mobility	4,546	420	22	1,723.1	219.2	20.0	10.3%	12.9%	14.7%
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	57	16,692.3	1,702.7	135.7	100.0%	100.0%	100.0%

2.2.2.2 FP7 Energy nanotechnology activities

Energy nanotechnology projects comprised 1.3% of the total number of projects in FP7[38] and, with 332 energy nanotechnology projects, 12.6% of FP7 nanotechnology projects. Nanotechnology activities make up approximately 10% of the total EC FP7 funding to date, and energy NT activities 12.8% of NT funding and 1.3% of total FP7 funding.

The broad objectives of FP7 group into four categories:

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

The largest proportion of funding for energy nanotechnology is seen under the Co-operation Specific Programme NMP (for Nanosciences, nanotechnologies, Materials and new Production technologies) with EUR 268.5 million (45% of total nanotechnology and energy funding in FP7) for 66 projects. Energy has the next highest funding under Co-operation with EUR 64.4 million (11%) for 19 projects and ICT has EUR 49.8 million (8%) for 16 projects. Joint Technology Initiatives take 2.5% of funding

[38] Data extraction January 2015

(EUR 15.2 million) for 9 projects. Co-operation projects therefore take almost 68% of funding under the above areas.

European Research Council (Ideas) activities have funding of EUR 105.3 million (18% of energy nanotechnology funding) for 65 projects, followed by Marie Curie Actions (People) with EUR 72.9 million (12%) of energy nanotechnology funding for 144 projects. Compared with FP6, the relative importance of activities for Human Resources and Mobility has decreased in terms of funding (from 15% to 12% of energy nanotechnology funding) and increased in terms of numbers of projects (from 22 to 144) and shares of total projects (from 39% to 43%).

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

FP7 Summary	Number of projects			EC contribution (MEUR)			Share of EC contribution		
	FP7	FP7 NT	FP7 EN	FP7	FP7 NT	FP7 EN	FP7	FP7 NT	FP7 EN
COOPERATION	7,834	756	112.0	28,336.3	2,803.8	402.4	63.1%	60.2%	67.7%
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	16	7,877.0	561.3	49.8	17.5%	12.0%	8.4%
NMP	805	412	66	3,238.6	1,595.6	268.5	7.2%	34.2%	45.2%
Energy	368	24	19	1,707.4	81.5	64.4	3.8%	1.7%	10.8%
Environment	494	10	1	1,719.3	26.9	2.5	3.8%	0.6%	0.4%
Transport	719	12	1	2,284.2	61.5	2.0	5.1%	1.3%	0.3%
Socio-economic Sciences	253	0	0	579.6	0.0	0.0	1.3%	0.0%	0.0%
Space	267	14	0	713.3	31.7	0.0	1.6%	0.7%	0.0%
Security	314	5	0	1,295.5	14.1	0.0	2.9%	0.3%	0.0%
General Activities	26	0	0	312.7	0.0	0.0	0.7%	0.0%	0.0%
Joint Technology Initiatives	736	46	9	1,966.4	177.0	15.2	4.4%	3.8%	2.5%
IDEAS	4,525	572	65	7,673.5	1,026.1	105.3	17.1%	22.0%	17.7%
European Research Council	4,525	572	65	7,673.5	1,026.1	105.3	17.1%	22.0%	17.7%
PEOPLE	10,716	1,158	144	4,777.5	579.9	72.9	10.6%	12.4%	12.3%
Marie-Curie Actions	10,716	1,158	144	4,777.5	579.9	72.9	10.6%	12.4%	12.3%
CAPACITIES	2,025	149	11	3,772.0	249.9	14.1	8.4%	5.4%	2.4%
Research Infrastructures	341	18	0	1,528.4	72.2	0.0	3.4%	1.5%	0.0%
Research for the benefit of SMEs	1,028	70	7	1,249.1	86.1	10.5	2.8%	1.8%	1.8%
Regions of Knowledge	84	4	0	126.7	7.3	0.0	0.3%	0.2%	0.0%
Research Potential	206	27	1	377.7	55.1	1.2	0.8%	1.2%	0.2%
Science in Society	183	16	1	288.4	16.5	1.5	0.6%	0.4%	0.3%
Research Policies	26	0	0	28.3	0.0	0.0	0.1%	0.0%	0.0%
International Cooperation	157	14	2	173.4	12.7	1.0	0.4%	0.3%	0.2%
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	332	44,917.3	4,660.8	594.7	100.0%	100.0%	100.0%

2.2.3 Activities by participant type

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

Table 2-5: Participations in FP6 and FP7 including funding and share of funding[39]

	Total FP6 and FP7			NT in FP6 and FP7			Energy in NT in FP6 and FP7		
	Particip.	EC Funding	Share of Funding	Particip.	EC Funding	Share of Funding	Particip.	EC Funding	Share of Funding
HES	76,777	25,736.0	41.8%	7,671	3,019.5	47.5%	818	342.7	46.9%
REC	53,384	17,304.4	28.1%	4,696	1,778.1	28.0%	518	206.2	28.2%
PCO	25,067	7,021.3	11.4%	2,275	615.4	9.7%	276	67.4	9.2%
SME	29,428	6,882.6	11.2%	3,239	769.1	12.1%	399	107.3	14.7%
Other	24,961	4,626.8	7.5%	1,059	174.2	2.7%	44	6.7	0.9%
Total	**209,617**	**61,571.1**	**100.0%**	**18,940**	**6,356.2**	**100.0%**	**2,055**	**730.2**	**100.0%**

Higher education institutes (HES) received close to half (47%) of the EC contribution to nanotechnology and energy, as also shown in the table above and the figure below. They are followed by research organisations (REC, 28%), small and medium-sized companies (SME, 15%), large companies (PCO, 9%) and other organisations (OTH, 1%).

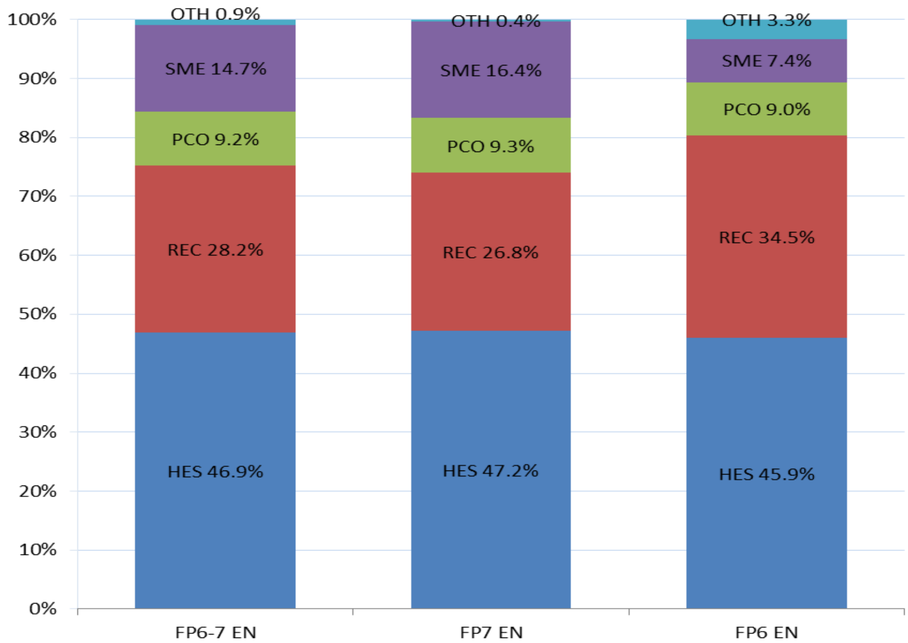

Figure 2-2: Shares of EC contribution by organisation type for nanotechnology and energy

The proportion of funding going to organisations in the higher education sector (47%) is nearly the same than that corresponding to their share of nanotechnology funding (47.5%), and higher than

[39] 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.

their share for FP funding overall (41.8%). For research organisations, their share drops from FP6 (34.5%) to FP7 (26.8%) and the proportion going to SMEs rises (from 7.4% to 16.4%). Overall, the participant types are rather aligned with those of NT and FP, the only difference being a slightly higher share of funding going to SMEs and slightly lower share of funding received by other organisations.

2.2.4 Activity by organisations receiving funding

The organisations receiving the largest amounts of funding for energy nanotechnology activities were the Fraunhofer-Gesellschaft[40] (DE) (EUR 22 million for 32 projects); the CEA[41] (FR) (EUR 17 million for 29 projects); the University of Cambridge (UK) (EUR 16.2 million for 21 projects) and the CNRS[42] (FR) (EUR 15.7 million for 39 projects).

All of the top 25 recipients are research organisations (10) or from the higher education sector (15). The top ten are from Germany, France, the UK, Switzerland, Italy, the Netherlands and Spain. Some organisations appear within the top ranks of European institutions for both publications and projects in energy nanotechnology, for example, the University of Cambridge (UK), EPFL (CH), Imperial College (UK) and the University of Oxford (UK). Others, such as the CNRS and CEA (FR) are stronger in projects and patent outputs (see later section of this report) but do not rank in the European top 25 for publications.

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40 Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de

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

42 Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr

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

	Energy - Top participants	Country	No. of Projects	EC Funding (MEUR)	Share of Energy Funding
1	Fraunhofer[43]	DE	32	21.99	3.01%
2	CEA[44]	FR	29	17.00	2.33%
3	University of Cambridge	UK	21	16.16	2.21%
4	CNRS[45]	FR	39	15.73	2.15%
5	EPFL[46]	CH	24	13.82	1.89%
6	CNR[47]	IT	34	13.47	1.84%
7	Technical University Delft	NL	16	9.41	1.29%
8	CSIC[48]	ES	25	9.34	1.28%
9	Imperial College London	UK	20	8.15	1.12%
10	Max Planck[49]	DE	17	7.97	1.09%
11	University of Oxford	UK	17	7.92	1.08%
12	FAU[50]	DE	8	7.60	1.04%
13	TNO[51]	NL	10	7.28	1.00%
14	EMPA[52]	CH	14	6.73	0.92%
15	Ludwig Maximilian University Munich	DE	6	6.62	0.91%
16	Lund University	SE	8	6.58	0.90%
17	ECN (Energy Research Centre of the Netherlands)[53]	NL	8	6.49	0.89%
18	IMEC[54]	BE	11	6.49	0.89%
19	Weizmann Institute of Science	IL	6	5.75	0.79%
20	Technical University of Denmark	DK	17	5.60	0.77%
21	ETH Zurich	CH	9	5.28	0.72%
22	Technion Israel Institute of Technology	IL	11	5.10	0.70%
23	Forschungszentrum Jülich[55]	DE	10	5.05	0.69%
24	Fraunhofer[56]	DE	32	21.99	3.01%
25	CEA[57]	FR	29	17.00	2.33%

[43] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[44] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[45] Centre National de la Recherche Scientifique, the National Centre for Scientific Research www.cnrs.fr
[46] École Polytechnique Fédérale de Lausanne, the Swiss Federal Institute of Technology in Lausanne www.epfl.ch
[47] Consiglio Nazionale Delle Ricerche, the Italian National Research Council www.cnr.it
[48] Consejo Superior de Investigaciones Cientificas, the Spanish National Research Council www.csic.es
[49] Max-Planck-Gesellschaft, the Max Planck Society www.mpg.de
[50] Friedrich-Alexander-Universität Erlangen-Nürnberg www.fau.eu
[51] Nederlandse organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek, Netherlands Organisation for Applied Scientific Research www.tno.nl
[52] Eidgenössische Materialprüfungs- und Forschungsanstalt, Swiss Federal Laboratories for Materials Science and Technology www.empa.ch
[53] Stichting Energieonderzoek Centrum Nederland www.ecn.nl
[54] Interuniversitair Micro-Elektronica Centrum Vzw, www.imec.be
[55] This is a member of the Helmholtz Alliance (Helmholtz-Gesellschaft)
[56] Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. www.fraunhofer.de
[57] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr

The table below indicates the most active companies in FP energy nanotechnology projects by funding: ten out of the first 25 are SMEs, five out of the first ten.

The UK company Johnson Matthey Plc. is the most active company in terms of funding (EUR 2.3 million) followed by two SMEs, BioGasol APS in Denmark (EUR 2.09 million) and B.T.G. (Biomass Technology Group BV) in the Netherlands (EUR 1.85 million). A Swiss SME, Solaronix SA, appears as the most active (in terms of the number of energy NT projects), participating in seven projects in total.

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

	Energy - Top Company Participants	Country	SME	No. of Projects FP6-7	EC Funding (MEUR)
1	Johnson Matthey Plc.	UK		6	2.30
2	BioGasol APS	DK	SME	1	2.09
3	B.T.G. Biomass Technology Group BV	NL	SME	2	1.85
4	Airbus Defence and Space GmbH	DE		5	1.80
5	Aixtron SE	DE		5	1.79
6	STMicroelectronics SRL	IT		5	1.75
7	Flisom AG	CH	SME	3	1.75
8	Beneq OY	FI	SME	3	1.73
9	CVD Technologies Limited	UK	SME	3	1.69
10	Siemens Aktiengesellschaft	DE		4	1.58
11	Cidete Ingenieros Sl	ES	SME	6	1.54
12	Philips Electronics Nederland B.V.	NL		2	1.51
13	NPL Management Limited	UK		5	1.45
14	Solaronix SA	CH	SME	7	1.45
15	Infineon Technologies AG	DE		2	1.36
16	Umicore	BE		2	1.34
17	BASF SE	DE		4	1.32
18	NSM Norbert Schläfli Maschinen AG	CH	SME	2	1.29
19	Acciona Infraestructuras S.A.	ES		3	1.28
20	Mbn Nanomaterialia S.p.A.	IT	SME	2	1.19
21	Infineon Technologies Austria AG	AT		3	1.18
22	Arkema France SA	FR		3	1.12
23	Nexcis	FR		1	1.12
24	Borregaard Industries Limited	UK		1	1.11
25	European Thermodynamics Limited	UK	SME	2	1.10

2.2.5 Participation by country

In total, 51 countries took part in energy 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 2-8: Top fifteen countries for FP participation ranked by funding received

Rank	Country	Energy NT funding (MEUR)	% of funding
1	DE	133.8	18.3%
2	UK	112.1	15.4%
3	FR	66.5	9.1%
4	IT	65.4	9.0%
5	ES	64.1	8.8%
6	NL	52.8	7.2%
7	CH	43.0	5.9%
8	SE	26.0	3.6%
9	BE	25.9	3.5%
10	DK	19.7	2.7%
11	IL	18.8	2.6%
12	FI	15.1	2.1%
13	IE	14.1	1.9%
14	AT	11.3	1.6%
15	GR[58]	10.4	1.4%
	Total	**679**	**93%**

The top six countries accounted for more than two-thirds of the total EC funding for energy nanotechnology projects. The same six countries, in almost the same order, head the ranking for nanotechnology projects and for FP projects overall, as seen in the table below. The list is topped by Germany with a share of 18.3%, followed by the UK (15.4%), France (9.1%), Italy (9%), Spain (8.8%) and the Netherlands (7.2%).

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

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

	FP Total			Nanotechnology			Energy and Nanotechnology		
	MEUR	**Rank**	**Share of FP**	**MEUR**	**Rank**	**Share of NT**	**MEUR**	**Rank**	**Share of EN**
DE	10,164.1	1	16.5%	1,121.5	1	17.6%	133.8	1	18.3%
UK	9,295.2	2	15.1%	845.9	2	13.3%	112.1	2	15.4%
FR	7,319.3	3	11.9%	760.9	3	12.0%	66.5	3	9.1%
IT	5,046.5	4	8.2%	505.2	4	7.9%	65.4	4	9.0%
ES	4,200.6	6	6.8%	481.0	5	7.0%	64.1	5	8.8%
NL	4,438.4	5	7.2%	444.3	6	7.6%	52.8	6	7.2%
CH	2,503.2	8	4.1%	338.0	7	5.3%	43.0	7	5.9%
SE	2,386.7	9	3.9%	271.6	8	4.3%	26.0	8	3.6%
BE	2,518.0	7	4.1%	258.4	9	4.1%	25.9	9	3.5%
DK	1,451.8	11	2.4%	143.6	12	2.2%	19.7	10	2.7%
TOTAL	**49,323.8**		**80.1%**	**5,170.4**		**81.3%**	**609.3**		**83.4%**

58 Greece, also indicated by EL. This document uses ISO 2-letter codes with Greece designated as GR.

The figure below shows the ranking of countries participating in energy nanotechnology projects. In most cases, the share of funding for energy nanotechnology projects is higher than the shares for both nanotechnology projects and FP projects as a whole. The exception to this is France, where this share is significantly lower: 9% of funding for energy NT projects, 12% for NT projects and 12% for FP projects in general. Switzerland (ranked 7th) is significantly more active in nanotechnology and energy than in nanotechnology, and more active in nanotechnology than in FP projects in general (as measured by funding received).

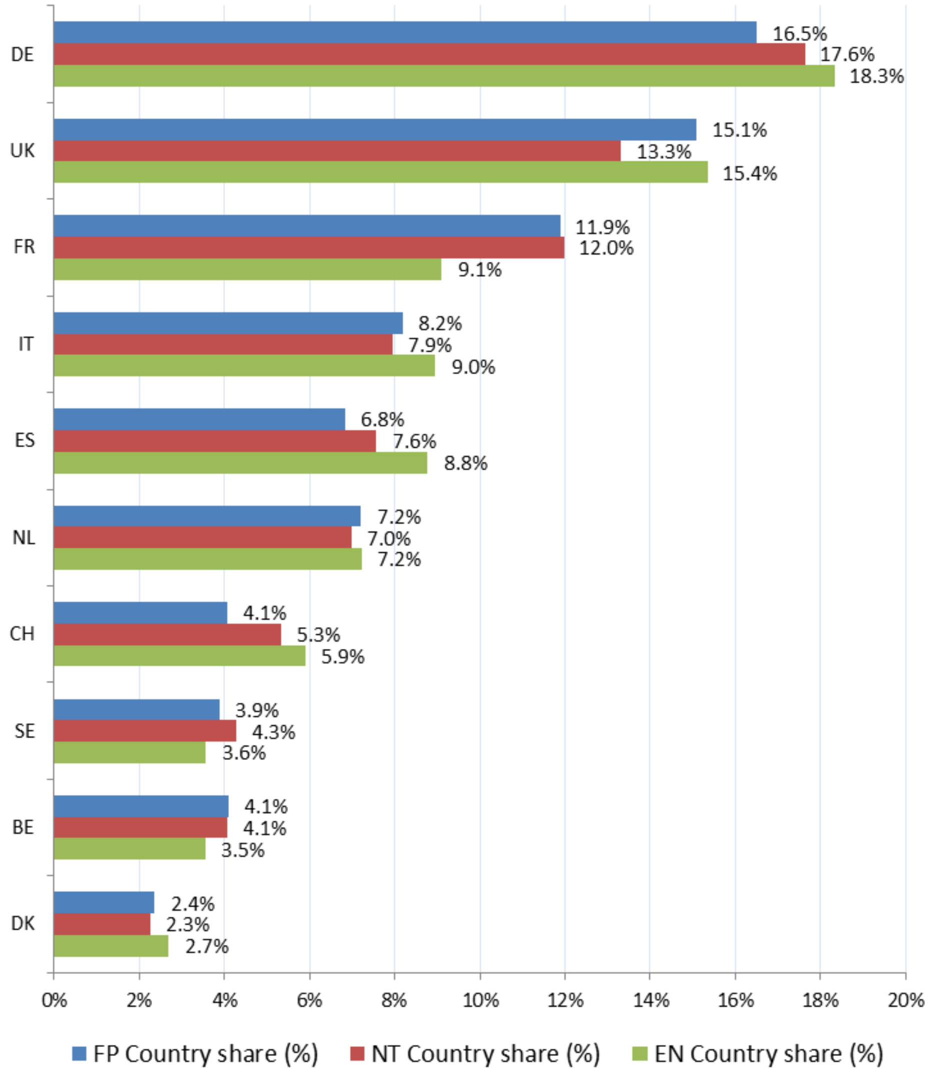

Figure 2-3: Percentage shares of FP funding by country in FP, NT and energy nanotechnology

In the figure below (the EC funding for energy nanotechnology projects in FP6 and FP7 (bars) and the country shares (points or diamonds), four countries have significantly increased their share of funding for energy nanotechnology projects from FP6 to FP7. These are Germany (15.2% in FP6 and 19% in FP7), the UK (13.8% in FP6 and 15.7% in FP7), Spain (7.5% in FP6 and 9.1% in FP7) and Switzerland (4.2% in FP6 and 6.3% in FP7). However, for France, Italy and Belgium the share of funding has decreased from FP6 to FP7 (an average 3% reduction). For the rest of the countries (the Netherlands, Sweden and Denmark) the funding shares remained largely unchanged between FP6 and FP7.

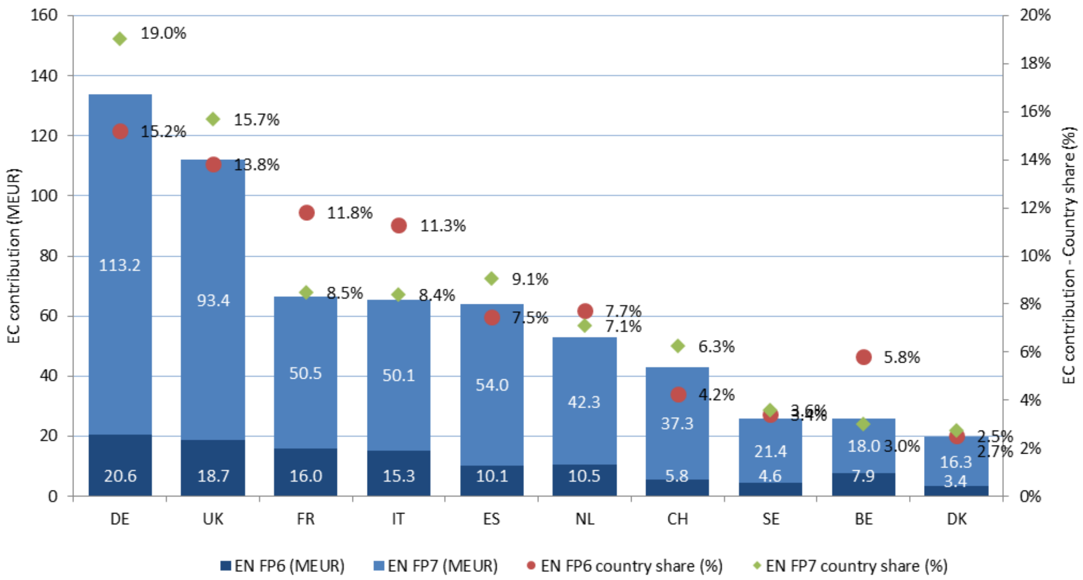

Figure 2-4: EC funding for energy NT activities in FP6 and FP7 in MEUR and country shares

2.2.6 Energy nanotechnology by sub-sector

The four energy sub-sectors under consideration in this report are solar energy (SO), energy storage (ST) (including batteries and capacitors), Hydrogen (HY) and Alternatives (AL) (including wave, wind and biomass). In addition, a fifth category called "Other" includes nanotechnology and generic energy related projects not directly associated with any of the sub-sectors. The following table shows the number of projects, funding in millions of euro and share of funding.

Table 2-10: Energy nanotechnology project funding by sub-sector and FP programme

	Number of projects			EC funding (MEUR)			Share of EC funding (%)		
	Total	FP7	FP6	Total	FP7	FP6	Total	FP7	FP6
Solar	200.3	174.8	25.5	347.2	288.2	59.0	47.5%	48.5%	43.4%
Storage	68.8	55.8	13.0	138.0	104.0	34.0	18.9%	17.5%	25.0%
Hydrogen	33.3	25.8	7.5	53.7	32.9	20.8	7.3%	5.5%	15.3%
Alternatives	32.5	29.5	3.0	86.2	82.0	4.2	11.8%	13.8%	3.1%
Other	54.0	46.0	8.0	105.4	87.6	17.8	14.4%	14.7%	13.1%

Projects related to nanotechnology and solar energy (SO) formed the largest sub-sector (200 projects, EUR 347 million, 48% of EN funding). The second largest sub-sector was storage (ST) (69 projects, EUR 138 million, 19%). Alternatives (AL) and Hydrogen (HY) both had 33 projects. AL captured 12% of funding (EUR 86 million) and Hydrogen 7% (EUR 54 million). The sub-sector had 54 projects and EUR 105 million (14%).

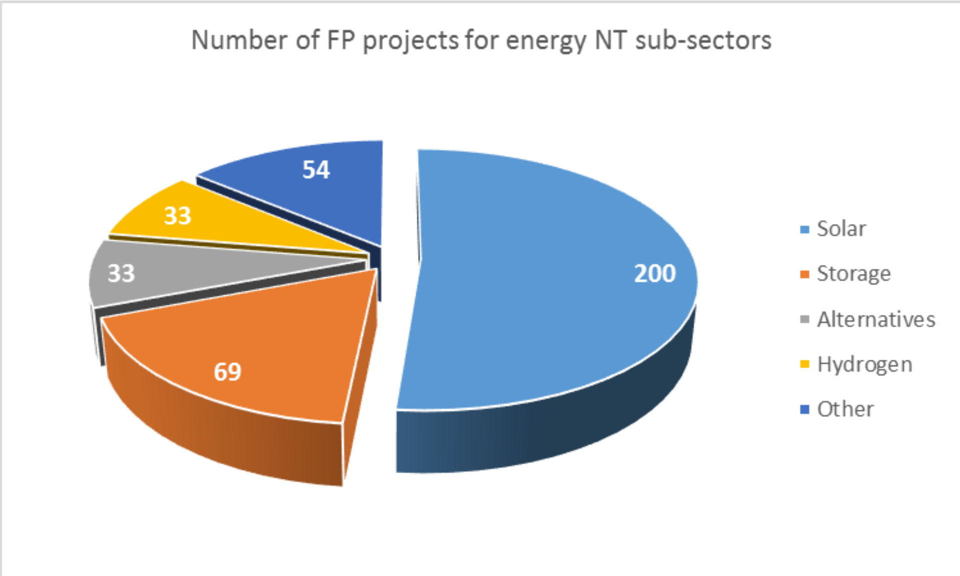

Figure 2-5: Number of energy nanotechnology projects by sub-sector

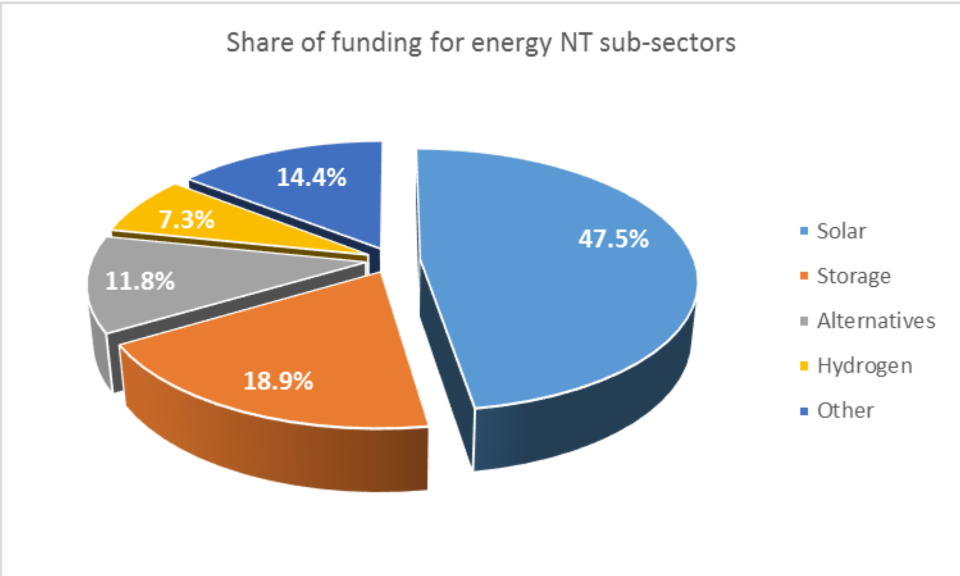

Figure 2-6: Share of funding of energy nanotechnology projects by sub-sector

The main messages that can be drawn from the comparison of NT energy sub-sectors are the following:

- In the largest of the sub-sectors, solar energy, 57% of the projects were collaborative RTD actions. Approximately half (49%) of the EC contribution was received by higher education sector. Germany (18%), the UK (17%) and Spain (9%) were the countries that received most of the funding dedicated to NT solar energy.
- Nanotechnology and Hydrogen is the energy sub-sector most focused on basic research. The activities carried out in HY projects were less focused on collaborative RTD and the organisations from research sector (higher education and research organisations) received over 80% of the EC funding dedicated to HY projects. The UK was the country that received most of the HY EC funding (24%) followed by Germany (20%) and Italy (8%).
- Nanotechnology and energy storage is the sub-sector in which the higher education sector received the lowest share of funding of nanotechnology and energy funding (42%) and in which large companies received the highest share of funding (11%). Storage is also the sub-sector in which the projects are most focused on adoption and innovation. The countries that received

most of the funding in nanotechnology and energy storage were Germany (21%), France (14%) and the UK (13%).

- The sub-sector dealing with nanotechnology and alternative energies is very focused on collaborative RTD (78% of the AL funding). It is also the sub-sector in which the companies (large companies and SMEs together) receive the highest share of funding (close to 30%). Germany (18%), the UK (14%) and Denmark (9%) are the countries that receive most funding in nanotechnology and alternative energies.

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

2.3 Other EU policies and programmes

2.3.1 EU policies and programmes: Industry

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

The Strategic Energy Technology Plan (SET-Plan), adopted by the European Union in 2008, was an initial step in establishing an energy technology policy for Europe. The principal decision-making support tool for European energy policy, it has goals of: accelerating knowledge development, technology transfer and up-take; maintaining EU industrial leadership on low-carbon energy technologies; fostering science for transforming energy technologies to achieve the 2020 energy and climate change goals; and contributing to the worldwide transition to a low carbon economy by 2050[59].

In 2008, the Commission proposed to launch six European Industrial Initiatives (EIIs)[60]: wind; solar (both concentrated solar and photovoltaic); carbon capture and storage; electricity grids; bioenergy; and nuclear fission. EIIs are joint large-scale technology development projects between academia, research and industry. The goal of the EIIs is to focus and align the efforts of the EC, Member States and industry in order to achieve common goals and to create a critical mass of activities and actors, thereby strengthening industrial energy research and innovation on the energy-related technologies that are most valuable for the European Union. In parallel, the European Energy Research Alliance (EERA)[61] has been working since 2008 to align the R&D activities of individual research organisations to the needs of the SET-Plan priorities, and to establish a joint programming framework at EU level.

Furthermore, in 2012, following the development of SET plan, industry and leading research organisations launched the Energy Materials Industrial Research Initiative (EMIRI), focused on advanced materials for low carbon energy and energy efficiency technologies. With more than 50 members across Europe, EMIRI is working across "the full Europe-based value chain from the lab (research and innovation on advanced materials) to the end-market development of various low carbon energy and energy efficiency technologies through the development of strategic elements for the competitive manufacturing of advanced materials and derived products"[62].

Research by companies in the EU is also supported through the EUREKA Eurostars[63] 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, 3 relate to nanotechnology and others to energy, including energy technologies, unconventional and alternative energies, energy management,

59 http://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan
60 https://setis.ec.europa.eu/activities/initiatives
61 http://www.eera-set.eu/
62 https://emiri.eu/about
63 https://www.eurostars-eureka.eu/

energy production, transmission and conversion, generators and electric engines, hydropower, renewable sources of energy and rational use of energy.

Another type of mechanism 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 energy, environment, ICT, production and processes, transport and the bio-based economy.

While one ETP (EuMaT) sits under the theme of Production and Processes, the other three belong to the theme of Energy.

- EuMaT – the European Technology Platform for Advanced Engineering Materials and Technologies - was launched in 2006 to assure optimal involvement of industry and other important stakeholders in the process of establishing of R&D priorities in the area of advanced engineering materials and technologies.
- The European Photovoltaic Technology Platform started in 2003 and currently has 1,700 members including 1,300 SMEs, 230 large companies, 120 research institutes, 20 associations and 30 governmental bodies. The interlinked goals of this European initiative are to mobilise all the actors sharing a long-term European vision for photovoltaics to realise the European Strategic Research Agenda for PV for the next decade(s) and to give recommendations for its implementation, and to ensure that Europe maintains industrial leadership in the area.
- The European Technology Platform on Renewable Heating & Cooling (RHC-Platform) was launched in 2009 and brings together stakeholders from the biomass, geothermal and solar thermal sector - including related industries - to define a common strategy for increasing the use of renewable energy technologies for heating and cooling. Building on the experience matured since 2005 within the European Solar Thermal Technology Platform (ESTTP) which was incorporated in the RHC-Platform, four major European organisations – EUREC[64], AEBIOM[65], EGEC[66] and ESTIF[67] – are leading the process towards the definition of a joint vision and strategic research agenda for the renewable heating and cooling sector.
- The European Wind Energy Technology Platform (TPWind) set up in 2006, has 150 wind energy expert members divided into different working groups. The objective of TPWind is to identify areas for increased innovation, and new and existing research and development tasks. TPWind also hosts the European Wind Initiative (EWI), a long-term, large-scale programme to improve and increase funding to EU wind energy R&D. The EWI has a budget of EUR 6 billion (of combined public and private resources) for the 2010 - 2020 period.

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[68]. The JTI FHC 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.

[64] The Association of European Renewable Energy Research Centres http://www.eurec.be/en/
[65] The European Biomass Association http://www.aebiom.org/
[66] The European Geothermal Energy Council http://egec.info/about/
[67] The European Solar Thermal Industry Federation http://www.estif.org/
[68] http://era.gv.at/directory/142

The Bio-Based Industries[69] (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 on developing bio-refining 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). Several are operating in the energy sector, for instance the one on energy-efficient buildings (EeB), green vehicles (EGVI) and Sustainable Process Industry (SPIRE).

- The cPPP on Energy-efficient Buildings within H2020 (originally launched as a PPP in 2008 under the European Economic Recovery Plan) aims "to develop affordable breakthrough technologies and solutions at building and district scale, facilitating the road towards future smart cities"[70]. The multiannual roadmap 2014-2020 proposes research and innovation priorities including the delivery of technologies needed for the new sustainable and competitive European construction industry.
- The European Green Vehicles Initiative (EGVI) is the continuation of the European Green Cars Initiative (2009-2013) under FP7. 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 coordinated 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)[71].

Under H2020, there is also the new cPPP on Sustainable Process Industry through Resource and Energy Efficiency (SPIRE). SPIRE encompasses eight sectors (cement, ceramics, chemicals, engineering, minerals and ore, non-ferrous metals, steel and water) that include more than 450,000 individual enterprises, provide jobs for 6.8 million employees and generate annually more than EUR 1,600 billion in turnover. Its purpose is to support the research and innovation activities "to lead to the breakthrough technologies needed to make the European process industry more sustainable and competitive, through improvements in resource and energy efficiency"[72].

2.3.2 EU policies and programmes: Energy

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.

In 2010, the European 2020 Energy Strategy[73] defined European energy goals to 2020, linking those goals closely to emissions by specifying that energy-related emissions account for almost 80% of the EU's total greenhouse gas emissions. 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%.

By 2010, nearly 45% of European electricity generation (and by 2013, 25% of its primary production of energy) was based on low-carbon energy sources, mainly nuclear and hydropower. However, many of those installations were then already coming to the end of their useful lifetimes, with the associated loss of over one third of generation capacity by 2020 in some parts of the EU. Replacing

[69] http://www.bbi-europe.eu
[70] https://ec.europa.eu/research/industrial_technologies/energy-efficient-buildings_en.html
[71] http://ec.europa.eu/research/press/2013/pdf/ppp/egvi_factsheet.pdf
[72] https://ec.europa.eu/research/industrial_technologies/sustainable-process-industry_en.html
[73] https://ec.europa.eu/energy/en/topics/energy-strategy/2020-energy-strategy

and expanding existing capacities offers an opportunity as well as a challenge - an opportunity to put in place systems with more technologically-advanced processes and materials, to introduce non-fossil fuel alternatives and cleaner energy sources, to adapt networks to renewable energy sources, and to improve storage facilities and transmission lines – in all of which nanotechnology could play a role - as well as phasing out financial subsidies that are potentially environmentally-harmful and establishing an integrated European energy market.

2.3.3 EU policies and programmes: European Institute of Innovation and Technology

The European Institute of Innovation and Technology (EIT)[74] 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.

KIC InnoEnergy was one of the first Knowledge and Innovation Communities (KICs) supported by the EIT. KIC InnoEnergy is a European company fostering the integration of education, technology, business and entrepreneurship and strengthening the culture of innovation. It addresses sustainable energy as its priority area and is a European alliance of 27 shareholders and an additional 100+ partners including companies, research institutes, universities and business schools.

2.3.4 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.

2.3.5 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) [75] 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

[74] 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/

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

region, 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 energy.

3 POLICIES AND PROGRAMMES IN MEMBER STATES FOR NANOTECHNOLOGY AND ENERGY

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

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

Austria: The Austrian NanoInitiative[76] (2004-2011, total funding EUR 70 million, administered by the Austrian Research Promotion Agency (FFG)). The initiative works on a collaborative basis across Austria and trans-nationally with consortia of research institutes, universities and firms working on problem-driven basic research questions with a medium-term perspective (5-7 years). The focus of the programme, matching the remit of its funding agency FFG, has been to invest in projects with considerable market potential and relevant to Austrian companies. NANO aimed to address the following issues: *What is the best way for Austria to harness the opportunities in nanotechnology, for instance for the sake of environmental and energy technology, new resource-saving products or for small- or medium-sized enterprises?* The type of activities begun under the programme are now continuing under the thematic areas FFG's research funding programmes. For example, since 2012, nanotechnology is supported, *inter alia*, via FFG's thematic research funding for *Production of the Future*.

France: The French Agence National de la Recherche (ANR) channels public funding into priority areas including Nanotechnologies and Manufacturing. Since 2006, the P2N programme[77] aims to strengthen national excellence in the areas of micro and nano-engineering (ranging from core technologies to systems), and speed up technology transfer to French firms in order to exploit the potential of the nanotechnologies. P2N also addresses nanotechnologies for sustainable development. Complementary to P2N, the Sustainable Electricity Production and Management (PROGELEC) programme aims to accelerate French research for the development of renewable energies 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 2011, the German Ministry for Education and Research (BMBF) published the Action Plan Nanotechnology 2015 outlining the strategy for responsible development, innovation and public dialogue on nanotechnology for the period 2010-2015. The plan included proposals for developing nanotechnology in five main areas including energy. In parallel, there are the Innovation Alliances, providing funding for strategic co-operation between industry and public research in key technology areas that demand a large amount of resources and a long time horizon, but promise considerable innovation and economic impacts. Public funds and funding from industry is combined in a typical proportion of 1:5 (public: private). Among the (currently) nine innovation alliances, two target the energy sector: the innovation alliance for organic photovoltaics for the use of renewable energy and the innovation alliance on lithium-ion batteries for the storage of energy.

The Netherlands: NanoNed (2004 – 2010, total funding of EUR 235 Million administered by the Dutch Ministry for Economic Affairs), the Nanotechnology R&D initiative in the Netherlands, has clustered the Dutch expertise on nanotechnology and enabling technology into a national network. The NanoNed programme was organised into eleven independent programmes, or flagships, amongst these being energy. In 2011, NanoNed was followed by NanoNextNL[78], a consortium of more than a hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities. Stakeholders collaborate on fundamental as well as applied research through research projects. NanoNextNL is expected to grow into an open-innovation ecosystem, with new partners joining the consortium. Industry has committed to continue its support for

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

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

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

NanoNextNL after 2015. NanoNextNL has a theme dedicated to energy that contains the programmes on: a) efficient generation of sustainable energy (high-performance solar cells and advanced light management); and b) efficient energy utilisation by secondary conversion of energy and separation).

In addition, innovation in the Netherlands is organised under the *Top Sector Policy*[79] announced in 2010. Businesses, researchers and government work closely together in *Top consortiums for Knowledge and Innovation* (TKIs). The only policy objective that has been set specifically for the top sector policy is that public and private parties should participate in the TKIs for an amount of at least €500 million by 2015, 40% of which should be financed by trade and industry. The formal objective set for the top sector policy is that it should contribute to "a stronger innovative capacity in the Dutch economy." i.e. that the Netherlands will be ranked among the top five knowledge economies worldwide by 2020 and will spend 2.5% of GDP on R&D by 2020.

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

Portugal: The International Iberian Nanotechnology Laboratory[80] (INL) was established as the result of a joint decision of the Governments of Portugal and Spain, in November, 2005. With a total investment of EUR 46.5 million (of which EUR 30 million came from the European Regional Development Fund, "Spain – Portugal" Operational Programme, 2007-2013), INL is an international research organisation in the field of nanoscience and nanotechnology. Established as an Intergovernmental Organisation (IGRO), the INL is developing itself into a state-of the art research environment (including nanofabrication facilities) for materials science at nanoscale (the most relevant to energy at present), nano-electronics, nano-biotechnology and nanomedicine. In addition to being a facility for researchers in Portugal and Spain, it hosts those from non-EU countries such as Brazil.

Spain: The Sixth National Scientific Research, Development and Technological Innovation Plan (2008-2011) included the Strategic Action for Nanoscience and Nanotechnology, New Materials and New Industrial Processes (SANSNT), which addressed seven priorities, among these being 'knowledge-based intelligent materials with advanced material architectures for energy conversion', including new products that increase efficiency in obtaining solar energy (photovoltaic, thermal, etc.).

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

The United Kingdom (UK): 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).

The UK Enabling Technologies Strategy 2012-2015[81] also addressed four enabling technologies - advanced materials; biosciences; electronics, sensors and photonics; and information and communication technology (ICT) to support business in developing high-value products and services in areas such as energy, food, healthcare, transport and the built environment. Nanotechnology is identified as having a significant underpinning role across most of these technology areas, particularly in the health-care and life sciences sectors.

[79] http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/smart-industry
[80] http://inl.int/
[81] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015

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 in areas including those relevant to energy (e.g. nanomaterials and devices). For example:

- From France, the web site of Campus France[82] states:
  "With more than 5,300 researchers and 240 laboratories working in the nanosciences and nanotechnologies, French institutions are engaged in a great many nano-research projects in the broad fields of electronics, communications, materials, energy, biotechnologies, pharmacology, medicine, health, and the environment. [….] With the research infrastructure built since the 1990s, France is one of the leaders in basic research in the nanosciences. The country ranks second in Europe, after Germany, in the amount invested in nanoscience research, and fifth in the world in number of publications in the field."

- On the German Trade and Invest Agency[83] website provides the information that:
  "Approximately half of the nanotechnology companies in Europe are from Germany; the country is number one in Europe in the nanotechnology industry. German companies manufacture products in the areas of nanomaterials, nanotools, nanoanalytics, and nanotools accessories (e.g. vacuum and cleanroom technology, plasma sources, etc.). They also manufacture and utilise nano-optimised components and systems, and they provide services in the areas of consulting, contract coating, technology transfer, and commissioned analysis and research …"

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

[82] http://ressources.campusfrance.org/catalogues_recherche/recherche/en/rech_nano_en.pdf
[83] http://www.gtai.de/

Table 3-1: Member State policies and programmes for nanotechnology

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
AT	Austrian NANO Initiative[84] (NANO)	2004-2011	Directly Targeting NT	Multiannual, funding collaborative R&D, co-ordinating NANO-related policy measures at national and regional levels. Since 2012, NT is supported via FFG's thematic research funding e.g. Production of the Future	IND SME HEI PRO	FFG	70 over 8 years
AT	------	From 2012	Thematic, not NT Specific	Since 2012, NT R&D is being supported via FFG's thematic research funding e.g. Production of the Future	All	FFG	450 for all disciplines (over the preceding 4 years when funding was managed by BMVIT)
ES	Strategic Action of Nano Science, Nano technologies, new materials and new industrial processes	2008-2011	Directly Targeting NT	To enhance the competitiveness of industry by generating new knowledge and applications based on the convergence of new technologies, where nanotechnology plays a central role.	IND SME HEI PRO	Ministry	33 over 4 years
FI	FinNano[85]	2005-2009	Directly Targeting NT	Multiannual funding for nano S&T to study, exploit and commercialise nano.	IND SME HEI PRO	Tekes	70 over 5 years
FR	PNANO P2N	2002-5 2006 -13	Directly Targeting NT	R&D on • Nanotechnologies, Nanodevices, Micro-Nanosystems • Simulation and Modelling of Nanosystems • Nanotechnologies for Biology, Health and Agro-food • Nanotechnologies for Energy and Environment • Integrative Research Projects for Nanosystems	IND SME HEI PRO and Individuals	ANR[86]	139.8 for P2N over 8 years
FR	Investissements d'avenir	From 2011	Generic	Excellence initiatives including nanobiotechnology and bioinformatics	IND SME PRO	ANR	12 per annum
DE	Nanotechnology Conquers Markets	2004-2006	Directly Targeting NT	Five leading-edge innovation programmes	All	BMBF	24 over 3 years
DE	Nano Initiative – Action Plan	2006-2010	Directly Targeting NT	Cross-departmental initiative led by BMBF: to speed up the use of the results of nanotechnological research for innovations; introduce nanotechnology to more sectors and companies; eliminate obstacles to innovation by means of early consultation in all policy areas; and enable an intensive dialogue with 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	All	BMBF	500 over 6 years

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

Country	Name of Initiative	Dates	Relevance	Description	Target Groups	Implementing Body	Budget (EUR millions)
				private funds are combined in a 1:5 ratio.			
NL	NanoNed	2004-2011	Directly Targeting NT	NanoNed was organised into eleven independent flagships based on regional R&D strength and industrial relevance, including energy.	IND SME HEI PRO and Individuals	Dutch Ministry for the Economy	235 over 8 years
NL	NanoNextNL	2011-2015	Directly Targeting NT	Consortium-based system (over one hundred companies, nine knowledge intensive institutes, six academic medical centres and thirteen universities). Stakeholders collaborate on fundamental and applied research projects.	IND SME HEI PRO and Individuals	Dutch Ministry for the Economy	125 over 5 years
NL	Top sectors	2010 to date	Directly Targeting NT	The Top Sector Policy involves government support in nine key economic areas (the top sectors) through a combination of generic (i.e. financial) instruments and a focused emphasis on achieving optimum cooperation in the „golden triangle" formed by companies, research institutions and government. Top sector technologies in materials, electronics/optics and sensors, etc. are used for applications like energy, health and water. The policy works through Top Consortia for Knowledge and Innovation (TKIs).	IND SME HEI PRO	Dutch Ministry for the Economy	Objective for public and private sector to participate in the Top Consortia for Knowledge and Innovation (TKIs) for an amount of at least EUR 500 million by 2015, 40% of which from trade and industry.
PT	International Iberian Nanotechnology Laboratory	2005 to date	Directly Targeting NT	International research organisation in the field of nanoscience and nanotechnology, the result of a joint decision of the Governments of Portugal and Spain. Becoming a state-of the art research environment (including nanofabrication facilities) for nano-biotechnology, nano-electronics, nanomedicine and materials science at nanoscale. INL hosts researchers from the EU and non-EU countries including Brazil.	IND SME HEI	Governments of Portugal and Spain	46.5 (of which 30 from ERDF Spain – Portugal" Operational Programme) over 7 years
UK	Micro and Nanotechnology Manufacturing Initiative[87]	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	

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

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

4 POLICIES AND PROGRAMMES IN OTHER COUNTRIES[88]

4.1 Europe

4.1.1 Non-EU Member States

4.1.1.1 Norway

From 2002 to 2011, Norway addressed nanotechnology through its Programme on Nanotechnology and New Materials (NANOMAT)[89], 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)[90]. Managed by the Research Council of Norway[91], this large-scale programme covers research on nanoscience, nanotechnology, micro-technology and advanced materials. The programme is designed to further raise the level internationally of the Norwegian knowledge base in nanotechnology and advanced materials. NANO2021 receives funding from the Ministry of Education and Research and the Ministry of Trade and Industry. The annual budget in the period 2013-2021 has been set at NOK 92.1 million (EUR 10 million at the current exchange rate, October 2015)[92].

Within the thematic priority areas NANO2021 there is one in particular that addresses nanoscience, nanotechnology, micro-technology and advanced materials applied to the energy arena[93].

4.1.1.2 The Russian Federation

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

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

RUSNANO now combines an open joint-stock company and a Fund for Infrastructure and Educational Programmes (FIEP). It had capital funding in 2008-2009 of over USD 4 billion (EUR 2.8 billion[94]) but this dropped to USD 2.6 billion (EUR 1.9 billion[95]) by the end of 2010, falling further thereafter. A gradual privatisation of RUSNANO began in 2011. The mission of RUSNANO is to grow the national nanotechnology industry through the commercialisation of nanotechnology and the co-ordination of nanotechnology-related innovation. It acts as a co-investor in nanotechnology projects having substantial economic or social potential.

RUSNANO has a very wide range of activities spanning from research to foresight to infrastructure,

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[88] 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)

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

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

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

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

[93] Ibid

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

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

education, standards and certification. Its research projects fall under six clusters, some of them relevant to energy, such as the *solar energy and energy saving cluster.*

4.1.1.3 Switzerland

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

CTI funds the Swiss MNT network (micro and nanotechnology) as one of the core innovative themes of national and international importance[96]. 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[97]. 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[98], and Nano-Cluster Bodensee[99]. Most activities are strongly focused on R&D to support industry.

4.2 The Americas

4.2.1 North America

4.2.1.1 Canada

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

Alberta

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

Following the announcement in 2007 of the Government of Alberta's Nanotechnology Strategy, nanoAlberta was created as an implementation organisation for that Strategy. NanoAlberta provides leadership to and co-ordination of the Province's wide range of capabilities, organisations and individuals with the aim of gaining a return of CND 20 billion (EUR 13.4 billion[100]) in market share for nano-enabled commerce by 2020. One of the specific industries targeted is *energy and environment*.

Work at the University of Alberta on nanoscience, chemical engineering, and biochemistry has led to developments in areas as diverse as solar cell development, clean coal processing and soil remediation. In particular, the National Institute for Nanotechnology (NINT), a joint initiative between the University of Alberta, the Government of Canada, the Government of Alberta and the National Research Council (with an initial investment of CND 120 million (around EUR 86.5 million[101])) is active in the field of energy sustainability and new energy sources[102].

Quebec

NanoQuébec is a not-for-profit organisation funded by the MEIE (Ministère de l'Économie, de

[96] https://www.kti.admin.ch/kti/en/home/unsere-foerderangebote/Unternehmen/internationale-netzwerke-und-forschungskooperationen-neu/spezialthema-japan-schweiz1/foerderlandschaft-schweiz.html
[97] http://www.swissmntnetwork.ch/content/
[98] http://www.i-net.ch/nano/
[99] http://www.ncb.ch/wordpress_neu/
[100] Current conversion rates, October 2015
[101] Average yearly conversion rate, 2001(*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-cad.en.html)
[102] http://www.research.ualberta.ca/OurWork/Energy.aspx

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[103] specifically targets four priority sectors: microsystems, health, industrial materials and forestry. It covers infrastructure, financing of innovation, knowledge transfer and technology transfer, and national and international outreach horizontally across the four priority areas.

Via a central point (QNI or Quebec Nanotechnology Infrastructure), it co-ordinates and provides infrastructure for 300 experts using a fund of CND 300 million (EUR 200 million[104]). QNI has particular strengths in micro-nanofabrication, characterisation, synthesis and modelling. Other infrastructure can be accessed but is not funded via QNI.

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

4.2.1.2 The United States of America (US)

The National Nanotechnology Initiative[105] was launched in 2000 across a group of eight Federal agencies with some responsibility for nanotechnology research, application and/or regulatory activity, and has grown to include 25 Federal agencies. It aims to create collaborations and bring together expertise to work on shared goals, priorities, and strategies thereby leveraging the resources of the participating agencies. The goals of the NNI Goals are to advance world-class nanotechnology research and development; foster the transfer of new technologies into products for commercial and public benefit; develop and sustain educational resources, a skilled workforce and the supporting infrastructure and tools to advance nanotechnology; and support the responsible development of nanotechnology.

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

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

In February 2014, the National Nanotechnology Initiative released a Strategic Plan[106] 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 (all of which have relevance for energy and nanotechnology). The five

[103] http://www.nanoquebec.ca/media/plan-action_en1.pdf
[104] Current conversion rates, October 2015.
[105] http://www.nano.gov/
[106] http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf

Nanotechnology Signature Initiatives (NSIs) are also highly-relevant to energy (particularly the first one) covering:

- nanotechnology for solar energy collection and conversion (that includes improving photovoltaic solar electricity generation, improving solar thermal energy generation and conversion; and improving solar-to-fuel conversions);
- nanoelectronics for 2020 and beyond (including the energy sector as an application area);
- nanotechnology knowledge infrastructure (NKI) (related to energy as well);
- sustainable nanomanufacturing;
- nanotechnology for sensors and sensors for nanotechnology.

The 2014 NNI Strategic Plan also identifies potential challenges in which nanotechnology can play a role. The Strategy mentions the different priorities and interests of Federal agencies, for example:

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

The NNI's budget supplement proposed by the Obama administration for Fiscal Year 2015 provided for USD 1.5 billion (EUR 1.2 billion[107]) of funding. Cumulative NNI investment since fiscal year 2001, including the 2015 request, totals almost USD 21 billion (EUR 17 billion[108]). Cumulative investments in nanotechnology-related environmental, health, and safety research since 2005 is nearly USD 900 million (EUR 680 million[109]). 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, whose mission is related to measurement sciences and standards development, have areas dedicated to nanotechnology as well as to energy (having a specific portal dedicated to each of them)[110][111]. NIST provides facilities to support production, through the Centre for Nanoscale Science and Technology (CNST)[112], established in 2007. The CNST facilitates the access to commercial state-of-the-art nanoscale measurement and fabrication tools through its NanoFab. In addition, NanoLab gives the chance to researchers to collaborate through the Energy research group that develops instruments designed to reveal the nanoscale physical and chemical processes and properties critical to advances in energy conversion, transport and storage"[113]. One of the NanoLab focus areas is *energy storage, transport, and conversion* in the forms of: theory and modelling of materials for renewable energy; nanostructures for energy conversion; opto-electrical characterisation of nanostructured photovoltaic materials and devices; nanoscale functional and structural characterisation of thin-film inorganic solar cells; and nanostructured thermo-electrics.

The US Department of Energy (DoE) has established five Nanoscale Science Research Centres that provide facilities and instruments to the international academic, industry and government research community for successfully peer-reviewed research projects[114]. The centres are: Centre for Functional Nanomaterials (CFN), Centre for Integrated Nanotechnologies (CINT), Centre for

[107] Average yearly conversion rate, 2015 (*source*: www.wolframalpha.com)
[108] Average yearly conversion rate, 2001-2015 (*source*: www.wolframalpha.com)
[109] Average yearly conversion rate, 2005-2015 (*source*: www.wolframalpha.com)
[110] http://www.nist.gov/nanotechnology-portal.cfm
[111] http://www.nist.gov/energy-portal.cfm
[112] http://www.nist.gov/cnst/index.cfm
[113] http://www.nist.gov/cnst/erg/index.cfm
[114] http://science.energy.gov/bes/suf/user-facilities/nanoscale-science-research-centers/

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[115] with the main goal of conducting basic research and instrumentation development in nanotechnology linked to energy-related research and development programmes[116]. The DOE programmes *EV Everywhere* (for electric vehicles) and *SunShot* (for solar energy) are using engineered nanomaterials and nanoscale processes to collect and store energy.

Another important actor active in nanotechnology is the NSF. This federal agency, with an annual budget of USD 7.3 billion (EUR 6.8 billion[117]) (FY 2015), funds approximately 24% of all federally-supported basic research (except for medical sciences) conducted by America's colleges and universities[118]. NSF deals with energy through its Chemical, Bioengineering and Environmental and Transport Systems Division which has a programme on energy for sustainability. Current topics (many of which would address nanotechnology and energy) include: biomass conversion, biofuels & bioenergy; photovoltaic (PV) solar energy (particularly oriented to nanotechnology); advanced batteries for transportation and renewable energy storage; and wind energy[119].

The US Department of Defence contributes to nanotechnology research through its Defence Nanotechnology Research and Development programme[120]. This document is partially connected to energy-related matters for instance energy storage for navy devices and systems and thermal energy conversion.

In additional to these Federal initiatives, there exist also several policy initiatives at US State level[121]. Programmes for the promotion of nanotechnologies currently exist in 23 states. Notable examples are the Texas Emerging Technology Fund[122], the Oklahoma Nanotechnology Initiative[123], the Illinois Nanotechnology "Collaboratory"[124], and the Oregon Nanoscience and Micro-technologies Institute (ONAMI)[125]. 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.

4.2.2 South America

4.2.2.1 Argentina

A first initiative to foster nanotechnology in Argentina was established in 2003 when the national Science and Technology Secretariat started to organise research networks in the field. In 2004, the Secretariat, looked to address gaps in what being done under the National Agency for Scientific and Technological Promotion (ANPCYT, Agencia Nacional de Promoción Científica y Tecnológica[126]) 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)[127] 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

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[115] http://www.anl.gov/cnm/about-us
[116] http://www.anl.gov/cnm/group/nanophotonics
[117] Current conversion rate, November 2015 (*source*: www.wolframalpha.com)
[118] http://www.nsf.gov/about/
[119] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501026
[120] http://www.nano.gov/sites/default/files/pub_resource/dod-report_to_congress_final_1mar10.pdf
[121] http://www.nano.gov/initiatives/commercial/state-local
[122] 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.
[123] http://www.oknano.com /
[124] http://nano.illinois.edu/collaboration/index.html
[125] http://onami.us/
[126] http://www.agencia.mincyt.gob.ar/frontend/agencia/fondo/agencia
[127] http://www.fan.org.ar/en/

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)). The plan addresses six strategic sectors, including energy and environment and sustainable development. For instance, the former contains actions on solar energy, energy distribution, alternative processes for the production of biofuels from second generation, rational and efficient use of energy[128].

4.2.2.2 Brazil

Systematic policy support for nanotechnology started in 2001, when the Brazilian Ministry of Science and Technology (MCT) through the Brazilian National Research Funding Agency (Conselho Nacional de Desenvolvimento Científico e Tecnológico or "CNPq") earmarked BRL 3 million (USD 1 million) (EUR 1.12 million[129]) over four years to form Co-operative Networks of Basic and Applied Research on Nanosciences and Nanotechnologies. Four national research networks were established: semiconductors and nano-structured materials; nano-devices; molecular nanotechnologies and interfaces; and nano-biotechnology. In late 2004, a network on Nanotechnology, Society and Environment was created that was independent of the formal funding mechanisms.

Since 1999, Brazil's national plan has comprised an annual budget and a four-year strategic plan (the Plano Plurianual or PPA). In 2003, the Ministry created a special division for the general co-ordination of nanotechnology policies and programmes whose work resulted in a proposal for specific nanotechnology-related funding. That proposal was taken up in the PPA in 2004-2007, which provided for BRL 78 million (c. USD 28 million) (EUR 22 million[130]) 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[131]) to c. USD 30 million (EUR 24 million[132]) for those two years. Ten new research networks were set up to continue previous research activities but linking more closely to broader industry, technology, and trade policies. Industrial policy helped to reinforce the strategic status attributed at national level to nanotechnology and its role in enhancing Brazil's competitiveness. Of particular importance in the programmes was the development of qualified human resources, the modernisation of infrastructure and the promotion of university-industry co-operation.

In 2012, the Brazilian Ministry for Science, Technology and Innovation (MCTI) launched the SisNANO[133] initiative, enabling scientists throughout Brazil to conduct experiments at 26 "open" laboratories offering the very best equipment for research in nanotechnology. University students and staff can use the facilities free of charge – provided they submit a good research proposal – while scientists working in industry are able to access specialist equipment and expertise at highly subsidised rates. Energy is one of the strategic sectors identified in the nanotechnology area. An example relevant for the energy sector is the Brazilian Centre for Research in Energy and Materials (CNPEM)[134], located in the city of Campinas. It is a private non-profit organisation approved by the Ministry of Science, Technology and Innovation (MCTI) to manage four national laboratories

[128] http://www.argentinainnovadora2020.mincyt.gob.ar/?page_id=194
[129] Average yearly conversion rate, 2001(*source*: www.wolframalpha.com)
[130] Average yearly conversion rate, 2004-2007 (*source*: www.wolframalpha.com)
[131] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[132] Average yearly conversion rate, 2005-2006 (*source*: www.wolframalpha.com)
[133] Sistema Nacional de Laboratórios em Nanotecnologias ftp://ftp.mct.gov.br/Biblioteca/39717-SisNANO.pdf
[134] http://cnpem.br/

including the Brazilian Bioethanol Science and Technology Laboratory (CTBE) and the Brazilian Nanotechnology National Laboratory (LNNano). Other centres include the Centre of Nanotechnology for Materials and Catalysis (CENANO)[135], LMNANO (Laboratorio Multiusuario de Nanotecnologia) which is active energy and nanotechnology, and LIN that is specialised in renewable energy.

In 2013, MCTI launched the Brazilian Nanotechnology Initiative (IBN) with funding estimated to be BRL 440 million (EUR 148 million[136]) for the 2013-2014 period. The implementation of IBN was an effort to further strengthen nanotechnology in Brazil by strengthening academic and industry linkages thereby to promote the scientific and technological development of the nanotechnology sector.

4.3 Asia

4.3.1 Eastern Asia

4.3.1.1 China

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

The National High Technology Research and Development Programme (the 863[137] programme announced in 1986) focuses on key high-technology fields of relevance to China's national development, supporting research and development, strengthening technological expertise and laying the foundations for the development and growth of high technology industries. Its goals are 'promoting the development of key novel materials and advanced manufacturing technologies for raising industry competitiveness' including nanomaterials. The programme is supervised by the National Steering Group of S&T and Education, and is managed by the Ministry of Science and Technology.

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

The 1997 "National Plan on Key Basic Research and Development" together with the "National Programme on Key Basic Research Project (973 Programme)" sought to strengthen basic research in line with national strategic targets[138]. 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

[135] https://www.int.gov.br/english
[136] Average yearly conversion rate, 2013-2014(*source*: www.wolframalpha.com)
[137] 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.
[138] http://www.chinaembassy.bg/eng/dtxw/t202503.htm

publications.

Nanotechnology is given priority status under the MLP, being seen as one of the Chinese 'megaprojects' in science. Energy is one of eleven priority areas. In addition, other priority areas linked to energy are, for instance, transportation sector and urbanisation. The MLP identifies also frontier technologies related to energy, e.g. efficient energy material technology (particularly on solar cell-related materials), hydrogen and fuel cell technology and distributive energy supply technology.

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

4.3.1.2 Japan

Strategic prioritisation of nanotechnology started in Japan under the Second Science and Technology Basic Plan (STBP) 2001-2005. Among the eight priority R&D topics of national importance were energy and nanotechnology, as well as manufacturing technology and materials, 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)[139] in 2001 to JPY 97 billion (EUR 709 million[140]) in 2005.

In the subsequent STBP[141], which ran from 2006 to 2010, Japan established nanotechnology and materials as one of its four priority research fields, the others being information and communications, environmental sciences; and life sciences. Together with energy, environment, manufacturing and frontiers, these formed eight Promotion Areas. The total budget over the five years was JPY 250 trillion (EUR 200 billion)[142]. 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

[139] Average yearly conversion rate, 2001 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)
[140] Average yearly conversion rate, 2005 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)
[141] https://www.jsps.go.jp/english/e-quart/17/jsps17.pdf
[142] Average yearly conversion rate, 2006 (*source:* www.europarl.europa.eu/RegData/etudes/note/join/2007/379231/IPOL-TRAN_NT%282007%29379231_EN.pdf)

research and development without being specifically targeted.

4.3.1.3 Korea (South)

Long a topic of relevance in Korea, support for nanoscience and nanotechnology reached a new level in December 2000 with the announcement by the National Science and Technology Council (NSTC)[143] 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[144]); phase 2, 277.2 billion Won (EUR 1,541.8 million[145]).

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[146] (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)[147].

In total, 24 nanotechnology-related centres now exist in Korea. The Advanced Nanomaterials and Energy Lab, Bio-inspired Nanoenergy Materials institute, the Energy Nanomaterials Group, Nanoelectronics and Energy Device Lab are particularly relevant for the energy sector. The Korean Institute of Science and Technology (KIST)[148] has a Material and Life Science Division, covering nanotechnology, ICT and biotechnology. It has a Nanophotonics Research Centre in its Material and Life Science Division that focuses on solar cells, as well as optical devices, fibre optic devices and memory devices, using materials with various nano-structures such as quantum dots, quantum wells, nano-wires and photonic crystals[149]. In addition, by 2010, over forty universities had nanotechnology departments.

Under the Nanotechnology Development Promotion Act 2002, Korea also established in 2004 the Korean Nano Technology Research Society (KoNTRS)[150] as a mechanism for co-operation between researchers working on nanotechnology throughout the country, to develop collaborative research programmes between institutions (public and private) and to support the government in establishing appropriate national NST policies.

Korea has since continued to invest in nanotechnology, with the review by NSTC in 2006 of the first five years of its NNI leading to support continuing for an additional ten years. In this third phase of the NT Development Plan (2011-2020), there is greater focus on clean nanotechnology and overall the policy has evolved, moving away from funding fundamental research towards more application-driven actions.[151]

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[152] 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;

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

- 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)[153] 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[154]) 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[155]) each.

4.3.1.4 Taiwan (Chinese Taipei)[156]

The National Nanoscience and Nanotechnology Programme[157] was approved for a period of six years by the National Science Council (NSC) in 2002. The funding agencies include the Atomic Energy Council[158]. With a budget envelope of USD 700 million (EUR 740 million[159]) and actual expenditure estimated to be USD 625 million (EUR 486 million[160]) over 2003-2008, the programme targeted areas such as energy and environment and its aim was to foster nanotechnology research and development in research institutes, universities and private companies, achieving academic excellence and supporting commercialisation. The Academic Excellence (first theme) part of the programme includes physical, chemical and biological properties of nanostructures, nanosensors (nanoprobes), nanodevices and nanobiotechnology.

The second theme (industrialisation programme) includes nanotechnology for energy applications. Industrial applications are the remit of the Industrial Technology Research Institute (ITRI). ITRI focuses also on renewable energy, energy technologies and energy conservation technologies[161]. ITRI has 13 research laboratories and centres in areas including green energy and environment[162].

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

[153] http://www.nanotech2020.org/download/english_brochure.pdf
[154] Current exchange rate, November 2015 (*source*: www.wolframalpha.com)
[155] Current exchange rate (November 2015) (*source*: www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-krw.en.html)
[156] http://www.twnpnt.org/
[157] http://www.twnpnt.org/english/g01_int.asp
[158] http://www.facs-as.org/index.php?page=nanotechnology-program-in-taiwan
[159] Average yearly conversion rate, 2002 (*source*: www.wolframalpha.com)
[160] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2768287/
[161] https://www.itri.org.tw/eng/Content/MSGPic01/List1.aspx?SiteID=1&MmmID=620651711540203650
[162] https://www.itri.org.tw/eng/Content/Messagess/contents.aspx?SiteID=1&MmmID=617750213520253171

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

4.3.2 Southern Asia

4.3.2.1 India[163]

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[164]) in nanomaterials research and commercial development over the five-year duration of the initiative, 2002-2006. The funding was used for projects, centres of excellence, conferences, advanced courses (schools) and post-doctoral fellowships.

A capacity-building programme for nanoscience and nanotechnology (called Nano Mission)[165] was announced in 2007. It was implemented by DST with a budget of EUR 155 million over 5 years. In that time, India raised its publication output in nano-science and –technology generating about 5000 research papers and about 900 PhDs directly from Nano Mission funding. Under the programme, scientists were given access global state-of-the-art facilities in countries including Japan and Germany. The programme is also seen as having resulted in products including nano hydrogel-based eye drops, pesticide removal technology for drinking water, water filters for arsenic and fluoride removal and nano-silver-based antimicrobial textile coatings. Finally, it facilitated discussions on standards for nanotechnology at national level.

The continuation of the Nano Mission was approved by the Government in February of 2014 and EUR 91 million (INR 650 crore) were sanctioned for the time period 2012 to 2017[166]. 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)[167] has a network of 38 laboratories and other partners involving about 4600 scientists in research and development across a wide range of disciplines, including nanotechnology, and for application areas including electronics and instrumentation.
- In 2003, the CSIR launched the New Millennium Indian Technology Leadership Initiative (NMITLI) to foster public-private partnerships via grant-in-aid funding to public partners and soft loans to their industrial partners. The initiative specifically targeted nanosciences and nanotechnologies; biotechnology; energy and materials.[168]
- The CSIR's International Science and Technology Directorate (ISAD) facilitates nanotechnology

[163] 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

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

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

[166] http://timesofindia.indiatimes.com/home/science/Govt-approves-Rs-650-crore-for-Nano-mission/articleshow/30722422.cms

[167] www.csir.res.in/

[168] http://www.csir.res.in/external/heads/collaborations/NM.pdf

workshops and projects in collaboration with partners from South Africa, France, South Korea, China and Japan[169].

- The MST's Science and Engineering Research Council (SERC)[170] supports frontier and interdisciplinary research. Support for nanotechnology projects has been provided through its R&D schemes for basic science and engineering science.

Finally, with specific reference to energy, one of the centres of excellence of the Indian Association for the Cultivation of Science is on Photovoltaics and Sensor Devices[171].

4.3.2.2 Iran[172]

The Islamic Republic of Iran ranked 23rd in the world in nanotechnology in 2007, second to Korea in citations in Asia[173], but, by 2012, it had moved to 10th place[174, 175]. In 2013, Iran ranked 20th in science production in the world (Thomson Reuters) and 18th in science production for medicine. According to the Ministry, its share of global science production rose from 1.39% in 2013 to 1.69% percent in 2014, as measured by indicators including the number of scientific papers, the quality and quantity of documents, patenting inventions, industrial plans, partnership with foreign universities, and the use of technology in domestic organisations.

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

Iran began its nanotechnology activities with a Study Committee for Nanotechnology in 2001. Its work led to the development of the Iran Nanotechnology Initiative Council (INIC)[176], 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[177] (EUR 9 million[178]).

INIC has also funded the development of research and training facilities for nanotechnology research, such as the Institute for Nanoscience and Nanotechnology (INT) at the Sharif University of Technology. The INT, established in 2004, was the first institute to offer a PhD in nanotechnology in Iran[179]. 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[180].

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)[181], a body established in 2006 as a collaboration between the INIC and the Institute of Standard and Industrial Research of Iran (ISIRI)[182].

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

[169] http://www.teriin.org/div/ST_BriefingPap.pdf
[170] www.dst.gov.in/about_us/ar05-06/serc.htm
[171] http://nanomission.gov.in/
[172] See also http://www.sciencedev.net/Docs/Iran_Nano.pdf (2010)
[173] http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file11959.pdf
[174] http://statnano.com/report/s29
[175] http://www.nanotech-now.com/news.cgi?story_id=45237
[176] http://nano.ir/index.php?lang=2
[177] http://www.nanotech-now.com/news.cgi?story_id=36557
[178] Average yearly conversion rate, 2004-2010 (*source*: www.wolframalpha.com)
[179] http://blogs.scientificamerican.com/guest-blog/science-and-sanctions-nanotechnology-in-iran/
[180] http://nano.ir/index.php?ctrl=static_page&lang=2&id=397&section_id=22
[181] http://nanostandard.ir/index.php?lang=2
[182] http://www.isiri.com/

networking both within Iran and internationally; and generating economic added value from nanotechnology as a means of achieving economic development[183].

4.3.3 South-Eastern Asia

4.3.3.1 Malaysia

Priority emerging technologies, including nanotechnology and nano-biochips, nano-biosensors and photonics, were identified under Malaysia's Second National Science and Technology Policy (STP II), launched in 2003. Other products and technologies were also specified: 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)[184] 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[185] was created in 2011 as a company under the Ministry of Science, Technology and Innovation (MOSTI). It is responsible for commercialisation of nanotechnology research and development; industrialisation of nanotechnology; facilitation of investments in nanotechnology; and human capital development in nanotechnology. Also in 2011, the top-down Nanotechnology Research Grant (NanoFund) was introduced and NanoMalaysia Centres of Excellence created.

In addition, the Malaysia Institute for Innovative Nanotechnology (NanoMITe) has one of its research programme on energy (including low temperature solid-oxide fuel cells (SOFC) for power industry; flexible dye-sensitised solar cells (DSSC); and second generation catalytic pyrolysis conversion of palm oil EFB (empty fruit bunches) biomass to jet fuel).[186]

4.3.3.2 The Philippines[187]

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

4.3.3.3 Singapore

With the aim of transitioning to a knowledge-based economy, Singapore has relied, since the early 1990s, on its five-year basic plans for science and technology (S&T). Foresight and technology scanning were key components of the process by which the 2010 plan[188] was developed. Thirteen technology scanning panels were established, including one on 'Exploiting Nanotechnologies'. There were also foresight panels on energy, environmental technologies, semiconductors, broadband, information storage, manufacturing, materials and infrastructure, intelligent systems, the grid, information management, engineering science in medicine, and frontiers in chemicals.

In the 2010 strategy document, the connection is made between the S&T Plan and the Manufacturing 2018 Plan Intelligent National Plans of Singapore's Economic Development Board[189], and the Roadmap (ITR5) of the Infocomm Development Authority[190]. 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

[183] http://statnano.com/strategicplans/1
[184] http://www.mosti.gov.my/en/about-us/divisions-departments/national-nanotechnology-directorate-division-nnd/
[185] http://www.nanomalaysia.com.my/index.php?p=aboutus&c=whoweare
[186] http://nanomite.utm.my/?Research_Programmes___Energy
[187] http://www.techmonitor.net/tm/images/d/d1/10jan_feb_sf3.pdf
[188] https://www.mti.gov.sg/ResearchRoom/Pages/Science-and-Technology-Plan-2010.aspx
[189] www.edb.gov.sg
[190] www.ida.gov.sg

enable industrial clusters including environmental and engineering, ICT, electronics, precision machinery, transportation machinery, chemicals, and food. The Plan also indicates nanotechnology is fundamental and horizontal to these clusters.

The main funding agency for nanoscience and nanotechnology (NST) in Singapore is the Agency for Science, Technology & Research (A*STAR)[191]. A*STAR's Nanotechnology Initiative started in 2001 with the target of building on existing capabilities to develop specific areas of NST research always with applications and potential use by industry as a goal. A*STAR research institutes involved in NST include the Institute of Materials Research and Engineering (IMRE)[192]. Its Advanced Energy Storage Laboratory and its Molecular Materials Laboratory are particularly relevant for energy. The former focuses its research on energy storage materials and battery device for application in renewable energy, smart grids, biomass, etc. The latter, a collaboration with the Department of Chemistry of the National University of Singapore, focuses on energy materials, molecular catalysis, biomimetic materials; and carbon materials.

In 2010, A*Star's SIMTech launched the Nanotechnology in Manufacturing Initiative (NiMI) to foster collaborative efforts between research and industry, developing industrial capability and enhancing competitiveness. NiMI concentrates "on the application of nanotechnology in the processes of forming, joining and coating", particularly for the electronics industry, nanocomposite physical vapour deposition (PVD) coatings and others. Characterisation is also a relevant part of the initiative.[193]

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

4.3.3.4 Thailand

Thailand has been active in nanotechnology since at least 2003 when it established NANOTEC[194] 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 nanomaterials for energy and catalysis, hybrid nanostructures and nanocomposites; nano-characterisation; engineering and manufacturing characterisation; integrated nano-systems; nanoscale simulation; and functional nanomaterials and interfaces.

In 2012, the National Nanotechnology Policy Framework (2012-2021)[195] and the Nanosafety and Ethics Strategic Plan (2012-2016)[196] were approved by government for implementation by the Ministry of Science and Technology, and relevant agencies. The Framework has three primary goals:

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

The overall strategic direction of the Framework encompasses four target clusters, including energy and environment, electronics, food and agriculture, and defines seven flagship products including nano-electronics (photovoltaic films). 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.

[191] www.a-star.edu.sg/
[192] www.a-star.edu.sg/imre
[193] 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
[194] http://www.nanotec.or.th/th/wp-content/uploads/2013/05/NANOTEC-brochure11.pdf
[195] http://www.nanotec.or.th/en/wp-content/uploads/2012/02/The-National-Nanotechnology-Policy-framework-exe-sum.pdf
[196] http://www.nanotec.or.th/en/

The strategy in Thailand is largely focusing on product development through nanotechnology. To this end, NANOTEC is addressing national and NSTDA priorities under the Framework through ten flagship programmes. One of these is "future energy" that concentrates on "nano catalyst for production of future energy source such as Biojet and Carbon-based Supercapacitor from Biomass".[197]

4.3.4 Western Asia

4.3.4.1 Israel

The first nanotechnology policy initiative in Israel was the establishment of the Israel Nanotechnology Initiative (INNI)[198] in 2002 as a shared action of the Forum for National Infrastructures for Research & Development (TELEM)[199] and the ministry for the economy (now called the Ministry for Industry, Trade and Labour)[200]. INNI's mission is "to make nanotechnology the next wave of successful industry in Israel by creating an engine for global leadership". To achieve this, actions have been taken on scientific research in nanoscience and nanotechnology (NST); on increasing public-private collaboration on NST; on speeding up commercialisation of NST; and on leveraging funding from both public and private sources to support NST in Israel. INNI is closely linked to the national system with its Director appointed by the Chief Scientist at the Ministry, and its Board operating out of the MAGNET Programme[201] 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[202]) per annum for basic NST equipment plus another almost USD 10 million (EUR 8 million[203]) per annum for new infrastructure and facilities.[204] 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[205] 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[206]) 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[207, 208], in 2005 (before the official launch of the programme), the other five research universities receiving support in 2006. One of them is the Hebrew University Centre for Nanoscience and Nanotechnology whose focus areas includes nano-optronics for sensing and communication applications and nanomaterials for industrial applications and also has a specialisation in sol-gel-based nanomaterials. Work is also taking place at the Institute of Nanotechnology and Advanced Materials at Bar-Ilan University in several areas, including computers.[209] Furthermore, photonics and electronics is among the research activities of the Ilse Katz Institute for Nanoscale Science & Technology, at Ben-Gurion University, with a specialisation

[197] www.nanotec.or.th/en
[198] http://www.nanoisrael.org/
[199] http://www.trdf.co.il/eng/fundinfo.php?id=2846
[200] http://www.economy.gov.il/English/Pages/default.aspx
[201] 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.
[202] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[203] Average yearly conversion rate, 2012 (*source*: www.wolframalpha.com)
[204] Figures for funding under the programme to 2012.
[205] http://www.nanoisrael.org/category.aspx?id=1278
[206] Average yearly conversion rate, 2006 (*source*: www.wolframalpha.com)
[207] 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.
[208] Israel Institute of Technology http://www.technion.ac.il/en/
[209] http://nano.biu.ac.il/research-centers/nano-materials

in design, simulation and fabrication of nano-photonic chips and devices.[210]

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

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

4.3.4.2 Saudi Arabia[212]

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

During the implementation of the NNP, nanotechnology centres began to be established, such as the Centre of Excellence in Nanotechnology (CENT) established 2005 at the KFUPM[213]; and the CNT established in 2006 at the KAU[214]. 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)[215] established in 2010 at the KSU in the Riyadh Techno Valley. The KAIN covers areas including energy, food and environment, water treatment and desalination, telecommunications, and manufacturing of nanomaterials. 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.

4.3.4.3 Turkey

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

[210] http://in.bgu.ac.il/en/iki/Pages/Research-Activity1.aspx
[211] http://www.nanoisrael.org/category.aspx?id=13671
[212] A review of nanotechnology development in the Arab World, Bassam Alfeeli et al., Nanotechnology Review, 2013 (05/2013; 2(3):359-377)
[213] King Fahd University of Petroleum and Minerals, Riyadh
[214] King Abdul Aziz University, Jeddah
[215] http://nano.ksu.edu.sa/en

estimated[216] that nanotechnology received State support of about one billion Turkish Lira, or c. USD 500 million (EUR 367 million[217]). Over 20 nanotechnology research centres, departments and graduate schools have been established including NanoTam[218] and Unam[219] (with research areas that includes energy) at Bilkent University; Sabanci University Nanotechnology Research and Application Centre (SUNUM)[220] (with a focus on renewable energy systems and energy applications); and the Micro and Nanotechnology Department at the Middle East Technical University[221].

4.4 Oceania

4.4.1.1 Australia

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

In 2009-2010, the NNS was replaced with a National Enabling Technology Strategy (NETS), a comprehensive national framework for the safe and responsible development of novel technologies (including nanotechnology and biotechnology). With funding over four years of AUS 38.2 million (EUR 28.3 million[222]), 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[223] was prepared by the Australian Academy of Science, using funding received from the National Enabling Technologies Policy Section in the Department of Industry, Innovation, Science, Research and Tertiary Education. The Research Strategy identified among the grand challenges the importance of developing clean energy solutions, and highlighted among the selected areas of research *Nanostructured materials for clean energy* (hydrogen storage, lithium ion-batteries and fuel cells). In addition, the Strategy sees advances in computing infrastructure as helping to address the challenge of managing increased energy consumption. Materials design for clean energy applications, development of nanoporous membranes and fuel cells are also priorities, particularly since they all involve multi-scale, multidisciplinary expertise.

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

Australia also operates a network to link research facilities across the country, the Australian Nanotechnology Network[224]. The Network was established by bringing together four seed funding networks. It comprises about 1,000 active researchers from universities, institutes and government research organisations, half of whom are students. Its aims are to promote collaboration, increase multidisciplinary awareness and collaboration, foster forums for postgraduate and early career researchers, increase and improve awareness of nanotechnology infrastructure, and promote international links.

4.4.1.2 New Zealand

Nanotechnology strategies in New Zealand began by taking a networking approach and were led by

216 http://www.issi2015.org/files/downloads/all-papers/0720.pdf
217 Average yearly conversion rate, 2007-2014 (*source*: www.wolframalpha.com)
218 http://www.nanotam.bilkent.edu.tr/eng/main.html
219 http://unam.bilkent.edu.tr/?page_id=576
220 http://sunum.sabanciuniv.edu/
221 http://mnt.metu.edu.tr/
222 Average yearly conversion rate, 2010-2013 (*source*: https://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-aud.en.html)
223 https://www.science.org.au/publications/national-nanotechnology-research-strategy
224 http://www.ausnano.net/index.php?page=home

the MacDiarmid Institute for Advanced Materials and Nanotechnology[225]. 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[226]) funding for 2003-2006 from the Ministry of Education and, in early 2006, developed a "Nanotechnology Initiative for New Zealand"[227] identifying where capability in nanotechnology could be developed in the country. The Initiative identified six programmes for nanoscience and nanotechnology research: nanotechnology for energy; nano-photonics, nano-electronics and nano-devices; nanomaterials for industry; nano- and micro-fluidics; bio-nanotechnologies; and social impacts of nanotechnology.

Also in 2006, the New Zealand government released a Nanoscience and Nanotechnologies Roadmap (2006-2015)[228]. Highlighting international and national research, the Roadmap placed nanotechnology amongst government's strategic priorities, setting high-level directions for nanotechnology-related research and policy in New Zealand. Among the key sectors, some potential areas and type of applications were identified. One is dedicated to energy, namely *Energy and Industrial* (including applications like lubricants and fuel additives, energy storage, super-hard bearings and coatings, catalysts, energy generation and transmission). Three priority areas for public funding were identified: the creation of new materials; diagnostic devices; and tools and techniques. The Roadmap noted the crucial importance of the programme on nano-photonics, nano-electronics and nano-devices, included in the Nanotechnology Initiative for New Zealand. The Ministry of Science and Innovation was put in charge of policy actions to implement the Roadmap.

The Ministry of Science and Innovation *Statement of Intent 2011-14* highlighted two high-level priorities – growing the economy and building a healthier environment and society. In addition to the traditional resource sectors of New Zealand, it sought to capability in knowledge-intensive activities, such as high-technology manufacturing and the services sector. Six priority areas were identified including energy and minerals, high-value manufacturing and services, health and society, as well as biological sciences, hazards and infrastructure, and the environment[229].

4.5 Africa

4.5.1.1 South Africa

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

- In 2002, the formation of the South African Nanotechnology Initiative (SANi)[230] 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)[231] by the Department of Science and Technology (DST);
- In 2005, the publication of the National Strategy on Nanotechnology (NSN)[232] 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[233] and MINTEK[234]. Each centre has developed collaborative research programmes, often with other national institutions. These include programmes in designing and modelling of novel nano-structured

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225 http://www.macdiarmid.ac.nz/
226 Average yearly conversion rate, 2003-2006 (*source*: www.wolframalpha.com)
227 http://www.macdiarmid.ac.nz/a-nanotechnology-initiative-for-new-zealand/
228 http://statnano.com/strategicplans/13
229 http://www.mbie.govt.nz/
230 http://www.sani.org.za/
231 http://www.esastap.org.za/download/natstrat_advmanu_mar2005.pdf
232 http://chrtem.nmmu.ac.za/file/35e56e36b6ab3a98fac6fc0c31ee7008/dstnanotech18012006.pdf
233 http://www.csir.co.za/
234 http://www.nic.ac.za/

materials, at the CSIR-National Centre for Nano-structured Materials (NCNSM)[235], 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[236] enables joint projects and mobility[237] between S&T departments in those countries.

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

[235] http://ls-ncnsm.csir.co.za/
[236] http://www.ibsa-trilateral.org/
[237] http://www.ibsa-trilateral.org/about-ibsa/areas-of-cooperation/people-to-people

5 PUBLICATIONS IN ENERGY NANOTECHNOLOGY

5.1 Overview

Around 1.8 million publications were identified[238] from the Web of Science as being related to nanoscience and technology (NST)[239] between 2000 and 2014. Of these, over 140,000 relate to nanotechnology and energy. The numbers for the World and EU28 & EFTA (which includes here just Switzerland and Norway) are in the table below, as nanotechnology for energy and as a percentage of total energy publications.

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

Year	EU 28 & EFTA		World	
	Nanotechnology and energy	% of total energy publications	Nanotechnology and energy	% of total energy publications
2000	876	37.8%	2,106	37.1%
2001	961	38.6%	2,389	38.2%
2002	1,016	37.1%	2,775	40.4%
2003	1,092	38.4%	3,203	42.3%
2004	1,296	39.6%	3,935	43.8%
2005	1,550	41.9%	4,836	46.8%
2006	1,920	42.9%	6,071	48.6%
2007	2,027	41.7%	6,826	48.7%
2008	2,251	40.6%	8,013	48.9%
2009	2,798	42.7%	9,982	50.5%
2010	3,224	42.9%	12,200	51.9%
2011	4,148	45.5%	15,340	53.3%
2012	4,199	43.2%	17,502	53.8%
2013	5,074	44.1%	20,954	54.2%
2014	5,714	45.0%	24,739	55.9%
TOTAL	**38,146**		**140,871**	

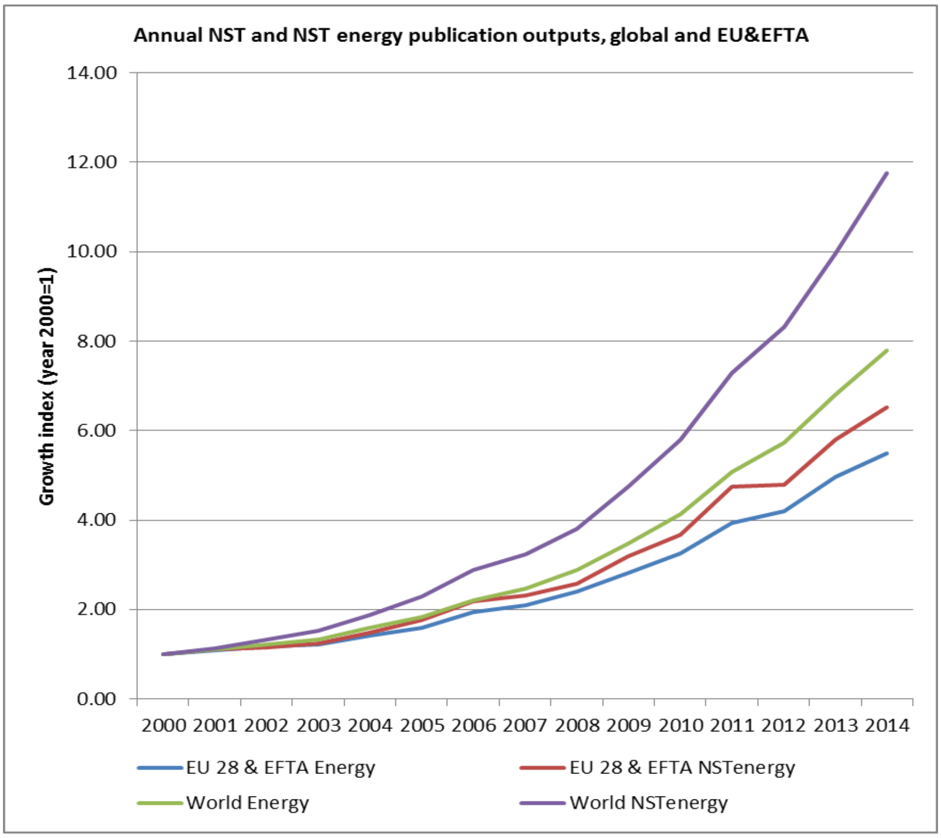
Source: Derived from Web of Science

The evolution over time of publications in nanotechnology energy, as well as the entire energy field (both for (i) EU28 and EFTA and (ii) the World), is depicted in the figure below, indexed by year 2000 (=1).

Of the over 140,000 publications on energy NST in 2000-2014, almost 46% related to solar and 29% to storage. 14% related to hydrogen. There is a much bigger interest in alternatives in general energy research than in energy NST research. This is because the topic of alternative energy is being covered under themes such as construction and transport rather than directly under energy. It is also the case that the 'alternatives' of solar and hydrogen are included as separate sub-sectors.

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

[239] 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 5-1: Annual NST energy publication output, worldwide and EU28&EFTA, 2000-2014 (indexed to 2000(=1))

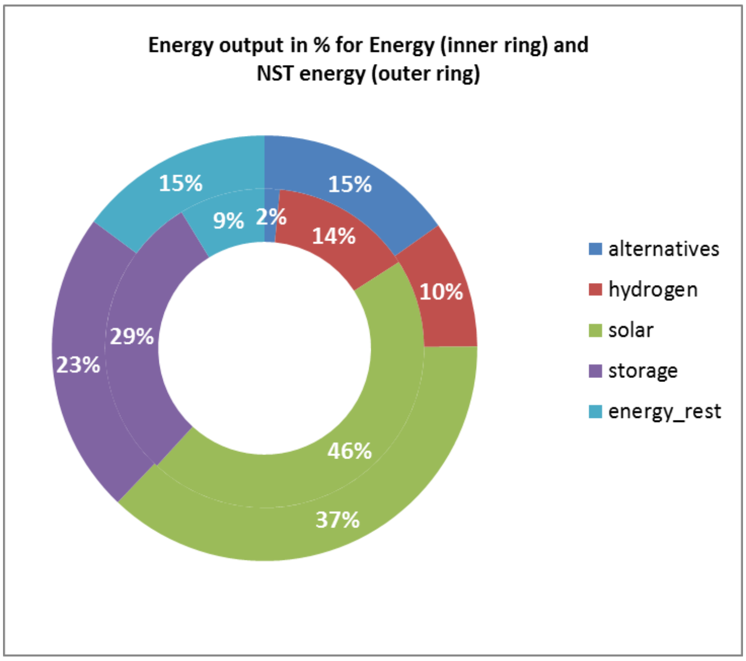


Figure 5-2: Publication outputs in energy, and in nanotechnology and energy (%), 2014

5.2 Activity by region and country

Over the period from 2000-2014, China showed a particularly strong increase in publication output while for other countries globally there was a normal growth of output.

By global region, based on the data for 2014 for the top 25 publishing countries for nanotechnology energy, Asia leads in publications, followed by the EU28 & EFTA. The distributions are presented in the table and figures below.

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

Region	npub
Asia	14457
EU28 & EFTA	5,714
North America	4,819
Middle East	945
Oceania	730
South and Central America	517

The most prolific countries for nanotechnology energy publications globally in 2014 were China and the USA, followed by Korea, Japan, India and Germany (by numbers of publications, npub).

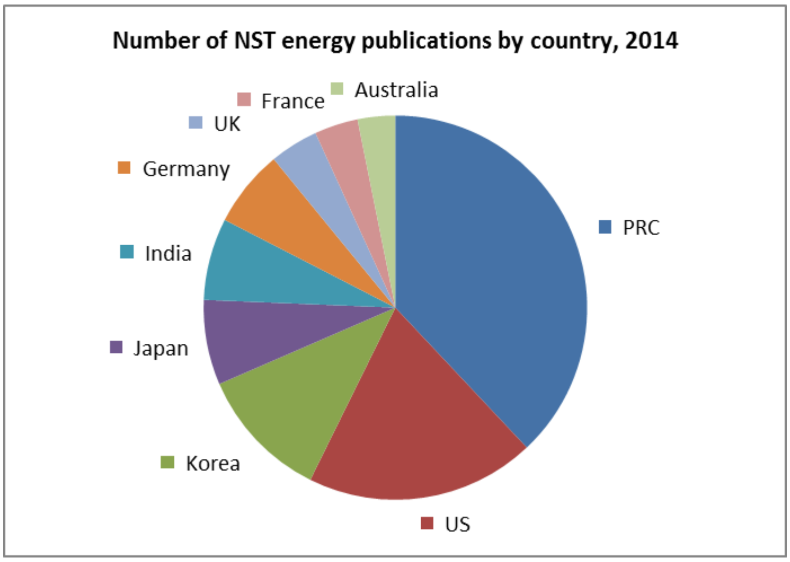


Figure 5-3: NST energy publications by country (top ten), 2014

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

Country	Region	npub
PRC (CN)	Asia	8,548
USA (US)	North America	4,352
Korea (KR)	Asia	2,517
Japan (JP)	Asia	1,609
India (IN)	Asia	1,552
Germany (DE)	EU28 & EFTA	1,467
United Kingdom (UK)[240]	EU28 & EFTA	921
France (FR)	EU28 & EFTA	828
Australia (AU)	Oceania	712
Italy (IT)	EU28 & EFTA	661
Spain (ES)	EU28 & EFTA	628
Singapore (SG)	Asia	596
Canada (CA)	North America	542
Saudi Arabia (SA)	Asia	405
Switzerland (CH)	EU28 & EFTA	373
Sweden (SE)	EU28 & EFTA	365
Malaysia (MY)	Asia	314
Poland (PO)	EU28 & EFTA	289
Turkey (TR)	Asia/ Europe	282
Brazil (BR)	South and Central America	254
Netherlands (NL)	EU28 & EFTA	237
Denmark (DK)	EU28 & EFTA	196
Belgium (BE)	EU28 & EFTA	178
Egypt	Africa	169
Greece (GR)	EU28 & EFTA	143

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

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

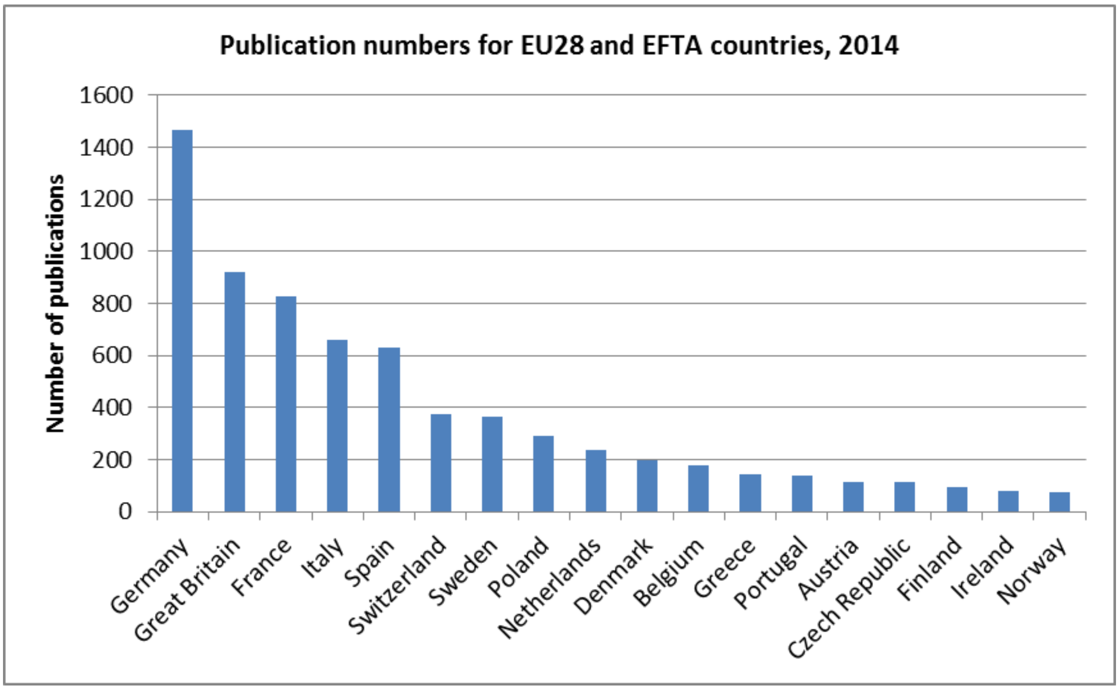


Figure 5-4: Number of NST energy publications by EU&EFTA countries, 2014
Data for the top NST energy publishing countries only

5.3 Activity by organisation type

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

The most active organisations in NST for energy publications are shown in the table below (2014). The higher education organisations with the most nanotechnology energy publications globally in 2014 was the Chinese Academy of Sciences as shown in the table of the top publishing organisations. Imperial College London (UK) is the only EU28 organisation that features in the table.

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

Country	University/ Research Institute	npub
PRC	Chinese Academy of Science	1,476
SG	Nanyang Technological University	361
PRC	Tsinghua University	292
PRC	University of the Chinese Academy of Science	285
PRC	Huazhong University of Science and Technology	266
PRC	Jilin University	264
PRC	Zhejiang University	261
PRC	University of Science and Technology of China	245
KR	Seoul National University	207
PRC	South China University of Technology	206
SG	National University of Singapore	200

Country	University/ Research Institute	npub
KR	Korea University	197
KR	Korean Institute of Science and Technology[241]	196
US	University of California Berkeley	193
PRC	Soochow University	190
KR	Sungkyunkwan University	187
PRC	Peking University	182
PRC	Shanghai Jiao Tong University	179
UK	Imperial College London	175
PRC	Fudan University	172
PRC	Yonsei University	170
KR	Korean Advanced Institute of Science and Technology [242]	167
PRC	Hanyang University	165
IN	Indian Institute of Technology	163

The top ten publishing institutions in the EU28 & EFTA in nanotechnology and energy are led by Imperial College (UK), the École Polytechnique Fédérale de Lausanne, EPFL (CH), the Technical University of Denmark (DK) and the University of Cambridge (UK), each with over 100 publications in 2014. Three of the top six are the United Kingdom, while Germany hosts four of the top ten.

Table 5-5: Number of energy nanotechnology publications by EU&EFTA organisation (top ten), 2014

Organisation	Country	npub
Imperial College London	UK	175
EPFL[243]	CH	145
Technical University of Denmark	DK	115
University of Cambridge	UK	106
Uppsala University	SE	100
University of Oxford	UK	93
Forschungszentrum Jülich[244]	DE	93
FAU Erlangen-Nürnberg[245]	DE	88
Karlsruhe Institute of Technology	DE	78
Technical University (TU) Dresden	DE	74

While publishing at a much less frequent rate, some companies are also active as shown in the table below of the top publishing companies worldwide. The companies with the most nanotechnology energy publications globally in 2014 were Polyera, IBM and Samsung.

[241] KIST: the Korea Institute for Science and Technology
[242] KAIST: the Korea Advanced Institute for Science and Technology
[243] École Polytechnique Fédérale de Lausanne
[244] A member of the Helmholtz Alliance (Helmholtz Gesellschaft)
[245] Friedrich-Alexander-Universität Erlangen-Nürnberg

Table 5-6: Number of energy nanotechnology publications by company (top 8), 2014

Company	npub
Polyera Corporation	21
IBM Corporation	20
Samsung Electronics Co. Ltd.	17
Samsung Advanced Institute of Technology	16
General Motors Corporation	14
BASF SE	12
Toyota Motor Company	11
Samsung SDI	11

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

6 PATENTING IN ENERGY NANOTECHNOLOGY

6.1 Overview

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

The patents and patent families (groups of patents related to the same invention) were identified by searching using the combination of keywords (identified within the NanoData project for the sector (and sub-sector, as appropriate)) and IPC (International Patent Classification) numbers. The IPC numbers used were both those for nanotechnology (i.e. B82, or B82Y for manufactured nanomaterials) and those related to the sector under consideration (ICT, health, energy, etc.)[246]. 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[247] applications registered at WIPO are protected under the Patent Cooperation Treaty (PCT), an international treaty that enables the filing of patents to protect inventions in the countries[248] that are members of the treaty.

6.2 Number and evolution over time of energy nanotechnology patent families

Using the above methodology, 44,391 (simple) nanotechnology patent families[249, 250] of granted patents and patent applications were found in the period 1993-2011[251]. All were from the European Patent Office (EPO or EP), US Patent and Trademark Office (USPTO or US) or the World Intellectual Property Organisation (WIPO)[252].

In the same period, the number of energy-related patent families identified among the nanotechnology patents is 1,858, 4.2% 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 energy and nanotechnology is in the US (83.4%) and the lowest at the EPO (33.6%), the difference being more than a factor of two (see table below).

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

Nanotechnology and Energy Applications (1993-2011)	Absolute Number	Percentage
Total Patent Families	1,858	100%
PCT Applications	979	52.7%
EP Applications	625	33.6%
US Applications	1,550	93.4%

[246] 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.
[247] http://www.wipo.int/pct/en/
[248] 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
[249] The definition of simple family is used, in which all documents having exactly the same priority or combination of priorities belong to one patent family (http://www.epo.org/searching/essentials/patent-families/definitions.html). The patent families include at least one PCT, EPO or USPTO patent application.
[250] 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/
[251] This year refers to the oldest year of the priority patents.
[252] While patents can be filed in individual patent offices, many inventors choose to file applications under the Patent Classification Treaty (PCT). All WIPO applications are PCT applications.

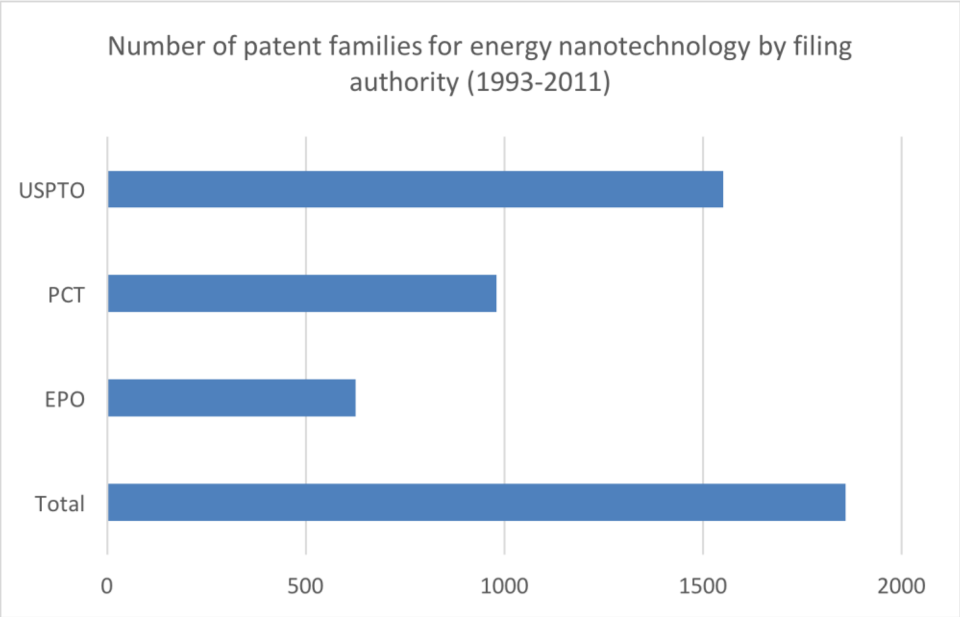


Figure 6-1: Number of patent families by filing authority (PCT, EPO, and USPTO)

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

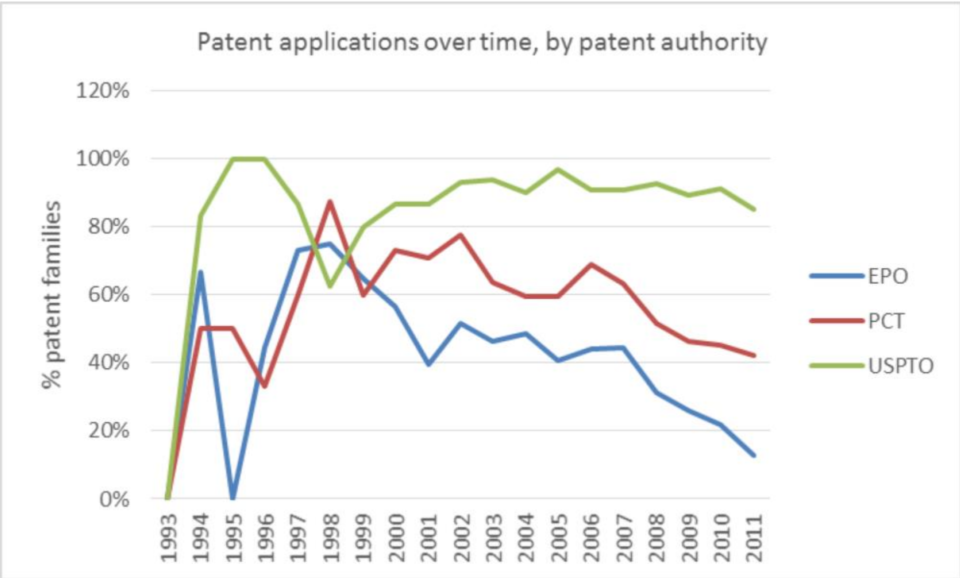


Figure 6-2: Evolution over time of WIPO (PCT), EPO and USPTO energy nanotechnology patenting

Since 2000, the trend in the percentage of energy nanotechnology patent applications to the EPO and for PCTs is similar, dropping significantly over time, the EPO more steeply than the PCT, while the percentage has been more stable for USPTO filings. This trend may indicate that patent filing in the US has remained important while the importance of filing in Europe or as a PCT has decreased. It may also reflect the fact that the majority of patentees are from the US, as indicated in the following sections. The trend supports the concept that patenting in the US has become relatively more important over time than patenting at EPO or as a PCT.

6.3 Activity by filing country and region

By looking at PCT applications, it is possible to obtain an indication of the relative patenting activity of countries and regions. The top ten patent authorities through which PCT applications were filed are shown in the table, the USPTO (421 patent families) being by far the most prolific, followed by the patenting office of Japan (118) and the EPO (85) both with less than a third of the US total. The sum of the figures for the European patent offices in this top ten table and the EPO is just 156, considerably less than in the US. Even if all the remaining EU countries are allocated the figure of the patenting office of the next highest European country (Austria, 6 patent families), the total for the EU28 plus the EPO is still only 306, less than the US.

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

Receiving Authority	No. of Patent Families (1993-2011)
United States	421
Japan	118
European Patent Office (EPO)	85
Korea	41
France	27
International Bureau (WIPO)	27
United Kingdom	22
Germany	22
Canada	14
China	12

6.4 Activity by country of applicant

PATENT APPLICATIONS

Within the group of 1,858 energy-related nanotechnology patent families, there is at least one EU28 or EFTA applicant in just over 20% of them while there is participation from the rest of the world in almost 80% of cases.

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

	EU28 & EFTA	Rest of World
Number of energy nanotechnology patent families	377	1481
Percentage of energy nanotechnology patent families	20.3%	79.7%

Applicants may file patents with more than one patent authority, e.g. at the USPTO and as at the EPO. The table below shows the data for the top 20 countries of applicants, as well as indicating the percentage of patent families for each. EU28 and EFTA countries are marked in bold. As patents may be filed with more than one authority (including PCT, US and EP applications), the percentages can sum to more than 100%.

By far the highest number of patent families is found where the country of the applicant is the US (777 patent families). Japan (227, less than a third of the US number), Korea (216) and Germany (128) have the next highest number of applicants. In terms of applicants from Europe, Germany (128), France (63, less than half of the German total) and the United Kingdom (43) are followed by Austria (30), Italy (19), Spain (14) and the Netherlands (12). For Asia, the lead country for applicants, Japan (227), is followed closely by Korea (216). Taiwan (68) is in fifth place overall and China (54) in seventh.

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

	Country of applicant	No. of Patent Families	PCT	US	EP
1	United States	777	57%	91%	31%
2	Japan	227	55%	85%	31%
3	Korea	216	21%	90%	18%
4	**Germany**	**128**	**71%**	**64%**	**63%**
5	Taiwan (Chinese Taipei)	68	0%	100%	3%
6	**France**	**63**	**73%**	**75%**	**57%**
7	China	54	43%	67%	22%
8	Canada	43	44%	81%	21%
9	**United Kingdom**	**43**	**88%**	**60%**	**49%**
10	**Austria**	**30**	**53%**	**73%**	**57%**
11	**Italy**	**19**	**74%**	**63%**	**63%**
12	**Switzerland**	19	63%	58%	63%
13	Singapore	17	71%	59%	29%
14	India	15	67%	47%	27%
15	**Spain**	**14**	**57%**	**64%**	**43%**
16	**Netherlands**	**12**	**83%**	**83%**	**75%**
17	Australia	12	50%	83%	33%
18	**Belgium**	**9**	**67%**	**56%**	**56%**
19	**Finland**	**8**	**88%**	**50%**	**75%**
20	Israel	8	75%	100%	50%

Over 90% of patents of US applicants are filed with the USPTO while 57% are filed as PCTs. Only 31% are filed by US applicants at the EPO.

Some European applicants (DE, UK, IT, BE and FI) file more as PCTs than at either the EPO or USPTO. One explanation for this is that filing as a PCT provides applicants with more time to evaluate their invention and develop their patent before applying for a patent to be granted[253]. For example, 88% of patents have been filed as PCT by UK applicants in the 1993-2011 period for energy nanotechnology inventions. This compares with UK applicants filing 49% at the EPO and 60% at the USPTO.

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

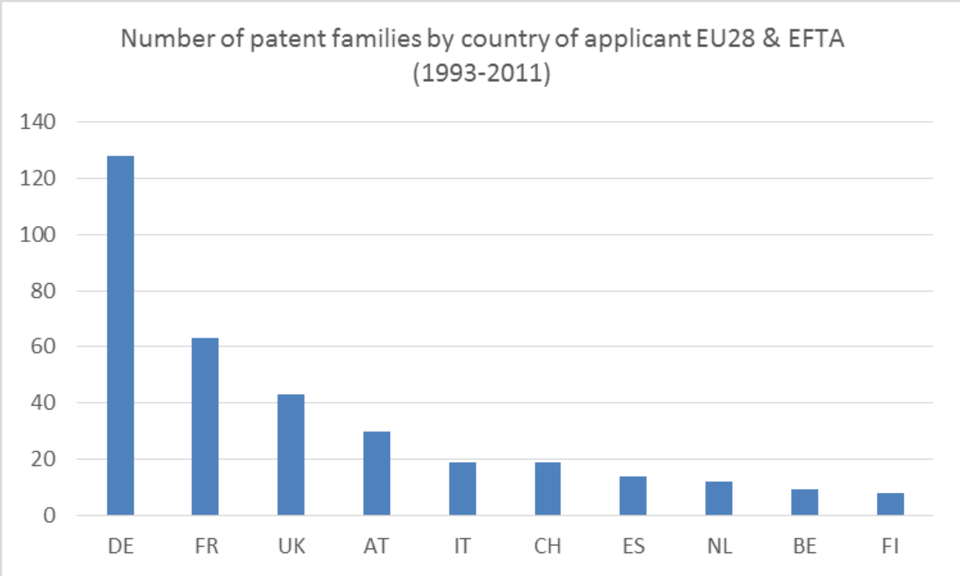


Figure 6-3: Number of patent families by country of applicant EU28/EFTA

Table 6-5: Patent families by country of applicant for EU28/EFTA (1993-2011)

World ranking	Country of applicant	No. of Patent Families	PCT	US	EP
4	Germany	128	71%	64%	63%
6	France	63	73%	75%	57%
9	United Kingdom	43	88%	60%	49%
10	Austria	30	53%	73%	57%
11	Italy	19	74%	63%	63%
12	Switzerland	19	63%	58%	63%
15	Spain	14	57%	64%	43%
16	Netherlands	12	83%	83%	75%
18	Belgium	9	67%	56%	56%
19	Finland	8	88%	50%	75%
21	Sweden	7	57%	57%	29%
23	Denmark	5	100%	20%	20%

GRANTED PATENTS

Applicants from the same EU and EFTA countries perform strongly in patents granted, namely those from Germany, France, Austria and the United Kingdom. All of the countries found to have patent holders are shown in the table below.

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

	Country of applicant	No. of Patents Granted (1993-2011)	
		EPO	USPTO
1	Germany	15	25
2	France	6	16
3	Austria	6	9
4	United Kingdom	5	6
5	Italy	4	4
6	Switzerland	2	2
7	Romania	1	3
8	Norway	1	1
9	Denmark	1	0
10	Finland	1	0
11	Spain	0	4
12	Netherlands	0	3
13	Greece	0	2
14	Sweden	0	2
15	Hungary	0	1
16	Ireland	0	1

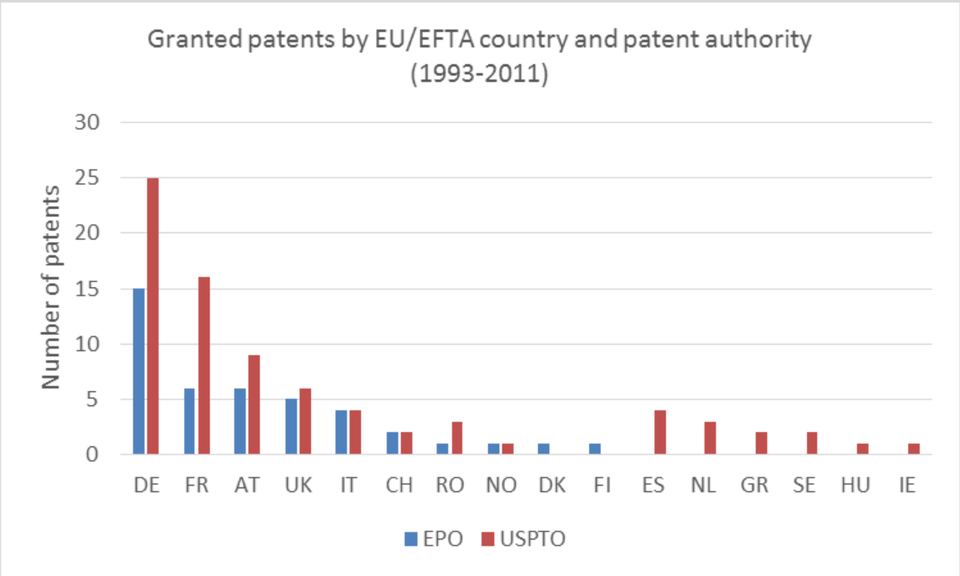


Figure 6-4: Granted patents by country of applicant for EU28/EFTA

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

Table 6-7: Comparison of patent filings and patents granted by country of applicant (1993-2011)

	Country of applicant	No. of Patent Families
1	DE	128
2	FR	63
3	UK	43
4	AT	30
5	IT	19
6	CH	19
7	ES	14
8	NL	12
9	BE	9
10	FI	8

	Country of applicant	No. of Patents Granted
1	DE	40
2	FR	22
3	AT	15
4	UK	11
5	IT	8
6	CH	4
7	ES	4
8	RO	4
9	NL	3
10	NO/GR/SE[254]	2

A very approximate estimate can be made of relative success in patenting between countries of applicants by comparing the number of patent families and the number of patents granted[255]. This reveals a 100% success rate for Romania and high success rates for Austria and Italy. Perhaps the most meaningful figures are those for countries with high numbers of both applications and granted patents – Germany (31%), France (35%), Austria (50%) and the United Kingdom (26%), highlighted in bold in the table below.

Table 6-8: Estimate of relative patenting success by country of applicant

	Country of applicant	No. of patents granted	Granted/ Applied %
1	Romania	4	100%
2	**Austria**	**15**	**50%**
3	Italy	8	42%
4	**France**	**22**	**35%**
5	**Germany**	**40**	**31%**
6	Spain	4	29%
7	**United Kingdom**	**11**	**26%**
8	Netherlands	3	25%
9	Switzerland	4	21%
10	Finland	1	13%

When considering the country of applicant and the country of inventor as seen in patent family data, it is clear that inventions are most often patented in the country in which they are invented (see table below). However, it is not uncommon to have inventions that are patented outside of the country in which they originate. In addition, some correlation that may be related to language is seen (e.g. inventors in Austria patenting in Germany and vice versa).

[254] These three countries have the same number of patents

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

Table 6-9: Country of applicant and country of inventor table for cross-comparison

INVT	US	DE	KR	JP	CN	AT	FR	CA	UK	IN
APPL										
US	741	27	17	17	15	24	10	14	7	9
DE	25	111	0	0	1	11	6	0	7	1
KR	17	0	214	5	5	1	0	4	0	3
JP	16	0	4	220	3	0	0	0	1	0
CN	15	3	5	3	52	0	0	0	1	0
AT	15	9	1	0	0	29	0	0	0	0
FR	12	5	0	0	0	0	59	1	0	2
CA	10	0	4	0	0	0	1	43	1	0
UK	7	1	0	0	1	0	0	1	40	1
IN	14	0	13	5	0	0	1	0	3	5

6.5 Patenting activity by organisation type

6.5.1 Universities and public research organisations

PATENT APPLICATIONS

Of the top ten universities and public research organisations (PROs) with the highest number of patent families (with percentages for PCT, US and EP applications), four are in the United States. France is the only EU28 country that features in the table, marked in bold.

Looking at the top 25 performing universities and PROs for patent families, 12 out of 25 are from the US, just two being from the EU28 or EFTA (the CNRS[256] and the CEA[257]). The tables below show the top ten universities and PROs by number of patent families, followed by the top non-US universities and PROs.

[256] Centre Nationale de la Recherche Scientifique
[257] Commissariat à l'Énergie Atomique et aux Énergies Alternatives

Table 6-10: Number of patent families for top ten universities and PROs (1993-2011)

Rank	Country	Organisation	No. of patent families	PCT	US	EP
1	US	University of California	47	47%	85%	21%
2	US	MIT[258]	24	79%	79%	21%
3	**FR**	**CNRS**	**18**	**83%**	**56%**	**72%**
4	KR	KIST[259]	16	13%	81%	6%
5	KR	ETRI[260]	13	8%	92%	0%
6	US	University of Michigan	12	100%	58%	83%
7	US	Princeton University	12	83%	75%	75%
8	KR	AIST[261]	12	17%	67%	17%
9	TW	ITRI[262]	11	0%	100%	0%
10	KR	Hanyang University	9	33%	0%	0%

The table below shows the top 20 performing universities and PROs for patent families in EU28/EFTA countries. French organisations perform strongly (as the top two and with five in the top 20), as do Germany (5 of the top ten), the United Kingdom (7 in the top 20).

Table 6-11: Number of patent families in the top 20 EU28/EFTA universities and PROs (1993-2011)

Rank	Country	Organisation	No. of Patent families	PCT	US	EP
1	FR	CNRS[263]	18	83%	56%	72%
2	FR	CEA[264]	7	71%	57%	57%
3	DE	Max Planck	5	60%	20%	0%
4	DE	Technical University of Dresden	5	60%	40%	0%
5	CH	EPFL	3	67%	33%	100%
6	UK	University of Nottingham	2	100%	0%	0%
7	ES	CSIC[265]	2	100%	0%	0%
8	DE	TITK[266]	2	100%	0%	0%
9	DE	Fraunhofer-Gesellschaft	2	50%	0%	0%
10	DE	University of Ulm	2	100%	0%	50%
11	FR	University Joseph Fourier	2	50%	100%	50%
12	FR	University Pierre et Marie Curie	2	50%	0%	50%
13	FR	École Polytechnique[267]	2	100%	50%	100%
14	BE	IMEC[268]	2	50%	0%	100%

[258] Massachusetts Institute of Technology
[259] Korean Institute of Science and Technology http://eng.kist.re.kr/kist_eng/main/
[260] Korean Electronics and Telecommunication Research Institute
[261] National Institute of Advanced Industrial Science and Technology
[262] Industrial Technology Research Institute
[263] Centre National de la Recherche Scientifique
[264] Commissariat à l'Énergie Atomique et aux Énergies Alternatives, the French Alternative Energies and Atomic Energy Commission www.cea.fr
[265] Consejo Superior de Investigaciones Cientificas, the Spanish National Research Council www.csic.es
[266] Thüringisches Institut für Textil- und Kunststoff-Forschung eV
[267] École Polytechnique, University of Paris Saclay www.polytechnique.edu
[268] Interuniversitair Microelectronica Centrum, BE

Rank	Country	Organisation	No. of Patent families	PCT	US	EP
15	UK	University of Glasgow	1	0%	0%	0%
16	UK	University of Exeter	1	0%	0%	100%
17	UK	Imperial College	1	0%	0%	100%
18	UK	Bangor University	1	0%	0%	0%
19	UK	University of Nottingham	1	0%	0%	100%
20	UK	Isis Innovation Ltd	1	0%	0%	100%

GRANTED PATENTS

Of the top 15 universities and research organisations, three are from the EU28/EFTA countries (the CNRS and CEA (FR) and the Fraunhofer-Gesellschaft (Germany)) as shown in the table below which is ranked by the highest number of EPO patents granted between 1993 and 2011. Six of the organisations are from the US, three from Japan and one each from China and Korea.

Table 6-12: Universities / research organisations granted patents, by EPO patent numbers

Rank	Country	Organisation	EP	US
1	US	Wake Forest University	3	1
2	JP	Japan Science and Technology Agency - JST	2	5
3	JP	National Institute of Advanced Industrial Science & Technology AIST	2	2
4	**FR**	CNRS	2	6
5	US	Princeton University	2	6
6	CH	EPFL	2	1
7	CN	Institute of Metal Research, Chinese Academy of Sciences	1	0
8	JP	Central Research Institute of the Electric Power Industry	1	0
9	**FR**	CEA	1	4
10	**DE**	Fraunhofer	1	1
11	KR	Korean Institute of Energy Research	1	1
12	US	Carnegie Mellon University	1	1
13	US	Massachusetts Institute of Technology - MIT	1	14
14	US	University of Arkansas	1	1
15	US	University of Michigan	1	4

Ranking by the number of USPTO patents granted between 1993 and 2011, nine of the top 15 universities and research organisations are in the US with just two in the EU28/EFTA (the CNRS and CEA, France).

Table 6-13: Universities / research organisations granted patents, by USPTO patent numbers

Rank	Country	Organisation	US	EP
1	US	MIT	14	1
2	US	University of California	14	0
3	US	Boston College	7	0
4	**FR**	CNRS	6	2
5	US	Princeton University	6	2
6	TW	Industrial Technology Research Institute	6	0
7	US	North Carolina State University	6	0
8	JP	Japan Science and Technology Agency JST	5	2
9	**FR**	CEA	4	1
10	US	University of Michigan	4	1
11	TW	National Chiao Tung University	3	0
12	US	Northwestern University	3	0
13	US	Wisconsin Alumni Research Foundation	3	0
14	JP	National Institute of Advanced Industrial Science and Technology - AIST	2	2
15	US	William Marsh Rice University	2	1

6.5.2 Activity of companies

PATENT APPLICATIONS

Of the top ten companies with the highest number of patent families (with percentages for PCT, US and EP applications), there are three in the United States and in Japan and two in both Germany and Korea.

Table 6-14: Number of patent families for top ten companies (1993-2011)

	Country	Company	No. of Patent families	PCT	US	EP
1	KR	Samsung Electronics Co Ltd	46	2%	89%	22%
2	**DE**	**BASF SE**[269]	**33**	**63%**	**85%**	**47%**
3	US	Konarka Tech Inc	27	74%	52%	56%
4	KR	Samsung SDI Co Ltd	19	0%	58%	11%
5	JP	Sony Corporation	17	59%	76%	24%
6	JP	Sumitomo Chemical Co Ltd	14	79%	64%	21%
7	**DE**	**Merck Patent GmbH**	**13**	**54%**	**62%**	**77%**
8	JP	Toyota Jidosha Kk	12	25%	75%	25%
9	US	Plextronics Inc	11	82%	27%	55%
10	US	Honeywell	11	27%	90%	64%

In the EU28 and EFTA, of the top ten, six are in Germany with BASF and Merck by far the most prolific

[269] In 2008, BASF AG became BASF SE

Table 6-15: Number of patent families for top ten EU & EFTA companies (1993-2011)

Country	Company	No. of Patent families	PCT	US	EP
DE	BASF SE	33	63%	85%	47%
DE	Merck Patent GmbH	13	54%	62%	77%
FR	Arkema FR	7	71%	29%	29%
DE	Siemens AG	7	71%	14%	14%
DE	Heliatek GmbH	6	100%	67%	67%
SE	Qunano AB	4	50%	50%	50%
DE	Leonhard Kurz GmbH & Co270	4	50%	0%	50%
DK	Vestas Wind Systems AS	3	100%	33%	33%
DE	Novaled AG	3	67%	33%	100%
CH	Ciba Holding Inc.	3	67%	0%	100%

GRANTED PATENTS

The top ten companies that have been granted patents by the EPO and/or USPTO are shown in the tables below[271]. The first table shows the top ten when the figures are sorted to obtain the highest number of EPO patents and the second shows the top ten when they are sorted for USPTO patents. In both tables, there are six US companies and two from Japan. Germany is the only EU country and only appears in the table ranked by EPO patents.

Table 6-16: USPTO and EPO granted patents by company, sorted by EP patents (1993-2011)

Country	Company	EP	US
KR	Samsung Electronics Co Ltd	5	15
DE	Merck Patent GmbH	4	2
US	Honeywell International Inc	3	7
JP	Matsushita Electric Industrial Co Ltd	2	2
JP	Sony Corporation	2	9
US	3M Innovative Properties Company	2	4
US	Air Products and Chemicals Inc	2	3
US	Cabot Corporation	2	1
US	E Ink Corporation	2	3
US	Konarka Tech Inc	2	12

[270] Leonhard Kurz Stiftung & Co.
[271] This data does not take account of there being multiple offices of one company. Where the name differs in the database, the companies are taken as being different.

Table 6-17: USPTO and EPO granted patents by company (sorted by US patents)

Country	Company	US	EP
KR	Samsung Electronics Co Ltd	15	5
US	Konarka Tech Inc	12	2
JP	Sony Corporation	9	2
KR	Samsung SDI Co Ltd	8	0
US	Nanosolar Inc	8	0
US	Honeywell International Inc	7	3
US	E. I. du Pont de Nemours et Cie	5	0
US	3M Innovative Properties Company	4	2
JP	Toyota Jidosha KK	4	1
US	General Electric Company	4	0

The next section of the report looks at products and markets for energy through nanotechnology.

7 PRODUCTS AND MARKETS FOR ENERGY THROUGH NANOTECHNOLOGY

7.1 Introduction

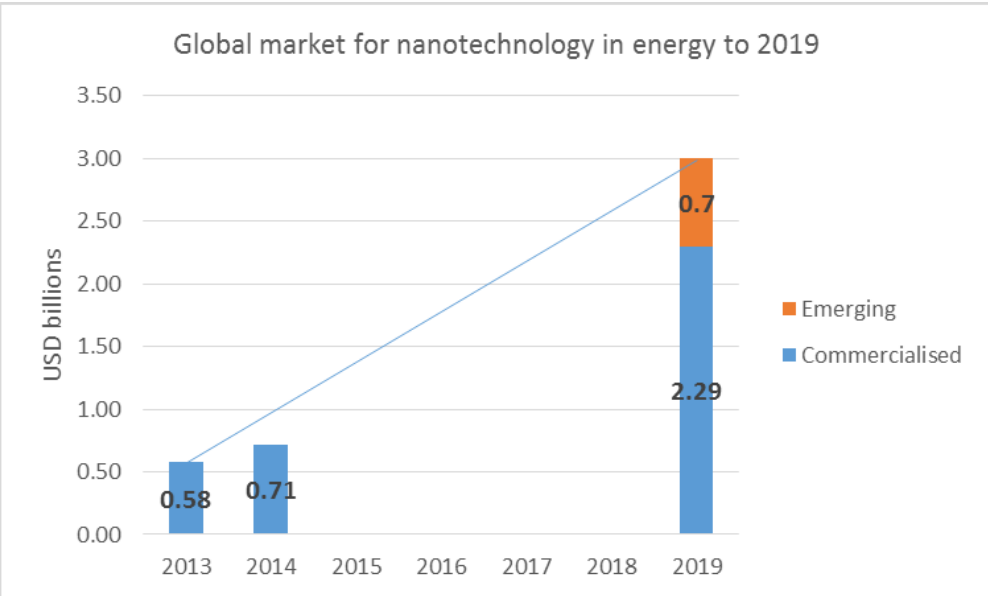
The commercial applications of nanotechnology in the field of energy includes: photovoltaics cells and their components; nanotubes and particles for use in capacitors and batteries, and nanomaterials for the application in the field of alternative energy production.

Many companies identify themselves as being active nanotechnology. Where their product is generic with many applications in a wide range of sectors, one of which is energy, their product will often not appear as energy-specific. Here efforts have been made to identify only products that are energy-specific thereby increasing the relevance (but reducing the number) of products.

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

7.2 Global markets and forecasts for energy products using nanotechnology

Global sales for nanotechnology products in the energy sector account for USD 584 million in 2013 and are forecast to be USD 3 billion in 2019. The figure below shows the forecast growth in commercialised products (USD 2.3 billion in 2019) and the expected growth in emerging products (USD 706.6 million in 2019). It is seen that much of the growth is expected to be driven by already commercialised products.

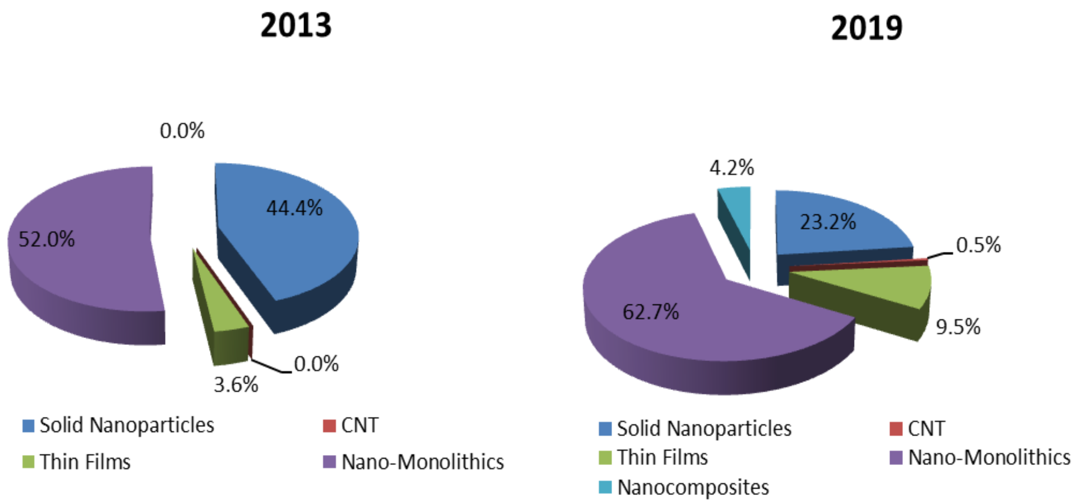


Source: BCC Research, 2014

Figure 7-1: Global market outlook for nanotechnology in energy to 2019

A comparison of global sales estimates by type of nanomaterial shows that nanomonolithics[272] account for the largest share in 2013 and that is expected to further increase to 2019. The main driver of this trend is the expected growth in the building insulation market.

[272] Nanostructured monolithics have an internal structure that has nanoscale attributes but the overall form of the material is a bulk solid. They include solids with internal nanopores, nanotubes or nanofibres; aerogels; and some metals, alloys and composites. (BCC, 2014)



Source: BCC Research, 2014

Figure 7-2: Global sales estimates for nanotechnology and energy by material type, 2013 and 2019

The share of solid nanoparticles is expected to decrease by 2019 to about half of its size in 2013, while sales of thin films 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 table below highlights available market estimates and forecasts for energy nanotechnology products. There is very high predicted growth in areas such thin film batteries (CAGR 90%) and photovoltaics (CAGR 86-123%) as well as lithium-ion batteries (CAGR 36-37%). The materials for energy applications also show high growth (CAGR 41%). One indication of the uncertainty in the market is the CAGR forecast for energy and nanotechnology overall at global level which, at 20%, is lower than the estimated CAGR for any of the application areas in which forecasts have been made.

Table 7-1: Global market value estimates for nanotechnology and energy 2014 and 2019 (multiple sources)

	2014 USD (billion) (EUR (billion))	2019 USD (billion) (EUR (billion))	USD CAGR[273] %	Source
Global energy nanotechnology	0.71 [0.94]	3.0 [2.75]	20	BCC
Nanomaterial for energy	0.2 [0.27]	2.3 [2.1]	41	R&M[274]
Nanotechnology energy applications	**USD (million) [EUR (million)]**	**USD (million) [EUR (million)]**		
Photovoltaics	0.8 [1.1]	44 [40.1]	123	BCC
Photovoltaics	68	820	86	R&M[275]
Lithium-ion batteries	95.5 [127]	450 [413]	36	BCC
Lithium-ion battery systems	63 [84]	575 [528]	37	R&M[276]
Solid-state thin film batteries	66 [88]	6000 [5500]	90	R&M[277]
CNT battery electrodes	---	6.8 [6.2]	---	BCC
CNT super-capacitors	---	13.6 [12.5]	---	BCC
Graphene super-capacitors	---	9.5 [8.7]	---	BCC
Nanostructured polymer filters for energy recovery	---	3.1 [2.85]	---	BCC
Ceria diesel fuel additives	---	1.7 [1.56]	---	BCC
Energy efficient films for heating and energy applications	75 [100]	---	---	VDI[278]

Other estimates quote the markets as follows:

- for nano-enabled photovoltaics, USD 68 million in 2011, rising to USD 820 million in 2015[279];
- for solid-state batteries, USD 66 million in 2012, rising to USD 6 billion in 2019[280]; and
- for nano-enabled lithium-ion batteries, USD 63 million in 2010, rising to USD 575 million in 2017[281].

273 Compound annual growth rate CAGR based on USD figures (i.e. does not incorporate change in EUR/USD currency exchange rate)
274 Not 2014 but 2010; not 2019 but 2017; Research and Markets
275 Not 2014 but 2011; not 2019 but 2015; Research and Markets
276 Not 2014 but 2010; not 2019 but 2017; Research and Markets (2011)
277 Not 2014 but 2012; Wintergreen Research (2012)
278 Not 2014 but 2013; VDI TZ (2013)
279 Research and Markets 2011: "Nanotechnology and Photovoltaics: Market, Companies and Products", http://www.researchandmarkets.com/reports/1556877/nanotechnology_and_photovoltaics_market.pdf
280 Winter Green Research 2012: "Solid State Thin Film Battery: Market Shares, Strategies, and Forecasts, Worldwide, Nanotechnology, 2013 to 2019", Market report abstract http://www.researchmoz.com/solid-state-thin-film-battery-market-shares-strategies-and-forecasts-worldwide-nanotechnology-2013-to-2019-report.html
281 Research and Markets 2011: "Nanomaterials and the World Lithium Ion Battery Market: Applications, Products, End User Markets, Companies and Revenues", Market report abstract

Energy nanotechnology market estimates and forecasts are considered in greater detail in the remainder of the chapter. The section that follows explores these markets in greater detail, beginning in each case with the technology and products (with company examples) and concluding with market estimates and forecasts. The market data presented there is based mainly on reports by BCC Research[282]. 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.

7.3 Commercialised products for energy through nanotechnology

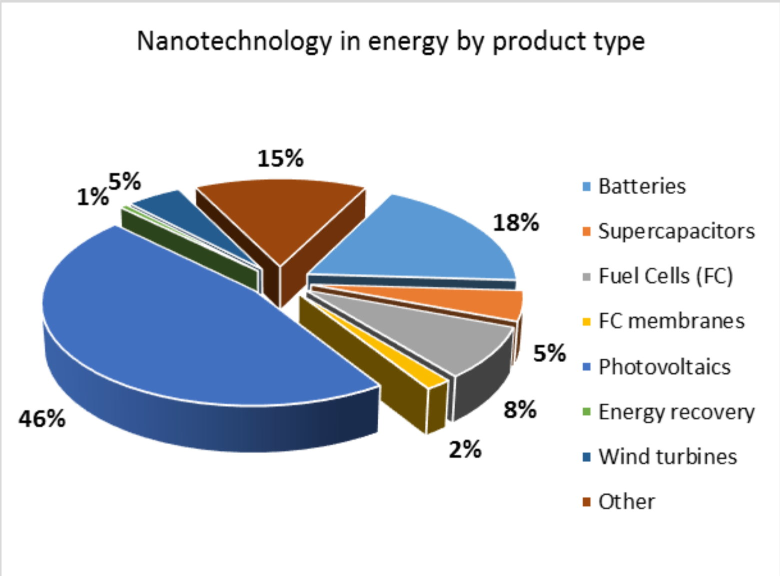
7.3.1 Overview

To date, 168 energy-related products using nanotechnology have been identified as being commercially-available on the market. Almost half (46%) of those are in the area of photovoltaics, coatings and conductive inks that are being used in the production of photovoltaic cells in particular. Lithium ion batteries (18%) account for the second largest share as shown in the figure below.

The four NanoData sub-sectors are:

- Solar energy (Solar, SO);
- Storage, batteries and capacitors (Storage, ST);
- Hydrogen energy and storage (Hydrogen, HY); and
- Alternative power generation technologies (Alternatives, AL).

Products that do not fit into the above sub-sectors were characterised as Other (OT).



Source: JIIP, 2015

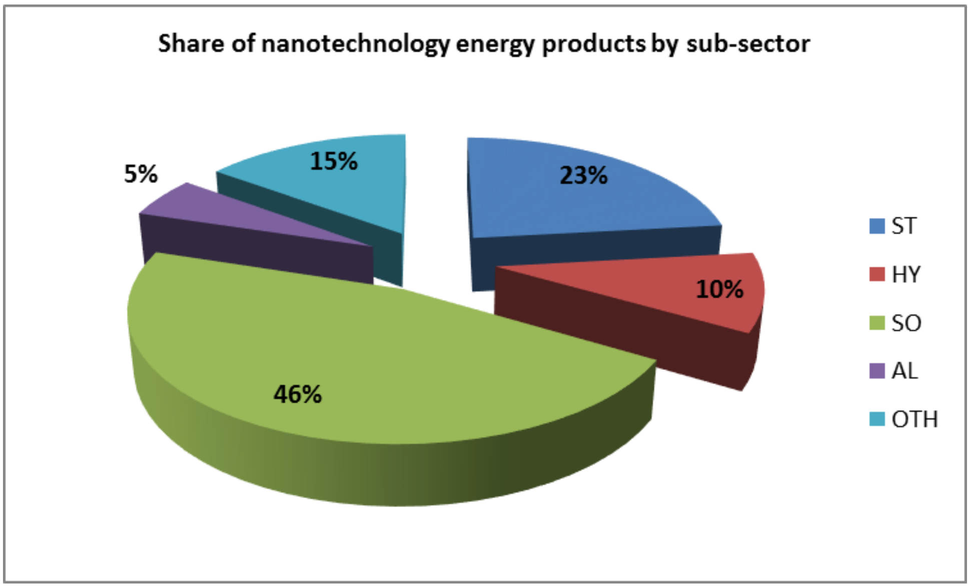
Figure 7-3: Nanotechnology products in energy by application

Given the predominance of photovoltaic products, as expected, the largest share of products (46%) is categorised as solar (SO), as seen in the figure below. Energy storage (ST) accounts for the second

http://www.businesswire.com/news/home/20110221005407/en/Research-Markets-Projected-575-Million-Nanomaterials-World#.VO9G-_nF-UU

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

largest share among subsectors, with 23%. Fifteen percent of products are outside of the five sub-sectors and include mainly aerogels and fuel additives, as shown in the figure below.



Source: JIIP, 2015

Figure 7-4: Share of nanotechnology energy products by sub-sector

7.3.2 Products for energy through nanotechnology, by application market

For the discussion of trends related to products and commercial application markets, the table below provides an overview of intersections between the sub-sectors as defined under the NanoData project and commercial application markets based on existing data[283]. Black dots indicate where data is available and products exist. Fuel cells and fuel cell membranes are categorised as both storage and hydrogen as the two categories overlap in this case.

Table 7-2: Application markets and sub-sectors

	Solar	Storage	Hydrogen	Alternatives	Other
Photovoltaics	•				
Batteries		•			
Fuel cells		•	•		
Fuel cell membranes		•	•		
Energy recovery ventilators				•	
Wind turbines[284]				•	
Diesel fuel additives					•
Petroleum refining					•
Synthetic fuel production					•
Building insulation					•

[283] BCC Research (2014), Nanotechnology, a realistic market assessment.
[284] There are no market data and forecasts available for wind turbines and nanotechnology

Each one of the ten commercial application markets of nanotechnology for energy identified in the table above is considered in more detail below by product type as follows:

- Photovoltaics (solar cells);
- Batteries;
- Fuel cells;
- Fuel cell membranes;
- Hydrogen storage;
- Alternatives
    - Energy recovery ventilators;
    - Wind turbines;
- Other products
    - Diesel fuel additives;
    - Petroleum refining;
    - Synthetic fuel production; and
    - Building insulation.

7.3.2.1 Photovoltaics

A CURRENT PHOTOVOLTAIC TECHNOLOGY AND PRODUCTS

Photovoltaic cells, more commonly known as solar cells or PVs, are devices that absorb light energy from the sun and convert it directly into electricity[285]. There have been three generations of photovoltaic technologies:

- First generation: built on high quality, single crystal silicon wafers, these solar cells consist of large area, single p-n junction diodes which can achieve very high efficiency (close to the theoretical efficiency of 33%) but their production costs are prohibitively high;
- Second generation: thin-film devices based on cadmium telluride (CdTe), copper indium gallium selenide (CIGS), amorphous silicon and micromorphous silicon, these solar cell can function at lower energy levels and have lower production costs. However, they suffer from much reduced energy conversion efficiencies compared to the first generation because of the defects inherent in the lower-quality processing methods.
- Third generation: these are technologies that aim to increase the efficiency of second generation solar cells while maintaining low production costs[286].

It is the third generation that is of most interest here as there are several new technologies available for photovoltaics that make use of **nanoscale thin film materials**, in particular, dye-sensitised solar cells (DSSCs), quantum dot PVs, nanocomposite PVs and graphene-based PVs.

Dye-sensitised solar cells (DSSCs) use titanium dioxide nanoparticles doped with dye molecules (e.g. ruthenium complexes) for charge separation. Light absorption causes the emission of electrons in the dye molecules, electrons that are absorbed by the titanium dioxide particles and transferred to the electrode via a redox electrolyte. The dye molecules are regenerated in the electrolyte by an iodide/triiodide redox couple. Advantages of dye solar cells include cheap manufacturing processes involving screen printing; their ability to operate even at diffuse light levels (e.g. for internal applications) as well as the transparency and colour design possibilities of the cells (for attractive and novel architectural design applications)[287].

Dyesol (Australia) was the first company to produce DSSCs for the commercial market, opening its manufacturing facilities in Queanbeyan, Australia, in October 2008[288]. Other manufacturers of note include Solaronix (Aubonne, Switzerland), G24 Power Ltd. (Newport, UK), and Jintext (Taiwan).

Quantum dots (QDs) are another attractive alternative in the quest to upgrade photovoltaics. They could lead to high power-conversion efficiencies in solar cells as well as offering spectral tunability, as the absorption properties of QDs depend on their size and they can be tuned across the visible light spectrum from the red to the blue region (from 650 to 400nm) by decreasing the particle

[285] Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.6
[286] Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.7
[287] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.37
[288] Dyesol Investor Update 2012

diameter.[289] Solar cells based on quantum dots have several advantages over other types:

- They can be manufactured in a room-temperature process, saving energy and avoiding complications associated with high-temperature processing of silicon and other PV materials;
- They can be made from relatively abundant, inexpensive materials that do not require extensive purification, as silicon does.
- They can be applied to a variety of inexpensive and even flexible substrate materials, such as lightweight plastics[290].

The first quantum dot-based PVs (based on indium arsenide/ gallium arsenide (InAs/GaAs) and produced by Cyrium technologies[291]) have begun appearing on the market and several types of quantum dot PVs are under development. These include intermediate-band-gap solar cells (in which one or more layers of quantum dots are sandwiched between normal PV semiconductor layers) and infrared PVs (quantum dot/polymer nanocomposite)[292].

Nanocomposite PV cells made from cadmium selenide nanorod/p3HT[293] polymer and lead sulphide nanocrystal/MEH-PPV[294] polymer thin films are expected to reach the commercial market at some point in the next five years, along with carbon fullerene-doped polymer solar cells. Konarka's recent bankruptcy has halted the commercialisation of its fullerene-doped Power Plastic polymer solar cells, for the time being at least, but other manufacturers are expected to have one or more similar products on the market by 2017[295].

Significant effort has also been devoted to using **graphene** to improve the overall performance of organic photovoltaic cells (OPVs) and dye sensitised solar cells (DSSCs) with graphene potentially acting as an electrode, an active layer, an interfacial layer and/or an electron acceptor[296].

In June 2013, researchers from MIT announced their aim to develop a new thin, light and efficient solar cell made from **graphene and molybdenum disulphide**, up to 1,000 times more effective than silicon based panels in those three respects. The aim is to maximise the power conversion through a unique method of stacking several layers of graphene and molybdenum disulphide[297].

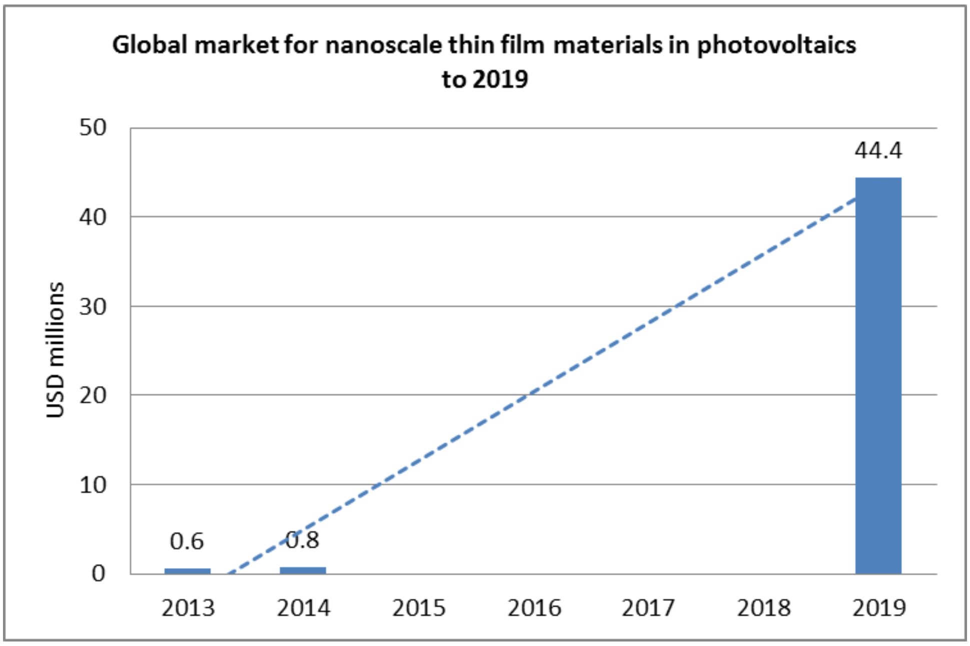
In March 2014, it was reported by researchers from the University of Cincinnati that the addition of even a small amount of **graphene flakes** to a polymer solar cell can improve the performance of the cell by as much as threefold over the conventional non-graphene variant[298].

In 2014, 2-DTech (UK), a manufacturer and supplier of 2D materials, joined with solar technology company Dyesol (Australia) to develop **graphene-enhanced solid state dye-sensitised photovoltaic cells**. Being relatively inexpensive to make, these solar cells would have many deployment advantages but their attractiveness is limited, relative to crystalline silicon PV cells, by their lower power conversion efficiency and shorter operating life. This collaboration will explore the possibility of incorporating graphene nanoplatelets (GNPs) within the perovskite charge-collecting regions of solid-state dye-sensitised solar cells so that efficiency levels can be boosted[299].

MARKET DATA AND FORECASTS [300]

Nanoscale thin film materials consumed in the fabrication of photovoltaics had a total value of USD 600,000 in 2013, rising to USD 800,000 in 2014 and forecast to rise to over USD 44 million by 2019[301].

[289] Laser Focus World: PHOTOVOLTAICS: Quantum Dots promise - next-generation solar cells, Volume: 42, Issue: 4, April 2006
[290] MIT Energy Initiative: New solar-cell design based on dots and wires, March 25, 2013
[291] http://www.cyriumtechnologies.com/
[292] BCC Research (2014), Nanotechnology, a realistic market assessment, p.102
[293] P3HT: poly(3-hexylthiophene)
[294] MEH-PPV: poly(2-methoxy-5-(2'ethyl-hexoxy)-1,4-phenylene-vinylene)
[295] BCC Research (2014), Nanotechnology, a realistic market assessment, p.102
[296] Chang DW (2014), Graphene in photovoltaic applications: organic photovoltaic cells (OPVs) and dye-sensitized solar cells (DSSCs), Journal of Materials Chemistry A Issue 31, 2014: 12136
[297] http://news.mit.edu/2013/thinner-solar-panels-0626
[298] http://phys.org/news/2014-03-discovery-solar-power-expensive-efficient.html
[299] http://www.nanowerk.com/nanotechnology-news/newsid=38410.php
[300] BCC Research (2014), Nanotechnology: A Realistic Market Assessment
[301] Ibid



Source: BCC Research 2014

Figure 7-5: Global market for nanoscale thin-film materials in photovoltaics to 2019

B Emerging market in photovoltaics: Transparent electrodes

Technology trends

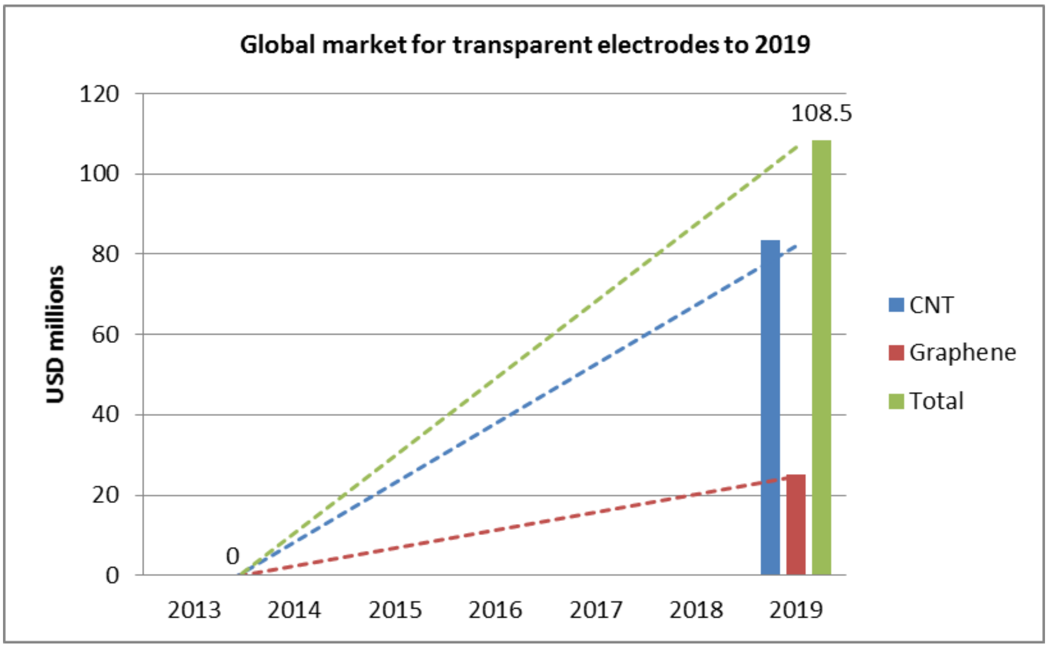
Transparent conducting oxides (TCOs) are electrical conductive materials with a comparatively low absorption of light. Usually prepared using thin film technologies, they are used in opto-electrical devices such as solar cells (photovoltaics), touch screens, LCD displays and other opto-electrical interfaces and circuitries[302]. To date, the industry standard in TCO is ITO, or tin-doped indium-oxide. Activities in this area include:

- Unidym (Sunnyvale, Calif.) has developed a **carbon nanotube**-based transparent electrode intended to replace indium tin oxide. Its CNT-based films are reported to be more mechanically and chemically robust than ITO and can be deposited using a variety of low-cost methods. Unidym has been providing samples to potential customers in the touch screen, LCD display, OLED and solar industries, there being no date set as yet for commercial production of CNT-based films, although it is highly probable to take place in the next five years.[303].
- **Graphene** (which is inherently thin and see-through) also has the potential to replace ITO in transparent electrodes. The EU-funded project GLADIATOR aims to achieve cost-effective production of high quality graphene with a large area suitable for numerous electrode applications. It will run until 2017, having reached its midterm and having already achieved some successes. Applications of the graphene will be demonstrated at the Fraunhofer FEP by integrating it into OLEDs. With graphene as an electrode, the researchers aim to create flexible devices with higher stability. Several types of OLED are being made using graphene electrodes including: a white OLED with an area of about 42 cm^2 to demonstrate the high conductivity, and a fully-flexible, transparent OLED with an area of 3 cm^2 to confirm the mechanical reliability[304].
- In March 2013, the Chinese firm Chongqing Morsh Technology Co. Ltd. received an order from Guangdong Zhengyang Technology Incorporated Company to supply at least 10 million **graphene** conducting film products per year for five years. The first commercial products incorporating the graphene films, possibly mobile phone touch screens, were scheduled to reach the market in late 2014[305].

[302] Andreas Stadler (2012), Transparent Conducting Oxides — an Up-To-Date Overview. Materials 2012, 5: 661
[303] BCC Research (2014), Nanotechnology, a realistic market assessment p.69
[304] http://cordis.europa.eu/news/rcn/128114_en.html
[305] Investorintel: Chinese Firms to launch First Mass Produced 15″ Single-layer Graphene Film, March 27, 2013

Market data and forecasts

Two nanomaterial-based thin film technologies (transparent carbon nanotube-based electrodes (such as the product Unidym is planning to launch in the near future) and graphene-based electrodes) are candidates to replace the indium tin oxide currently used in touch screens, LCD displays, solar cells, OLEDs and other electronic devices. Annual consumption of ITO for these applications is approximately USD 1 billion for the material alone (i.e. excluding deposition costs). Combined sales of these two transparent nanotechnology-based electrode materials could approach USD 109 million by 2019, as shown in the figure below[306].



Source: BCC Research, 2014

Figure 7-6: Global market for transparent electrodes to 2019

Case study: Sol Voltaics AB

Based in Sweden, Sol Voltaics AB[307] is an advanced materials company that has directed its efforts to the development of novel nanostructures in large quantities at low cost. The nanowire technology was developed at the Nanometre Structure Consortium at Lund University, Sweden[308]. Sol Voltaics is a spinout of QuNano AB, a company focusing on commercialisation of research from the University. The nanotechnology used has been particularly directed towards the solar energy domain.

Sol Voltaics AB has developed a nanomaterial that can be used to improve the efficiency of crystalline and thin film solar cells by up to 25 percent. The innovative nanomaterial, in the form of an ink referred to as SolInk, consists of gallium arsenide nanowires in a solution. The nanowires are manufactured using a proprietary manufacturing technology of Sol Voltaics AB (the Aerotaxy technology platform) the wires being made from gaseous form instead of the conventional substrate form. The process is between 100 and 1000 times faster than traditional techniques.

The effectiveness of this Sol Voltaics' technology has been demonstrated in research in collaboration with the University of Lund where a cell of indium phosphide nanowires covering 12 percent of the surface projected an efficiency of 13.8 percent. The latest achievement of the company is a 1-sun record conversion efficiency of 15.3% which has been achieved with

306 BCC Research (2014), Nanotechnology, a realistic market assessment, p.163

307 http://www.solvoltaics.com/

308 NanoLund, formerly known as the Nanometre Structure Consortium, founded in 1988, supports and coordinates activities within nanoscience and nanotechnology at Lund University. http://www.nano.lu.se/

a solar cell coated with its gallium-arsenide (GaAs) nanowire array (NWA) and has been verified by Fraunhofer-ISE. This is twice the efficiency record set earlier by a solar cell coated with its gallium-arsenide (GaAs) nanowire array (NWA).

Sol Voltaics obtained a total funding of USD 15.6 million (SEK 102 million, EUR 11.72 million) enabling it to progress to the pilot phase. Out of this, the Swedish Energy Agency provided a loan of USD 4.66 million (EUR 37.59 million). The remaining USD 9.4 million (EUR 7.06 million) came from a round of equity funding led by Umoe, a Norway based Investment Company. The company's 2014 revenues are valued at c. USD 20 million (EUR 15 million) of which c. USD 16 million (EUR 12 million) have been dedicated to R&D. The company has nearly 40 employees of whom about three quarters are focused on R&D in one way or another.

SolInk can be applied over solar panels to boost their efficiency. The gallium arsenide nanowires can be seen as minute solar cells (with dimensions of about one or two microns in length and around 100 nanometres in diameter). The layer of nanowires acts either as a second layer of solar panel for the silicon panels or as a stand-alone solution for thin-films. One of the most significant challenges associated with gallium arsenide, that limits its application in spite of its high performance, is its cost. This issue can only be addressed through commercial-scale manufacturing.

Such large-scale manufacturing of gallium arsenide could be expected to influence the solar industry as a whole. Sol Voltaics' SolInk technology could be used in cost-effective gallium arsenide solar panels or could be combined with crystalline silicon or thin- film modules in order to make them financially viable. In other words, a traditional crystalline silicon panel with 17% efficiency could be converted into a module with a 22% efficiency rating and the cost of energy brought down to 7 to 9 cents per kilowatt hour with the help of SolInk-equipped solar modules, thus making solar energy more competitive with respect to fossil fuels.

The company projects a strong portfolio of investors and partners and has a patent ownership of 47 patent families.

7.3.2.2 Batteries

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 represented by the general formula Li_yMO_2 ($y \approx 1$), 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[309].

Lithium-ion technology was introduced in the 1990's, increasing the energy density of battery cells by a factor of three and two relative to lead acid and nickel-cadmium (Ni-Cd) batteries respectively. 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[310]. They eventually wear out, and they cannot discharge energy quickly enough for applications requiring power surges, such as camera flashguns and power tools[311].

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 by Professor Yet-Ming Chiang and

[309] 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
[310] Ibid
[311] Graham-Rowe, Duncan (7 March 2005). "Charge a battery in just six minutes". New Scientist.

his group at the Massachusetts Institute of Technology (MIT)[312]. 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[313]. In 2012, Valence Technology filed for bankruptcy[314] 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 submicron 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) mentioned above are another approach to overcome 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 meters per gramme, much larger than the three square meters per gram 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 LTO batteries safety aspects[315]. A disadvantage of LTO batteries is that they have a lower inherent voltage (2.4 V), which leads to a lower energy density of about 30-110Wh/kg than conventional lithium-ion battery technologies (which have an inherent voltage of 3.7 V)[316].

LTO batteries have applications in electric vehicles and charging stations, coaches, yachts, wind and solar energy storage power, traffic signals, solar hybrid street lighting, UPS power supply, home storage, disaster relief emergency, weather radar, electricity, smart grid, communication base stations, hospitals, finance, telecommunications as well as system critical backup power systems[317]. They are used, for instance, in Mitsubishi's i-MiEVelectric vehicle[318] and Honda's Fit EV[319]. Public transportation, such as the large capacity electric bus project TOSA in the Swiss canton of Geneva, is using the high charging capability of LTO batteries to partly recharge the battery in 15 seconds while passengers are disembarking and embarking at bus stops[320].

- 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[321]. Altairnano's LTO batteries are being manufactured mainly for e-mobility applications. Altairnano has also deployed their LTO energy storage systems for electric grid ancillary services and in various military applications[322].
- Toshiba introduced its LTO battery in 2009 under the registered brand name Super Charge Ion

[312] A123 Systems, Inc.: Nanophosphate® Basics: An Overview of the Structure, Properties and Benefits of A123 Systems' Proprietary Lithium Ion Battery Technology
[313] Business Wire: Valence Technology, Inc. and Segway LLC Announce Joint Technology Development Program, November 04, 2004
[314] Chapter 11 in the U.S. Bankruptcy Court for the Western District of Texas
[315] Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015
[316] Green Car Congress: Toshiba Developing 3.0 Ah High Power SCiB Li-Ion Cell for HEV Applications. 21 May 2008.
[317] Investor Intel: Lithium Titanate Battery Technology – Bigger and Better, September 4, 2015
[318] Mitsubishi Chooses Super-Efficient Toshiba SCiB Battery For EVs. Integrity Exports. 2011-06-18.
[319] Toshiba's SCiB battery for the Fit EV. Green Car Congress. Nov 17, 2011.
[320] http://www.tosa2013.com/en#/tosa2013
[321] Bright Hub Engineering: Lithium Titanate Batteries Explained, 1/27/2011
[322] Ibid

Battery (SCiB™). The battery is designed to offer 90% charge capacity in just 10 minutes[323]. SCiB™ batteries are used in the Schwinn Tailwind electric bike[324] and in Mitsubishi's i-MiEV and Minicab MiEV electric vehicles[325].

- Other notable producers of LTO batteries include Leclanché (Yverdon-les-Bains, Switzerland) and Tiankang™ Battery (Hong-Kong, 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[326]. 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[327] 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.

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

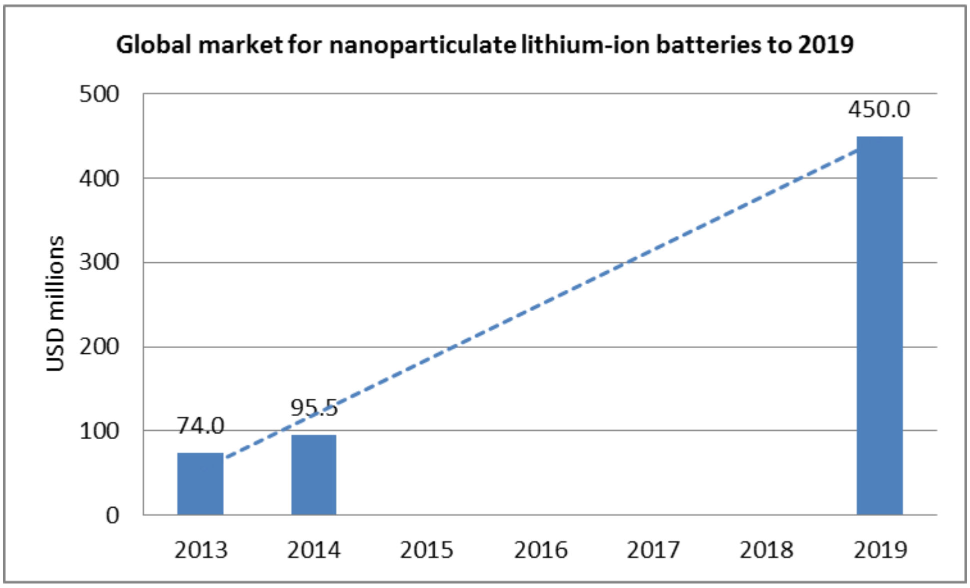
MARKET DATA AND FORECASTS

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.

323 http://www.scib.jp/en/
324 Syonyk's Project Blog: Schwinn Tailwind Battery Pack Teardown and Analysis, Sunday, June 7, 2015
325 http://www.toshiba.co.jp/about/press/2011_06/pr1603.htm
326 Leclanché: TiBox, Product Information
327 http://graphene-flagship.eu/graphene-shows-promise-for-next-generation-rechargeable-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[328].

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[329].



Source: BCC Research

Figure 7-7: Global market for nanoparticulate lithium ion batteries to 2019

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

[328] BCC Research (2014), Nanotechnology, a realistic market assessment, p.133
[329] BCC Research (2014), Nanotechnology, a realistic market assessment, p.134

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 market products: Batteries

B1 Paper batteries using carbon nanotubes

Technology and product trends

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).

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 appears closest to commercialisation is that of "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 ultrathin 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[330].

B2 CNT SUPER-CAPACITORS / ULTRA-CAPACITORS

TECHNOLOGY AND PRODUCT TRENDS

Supercapacitors (sometimes called ultra-capacitors) [331] [332] [333] 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 bridge the gap 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 nanotubular 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[334]. Several companies are pursuing this route, for example:

- 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 [335].

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[336].

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[330] BCC Research (2014), Nanotechnology, a realistic market assessment p.145
[331] With capacitance values greater than 1,000 farads at 1.2 volts
[332] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.46
[333] https://www.quora.com/What-is-meant-by-super-capacitor
[334] Hui Pan, Jianyi Li, and Yuan Ping Feng (2010), Carbon Nanotubes for Supercapacitor, Nanoscale Res Lett. 2010; 5(3): 654–668.
[335] http://www.greencarcongress.com/2012/06/skelcap.html
[336] BCC Research (2014), Nanotechnology, a realistic market assessment p.145

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[337]. 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[338].
- 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 one thousand times without significant loss of performance[339].
- 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** 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[340].
- 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[341].
- 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

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

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[337] http://www.graphene-info.com/graphene-supercapacitors
[338] http://phys.org/news/2014-10-energy-storage-future.html
[339] http://news.mit.edu/2014/crumpled-graphene-energy-storage-1003
[340] http://www.businesskorea.co.kr/english/news/sciencetech/4156-supercapacitor-tech-electric-vehicles-be-charged-1000-times-faster
[341] http://www.graphene-info.com/graphene-supercapacitors

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 super-capacitors

Technology and product trends

- 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)[342].
- 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[343]. 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[344] (Dublin, Ireland) is the producer of what is currently the only aerogel super-capacitor that is commercially available. Cooper Industries was acquired by the Eaton Corporation (Dublin, Ireland) in 2012.

Market potential

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).

7.3.2.3 Fuel cells

Technology and products

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.[345]

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[346]. 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).

[342] Ibid
[343] David G. Morrison, Carbon Foam Whips Up Greater Power Density For Supercapacitors, Electronic Design, Apr 3, 2000
[344] http://www.cooperindustries.com/content/public/en/bussmann/electronics/brands/powerstor.html
[345] 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.
[346] 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

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[347].

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[348].

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'[349] scheme for home fuel cells, with a planned installation of 50,000 units[350] and strong market growth[351].

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 25 experts working on products including Kraftwerk® (https://www.kickstarter.com/projects/ezelleron/kraftwerk-highly-innovative-portable-power-plant/posts/1396357), their award winning fuel-cell powered fast-charging device for mobile applications, a crucial product for the company. 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

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

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

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

349 "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/

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

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

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 7-3: Global market for fuel cells and platinum thin-film catalysts to 2019 (US 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: BBC Research, 2014

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%).

7.3.2.4 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[352].

DuPont™ Nafion ® PFSA membranes are non-reinforced films based on chemically-stabilised perfluorosulphonic acid/PTFE[353] 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[354].

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^{O} Celsius. New proton-conducting materials are needed in order to improve the commercialisation of PEMFCs[355].

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

352 Serrano E et al. (2013), Nanotechnology for Energy Production, in: Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge, p.22.
353 PTFE: polytetrafluoroethelyne
354 DuPont Fuel Cells: DuPont™ Nafion® PFSA Membranes, product information
355 Jurado J, et al. (2002), Protonic Conductors for Proton Exchange Fuel cells: an overview, Chem. Ind. 56 (6): 265

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[356].

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[357].

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.

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[358].

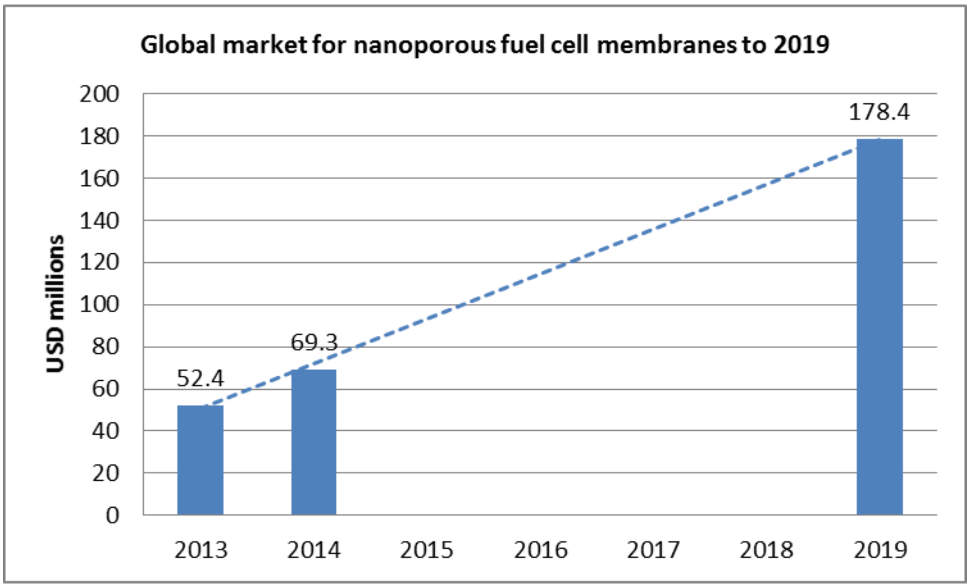
Table 7-4: Fuel cell sales by technology type to 2019

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

[356] https://genesisnanotech.wordpress.com/2015/04/26/nanotechnology-in-fuel-cells/
[357] http://cordis.europa.eu/result/rcn/86118_en.html
[358] BCC Research (2014), Nanotechnology, a realistic market assessment, p.168

Increasing competition from alternative (nanoscale and non-nanoscale) fuel cell membrane materials are expected to impact on the future market for nano-porous polymer membranes like Nafion. While fuel cells equipped with Nafion and similar nano-porous 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[359]. This will be compensated for by the overall growth in the size of the market, as seen in the figure below.



Source: BBC Research, 2014

Figure 7-8: Global market for nanoporous fuel cell membranes to 2019

B Emerging market products: Nanocomposite fuel cell membranes

Technology and product trends

Nanocomposite 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 nanocomposite membranes incorporating inorganic nanoparticles such as clay, ZrO_2, SiO_2, TiO_2 and zeolites have been developed. As a group, these nanocomposite membranes show higher conductivity and water uptake than unmodified Nafion as well as better thermomechanical properties[360].

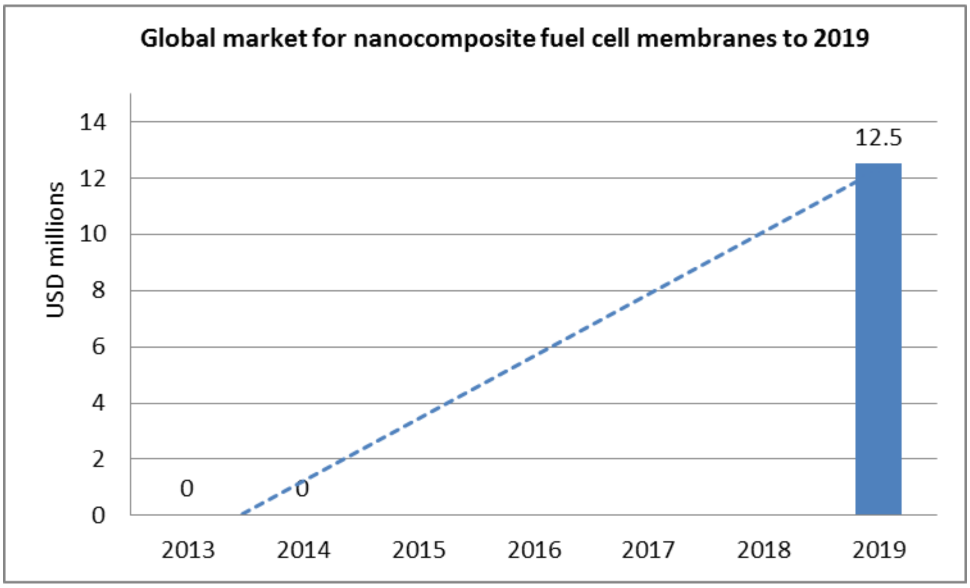
SiM Composites[361] (Quebec, Canada), has developed an alternative **nanocomposite membrane** technology that it calls SiMION. Data are not available on the composition of SiMION, but it may use a modified polyetheretherketone (PEEK) polymer in which silica nanoparticles are embedded. According to the 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[362].

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. 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

[359] BCC Research (2014), Nanotechnology, a realistic market assessment p.169
[360] BCC Research (2014), Nanotechnology, a realistic market assessment, p.124
[361] http://www.simcomposites.com/
[362] Ibid

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[363].



Source: BBC Research, 2014

Figure 7-9: Global market for nanocomposite fuel cell membranes to 2019

7.3.2.5 Hydrogen storage: Products by emerging market

A CNT-BASED HYDROGEN STORAGE

TECHNOLOGY AND PRODUCT TRENDS

In the field of hydrogen storage, application possibilities of nanotechnologies are mainly found in the optimisation of solid-state storage tanks. The tanks reversibly bind hydrogen (either chemically or by adsorption) into the storage material and release it again[364]. Storing hydrogen as a solid may offer the best option to store hydrogen through two basic mechanisms: physi-sorption (or physical adsorption) and chemisorption (or chemical adsorption). In physi-sorption, molecular hydrogen is adsorbed by intermolecular (van der Waals) forces. Examples of physi-sorption include the storing of hydrogen in carbon structures and organic or inorganic frameworks[365].

Carbon materials with a high surface area, good chemical stability and low density have received considerable attention for potential solid hydrogen storage. **Nanostructured carbon materials** (such as graphitic nano-fibres (GNF), multi-walled carbon nanotubes (MWNT), single-walled carbon nanotubes (SWNT), carbon nano-rods and carbon aerogels) demonstrate novel properties depending on the configuration of the electronic states of the carbon atoms[366].

Early reports on hydrogen storage in **carbon nanotubes and graphitic nano-fibres** proposed high storage capacities (up to 67 wt %) and started an extensive worldwide surge in research. Since then many experiments have been carried out using different methods, but such high values have not yet been reproduced by other groups. Furthermore, no hypothesis could support the unusually high storage capacities, and the high storage capacity results were more related to the faults of experiment. Nevertheless, hydrogen adsorption on carbon materials is still an attractive and improving field[367].

Responding to these technological challenges the US Department of Energy (DOE) in July 2003 issued a "Grand Challenge" for Basic and Applied Research in Hydrogen Storage. This Grand

[363] BCC Research (2014), Nanotechnology, a realistic market assessment p.203
[364] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.51
[365] Saghar Sepehri and Guozhong Cao (2009), Nanostructured Materials for Hydrogen Storage, in Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge,: p.139
[366] Saghar Sepehri and Guozhong Cao (2009), Nanostructured Materials for Hydrogen Storage, in Javier Garcia-Martinez (ed.) (2010), Nanotechnology for the Energy Challenge,: p.141
[367] Ibid

Challenge called for the establishment of hydrogen storage Centres of Excellence on Metal Hydrides, Chemical Hydrogen Storage, and Carbon-Based Materials, led by a DOE national laboratory and having a number of university, industry, and Federal laboratory partners. The Carbon-Based Materials Centre (2005-2010) was led by the National Renewable Energy Laboratory (NREL) in Golden, Colorado. The NREL Centre focused on breakthrough concepts for storing hydrogen in carbon-based materials such as **hybrid nanotubes, aerogels, and nano-fibres**, as well as novel materials such as metal-organic frameworks and conducting polymers. The Carbon Centre included seven university partners, one industrial partner, and four Federal laboratories[368].

Solid-state storage of hydrogen is a promising practical technology, but there is still no material or method that meets the requirements for a high-quality storage system[369]. There are therefore low expectations for successful commercial market applications of hollow carbon nanostructures to hydrogen storage in the next few years.

Market potential

In its report, EGY055B Building the Global Hydrogen Economy: Technologies and Opportunities, BCC Research projected that a commercial market for mobile hydrogen storage tanks should begin to develop between 2014 and 2019, when sales of the tanks are projected to reach at least USD 10 million. However, carbon nanotubes are only one of several technologies competing to supply this market, along with metal hydrides, zeolites, polymeric foams and other technologies. Particularly in view of the technical obstacles to commercialisation of carbon nanotube storage of hydrogen, nanotubes are unlikely to share in the small market that is expected to develop by 2019[370].

7.3.2.6 Alternatives

A Energy recovery systems for buildings

Technology and product trends

Energy recovery ventilation (ERV) is a process in residential and commercial heating, ventilation and air conditioning systems (HVAC systems) in which the energy contained in normally exhausted building or space air is recovered and used to treat (precondition) the incoming outdoor air. During the warmer seasons, the system pre-cools and dehumidifies. During the cooler seasons, it humidifies and pre-heats the air[371]. Companies active in this area include:

- Dais Analytic Corp. (Odessa, Fla.) uses a proprietary **nanostructured polymer filter** in the ConsERV systems which it manufactures and markets. The system preconditions incoming air by passing it through the nanostructured filter. According to the company, the ConsERV system is twice as effective as alternative technologies in managing latent and sensible[372] heat. Dais uses the same nanostructured polymer filter in its NanoAir system, which is still under development. NanoAir can replace traditional heaters (as well as air conditioners) simultaneously improving air quality and energy efficiency. The system can be used in many types of commercial and residential buildings and vehicles[373].
- Viessmann (Allendorf, Germany) has developed a **gas-driven zeolite** heating device to improve energy conversion efficiency and emission reduction for the heating of houses. The device combines a zeolite-water adsorption heat pump and a gas condensing boiler. The pump supplies heat at a higher temperature level by adding low-temperature heat to the work process. Due to the additional supply of ambient heat to the process, efficiencies of up to 135% relative to the heating value can be achieved, outperforming conventional condensing boilers with a maximum efficiency of 111%. This corresponds to a reduction in CO2-emission of 20% compared to the state-of-the-art in gas heating of detached and semi-detached houses[374].

[368] Antonio Bouza, John Petrovic, Carole Read, Sunita Satyapal, and Joann Milliken (2004), the National Hydrogen Storage project, Prepr. Pap.-Am. Chem. Soc., Div. Fuel Chem. 2004, 49(2),839

[369] Saghar Sepehri and Guozhong Cao (2009), Nanostructured Materials for Hydrogen Storage, in: p.151

[370] BCC (2014), Nanotechnology, a realistic market assessment, p.144

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

[372] Sensible heat is heat exchanged by a body or thermodynamic system that changes the temperature, and some macroscopic variables of the body, but leaves unchanged certain other macroscopic variables, such as volume or pressure (https://en.wikipedia.org/wiki/Sensible_heat)

[373] BCC Research (2014), Nanotechnology, a realistic market assessment, p.77

[374] Hessen Nanotech (2008), Application of Nanotechnologies in the Energy Sector, p.60

Company snapshot: Dais Analytic Corp.

Dais Analytic Corp. is a nanotechnology company providing applications for heating & cooling, water treatment and energy storage. Their formation goes back to 1993 as Dais Corporation, but it was not until 1999 that the company was incorporated as a nanotechnology polymer materials and processes company when they purchased the assets of Analytic Power Corporation.

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

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

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

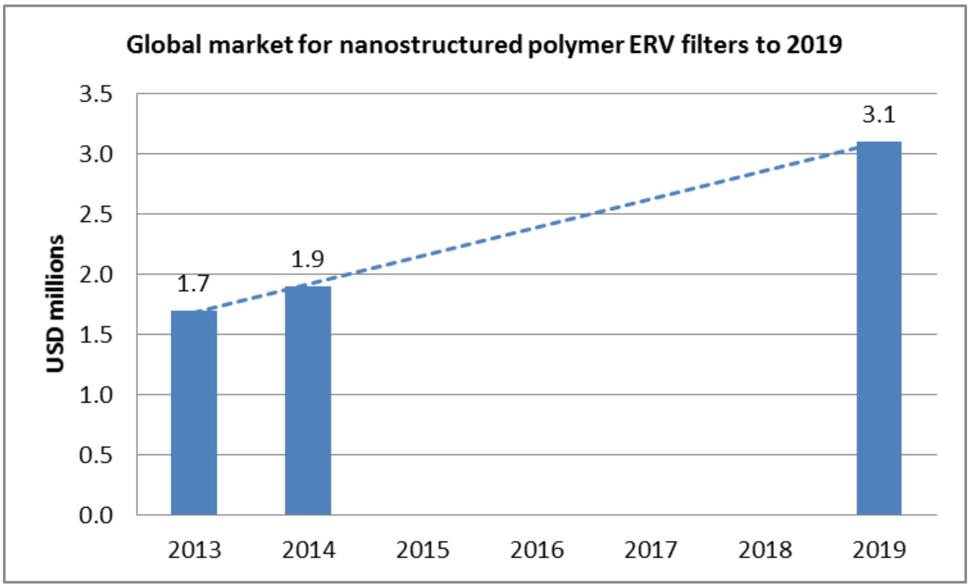
Also in 2015, Dais announced that it has raised USD 75 million for 18,000,000 shares in order to further the commercialisation of its products.

See: http://www.daisanalytic.com

MARKET DATA AND FORECASTS

In 2013, Dais Analytic Corp. earned about USD 1.7 million from sales of its ConsERV energy recovery ventilation system with its nanostructured polymer filter. Sales of ConsERV have grown at a CAGR of more than 10% since 2008. At this rate, sales should approach USD 3.1 million by 2019[375].

[375] BCC Research (2014), p.169



Source: BCC Research

Figure 7-10: Global market for nanostructured to 2019

B MATERIALS AND COATINGS FOR WIND TURBINES

TECHNOLOGY AND PRODUCTS

In wind turbines, **carbon nanotubes** can be used within the blades themselves making them stronger and lighter thereby improving energy efficiency. These blades are 50% lighter than glass fibre blades. The blades are also significantly stronger so larger blades can be used which will also start operating at lower wind speeds.

Bayer (since August 2015 Covestro) has been supplying its carbon nanotubes for use in the construction of carbon composite wind turbine blades for a Chinese manufacturer. The unusually high strength of the material (Hybtonite) is attributable to the Baytubes™ brand carbon nanotubes supplied by Bayer Material Science (since August 2015 Covestro). A Bayer Material Science customer in China manufactures rotor blades between 40 and 50 metres long from Hybtonite for large wind power plants[376].

Nanocoatings are also impacting the wind energy market, with **hydrophobic nanocoatings** applied to blades to prevent ice formation. **Anti-corrosion nanocoatings** are finding applications in shore wind turbines to fight corrosion caused by the conditions at sea[377]. Alpha Nano Solutions (Ashford, UK) manufactures hydrophobic, easy clean and low maintenance coatings for application to the blades of wind turbines.

REWITEC (Lahnau, Germany) sells REWITEC **Nanocoating as a protection** for wind turbine transmission and bearings, even under extreme environmental conditions. The metal-silicate layer created improves tribological properties, reduces pitting and grey staining, increases the scuffing load capacity, reduces the need for replacement components, extends operational lifecycles and, in consequence, increases system profitability[378].

MARKET DATA AND FORECASTS

There are no market data estimates for this application market.

7.3.2.7 Other products

A DIESEL FUEL ADDITIVES

TECHNOLOGY AND PRODUCTS

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[376] Neville T (2012), Industrial Wind Energy, BLAWS Honours Research Paper
[377] Nanotech Mag: Wind Turbines, September 2014
[378] REWITEC Nanocoating, product information

Multilayer ceramic capacitors, or MLCCs, are important building blocks in modern electronics and Efforts to reduce diesel particulate emissions include the use of **oxidation catalysts; diesel particulate filters (DPFs); low-sulphur diesel fuels; and fuel additives**. Some additives also improve fuel economy. One class of diesel fuel additives gaining acceptance comprises engineered nanomaterials composed of cerium compounds (nCe). These fuel additives also reduce emissions of fine particulate matter (PM2.5, i.e. 2.5 micrometre particulate matter) and alter the emissions of carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbon (HC) species, including several HAPs (hazardous air pollutants)[379].

Envirox is a cerium oxide-based **nanocatalyst for diesel fuels** manufactured by Energenics Pte Ltd. (Singapore) which lowers fuel costs, by reducing fuel consumption, with a corresponding reduction in greenhouse gas emissions (CO2) and other harmful exhaust emissions[380].

Clean Diesel Technologies, Inc.[381] 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). It also improves combustion which acts to reduce engine-out emissions. This FBC takes catalytic action into 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 enabling solutions, including: diesel particulate filtration, low emission biodiesel, carbon reduction and exhaust emissions reduction.

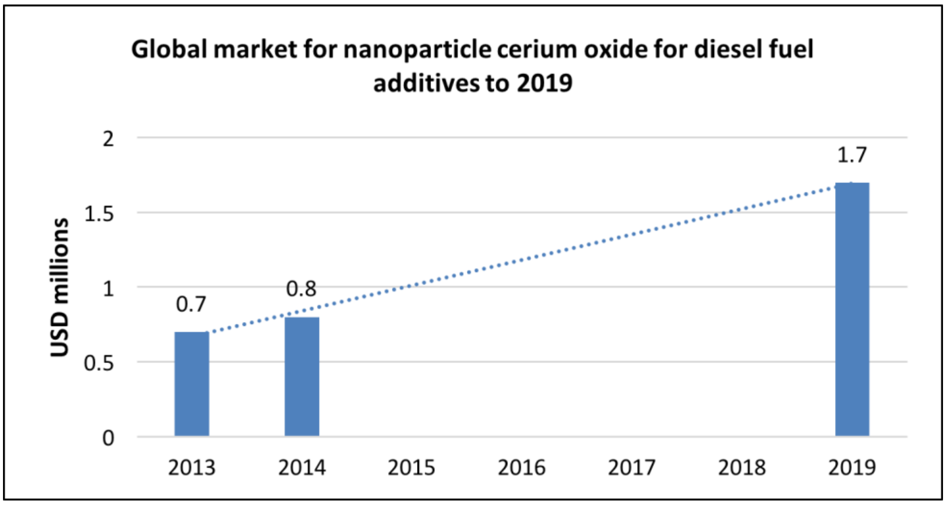
Eolys PowerFlex® is another **cerium oxide-based nanocatalyst for diesel fuels** (manufactured by Solvay) that was initially developed by Rhodia Electronics & Catalysis (now Solvay). Eolys PowerFlex® is being used with Peugeot diesel engines on basis on a long-term co-operation between Peugeot SPA and Rhodia that began in 1992.

MARKET DATA AND FORECASTS [382]

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 Petrol Ofisi (the Turkish national oil and gas company) with USD 12 million worth of Envirox per year.

Assuming that Energenics will, by 2019, be able to restore Envirox sales to at least the level prior to the loss of the Petrol Ofisi contract, USD 12 million, from the USD 3.6 million of 2013 (CAGR of 15.7%), generating nearly USD 1.7 million in consumption of ceria nanopowders on a proportional basis in 2019.

[379] Green Car Congress: EPA researchers find widespread use of nano cerium diesel fuel additives could have measurable impact on air quality, 21 October 2014
[380] http://www.energenics.co.uk/
[381] http://investor.cdti.com/
[382] BCC Research (2014), Nanotechnology: A Realistic Market Assessment, p.132



Source: BCC Research, 2014

Figure 7-11: Global sales for nanoparticulate cerium oxide for diesel fuel additives to 2019

Case study: Energenic 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 following a legal dispute over the intellectual property of the product. During 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 GBP 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: funding to Energenics of EUR 131,000) 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 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 (funding to Energenics of GBP 197,000) 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.: funding to Energenics of EUR 15,000). However, ReactaFire 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 (TRL) 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 Horizon 2020 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 USD 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 US.

2. As a small company, Energenics needs 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.

B Petroleum refining

Technology and products

Nanoparticulate catalysts used in petroleum refining include **nanoparticulate iron and nickel** for fluid catalytic cracking applications and molybdenum-disulphide (MoS_2) nanoclusters with cobalt and nickel nanoparticles for hydro-desulphurisation of petroleum. Many of these catalysts are proprietary, making it difficult to obtain much information about their properties, but it is assumed in market forecasts that they are nanoparticulate[383].

Rive Technology Inc.[384] (Cambridge, MA, USA) is a clean energy company, commercialising advanced **nanocatalyst technology** for petroleum refining to dramatically increase the yield of transportation fuels produced per barrel of crude oil. The proprietary technology, invented at MIT, makes traditional zeolite catalysts more accessible to large hydrocarbon molecules, allowing increased production of gasoline and diesel fuel. Rive's catalyst can be adopted by existing refineries and enable refiners to increase throughput and profitability with minimal capital investment[385].

Company snapshot: Rive Technology Inc.

Rive Technology, Inc. operates as a catalyst technology company for the petroleum refining industry. The company develops materials-based solutions for catalytic and separations processes, such as those in the petroleum refining, chemicals, and biofuels industries. It offers RiveCat, a catalyst that focuses on the conversion process in the refinery–fluid catalytic cracking.

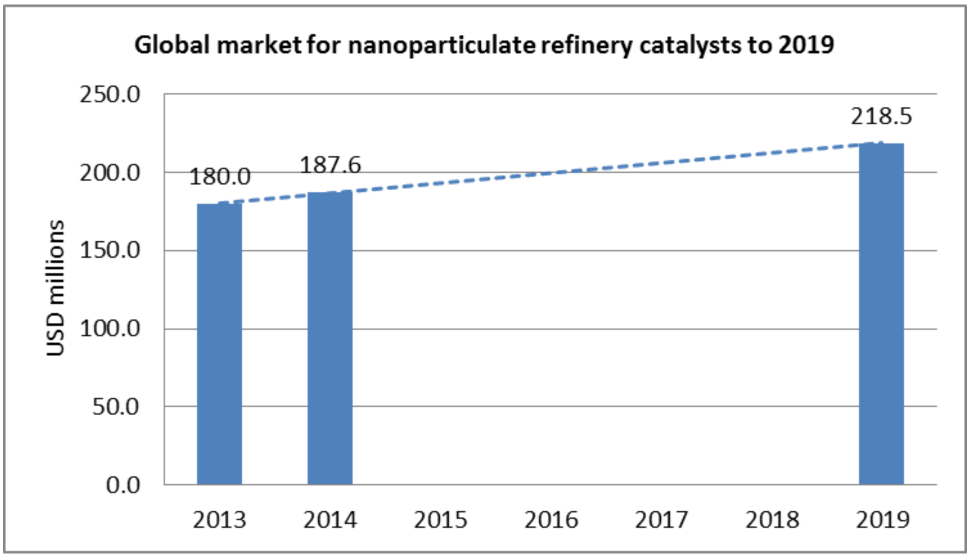
The company was founded in 2005 and is based in Cambridge, Massachusetts with a research and development branch in Princeton, N.J., USA. Rive has raised more than USD 67 million in venture capital and — as of 2010 — is partnered with W.R. Grace, a global supplier for refining technology, to manufacture its first commercial product. Two U.S. refineries have successfully trialled the technology. Last year, Rive demonstrated the technology's effectiveness in a paper published in the journal Chemical Communications.

In 2014 Rive Technology and Zeolyst International announced that they had entered into a Joint Development Agreement to further develop, manufacture, and market hydrocracking catalysts within the petroleum refining sector. http://www.rivetechnology.com/

Market data and forecasts

383 BCC Research (2014), Nanotechnology, a realistic market assessment, p.103
384 http://www.rivetechnology.com
385 Nanotech etc.: Nanotechnology used to improve oil refining process, November 22, 2013.

Nanoparticulate refinery catalysts are, in large part, proprietary. However, based on available data, it has been estimated the overall market for nanocatalysts in the refining industry was USD 180 million in 2013. The projections in the table below assume that the demand for refinery catalysts is proportional to the demand for refined petroleum products, and that the latter in turn is driven by trends in global GDP. Growth rates will remain around a CAGR of 3.1% to 2019.



Source: BCC Research

Figure 7-12: Global market for nanoparticulate refinery catalysts to 2019

C SYNTHETIC FUEL PRODUCTION

TECHNOLOGY AND PRODUCTS

Liquid fuels from coal may be produced using two different approaches, i.e. direct and indirect coal liquefaction (DCL and ICL), which are at a different stage of development. In both DCL and ICL, the challenge is to increase the hydrogen to carbon ratio (H/C) of the final product, and to produce molecules with appropriate boiling point at a reasonable overall cost[386]. The DCL process consists of the dissolution of coal in a mixture of solvents. This is followed by thermal cracking, whereby hydrogen is added as a donor solvent[387]. In the ICL process, the first step is the gasification of coal to produce a synthetic gas (syngas), which basically consists of carbon monoxide and hydrogen[388]. The second step consists of the conversion of the carbon monoxide and hydrogen in the syngas (using catalysts) to a range of hydrocarbon fuels/products such as gasoline, diesel, methanol and chemicals)[389].

Energy Catalysis Inc.[390] (Bordentown, NJ, USA) proposes a direct coal liquefaction technology and a direct biomass/coal liquefaction technology. Both platforms have been developed within R&D programmes funded by the US Department of Energy. The combination of novel **nanocatalysts** and reactor system will allow economic production of clean liquid fuels from coal, biomass/coal and other low-volatile hydrocarbons at a cost of less than USD 40 per barrel of synthetic crude oil. The technology is also applicable to refining heavy petroleum feedstock. The technology is more cost effective than current commercial processes.

Hydrocarbon Technologies Inc. (HTI) has developed a direct coal liquefaction (DCL) process used for converting coal into ultra-clean transportation fuels, such as gasoline, jet fuel, and diesel fuel, licensing the technology internationally (using **nanocatalysts**)[391]. A major project in China, worth USD 2 billion, was announced in the early 2000's involving the US's Department of Energy,

[386] IEA ETSAP Technology Brief S02 – May 2010, p.1
[387] Ibid
[388] IEA ETSAP Technology Brief S02 – May 2010, p.3
[389] http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/indirect-liquefaction
[390] http://energycatalysis.com/
[391] HTI Company Brochure

Hydrocarbon Technologies Inc. (a part of Headwaters Inc.) and Shenhua Group Corp., China 's largest coal company. The goal was to produce (mainly) diesel and gasoline from local low-sulphur coal, in a coal to liquid (or CTL) plant. The plant, located in Majata Province, Inner Mongolia, opened in November 2010 with an operating capacity of 1.2 million tons (70,000 barrels) annually[392] [393]. The aim for the facility was to produce 6 million tons of oil products per year[394]. It employed US-developed technology from Headwaters Inc. and Hydrocarbon Technologies Inc. (HTI) in conjunction with West Virginia University and the US Department of Energy.

Nanoparticles used in HTI's coal liquefaction process include several proprietary nano-engineered catalysts, including catalysts synthesised from aqueous solutions of iron salts with small percentages of elements such as cobalt, molybdenum, palladium, platinum, nickel, tungsten, or combinations thereof. Instead of the more common practice of allowing catalyst atoms to naturally form random geometric patterns on a support material, the HTI method guides these individual atoms into orderly and predictable arrangements[395]. HTI has also formed a strategic alliance with Axens (Rueil Malmaison, Hauts De Seine, France) called "Alliance DCL" to provide a single-source solution for producing ultra-clean fuels by direct coal liquefaction (DCL) alone or in combination with refinery residues or biomass. The two companies have combined their technologies and licensing activities for CTL projects worldwide[396].

Company snapshot: Headwaters Technology Innovation Group Inc.

Headwaters Technology Innovation Group, Inc. provides products, technologies, and services to the energy, construction, and home improvement industries. Its activities include producing biofuel; managing and marketing coal combustion products, including fly ash; designing, manufacturing, and marketing architectural stone veneer, concrete blocks, and bricks; and developing and deploying a range of technologies that improve natural resource utilisation, including heavy oil upgrading, coal liquefaction, and nanocatalyst applications. The company is based in Lawrenceville, New Jersey. Founded in 1943 as Hydrocarbon Research Inc., HTI is now a wholly-owned subsidiary of Headwaters Incorporated, whose headquarters are in South Jordan, Utah.

HTI offers the following technologies in the production of clean energy products from heavy oil or coal feedstocks: 1) the HCAT® Process—a proprietary patented method of hydrocracking heavy residual oil with low sediment formation; and 2) Direct Coal Liquefaction—a technology for producing ultra-clean fuels, from coal alone, or in combination with refinery residues or biomass.

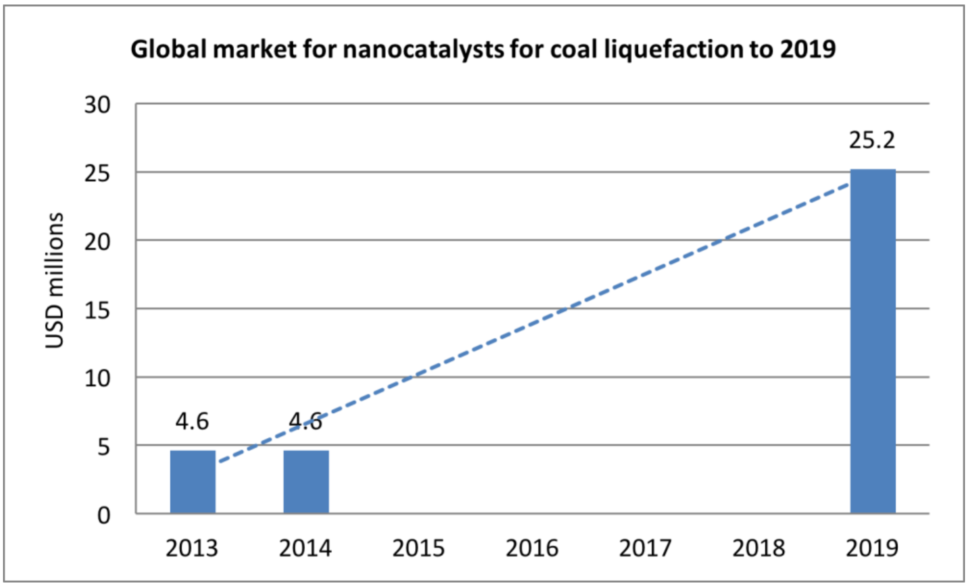
HTI is a world leader in hydro-processing (hydrogen-addition upgrading) technologies. Their technologies have been licensed and are in use, at the commercial scale, at several international locations.

See: http://hcat-hti.com

Market data and forecasts

The annual consumption of nano-catalysts by the Shenhua plant is estimated to be of the order of USD 4.6 million in 2013 and 2014, rising to USD 25.2 million in 2019 if it reaches its targeted annual output of 6 million tons of oil products[397].

[392] Nanonordic: Nanocatalysis: Particles for Peace (PfP)?
[393] World Energy Crisis: A Reference Handbook, By David E. Newton
[394] http://www.hydrocarbons-technology.com/projects/shenhua/
[395] BCC Research (2014), Nanotechnology, a realistic market assessment p.36
[396] Business Wire: Headwaters Incorporated and Axens Form Direct Coal Liquefaction Alliance, January 19, 2010
[397] BCC Research (2014), Nanotechnology, a realistic market assessment, p.131



Source: BCC Research

Figure 7-13: Global market for nano-catalysts used in coal liquefaction to 2019

D Building insulation

Technology and products

Aerogels are a diverse class of porous, solid materials that exhibit several extreme materials properties. Most notably, they have extremely low densities (ranging from 0.0011 to c. 0.5 g/cm^3). In fact, the lowest density solid materials that have ever been produced are all aerogels, including a silica aerogel only three times heavier than air that could be made lighter than air by evacuating the air out of its pores. However, most aerogels have densities of 0.020 g/cm^3 or higher (about 15 times heavier than air). Aerogels are 95-99% air[398] and are the dry, low-density, porous, solid framework of a gel when it is isolated from the liquid component. Aerogels have pores in the diametre range of <1 to 100 nanometres, being usually less than 20 nm[399].

Most aerogels are formed from silica although they have also been prepared from many other materials, including alumina, tungsten oxide, ferric oxide, tin oxide, nickel tartrate, cellulose, cellulose nitrate, gelatine, agar, egg albumen and rubber. Aerogels reportedly have the highest thermal insulation value of any solid material[400].

Company activity in this area includes the following:

- Aspen Aerogels, Inc.,[401] (Northborough, MA, USA) is an energy technology company that designs, develops, and manufactures aerogel insulation products used primarily in energy infrastructure facilities. Its products include Pyrogel XT/XT-E, used to reduce the risk of corrosion under insulation in high temperature operating systems; Pyrogel XTF, for fire protection; Cryogel Z for use in sub-ambient and cryogenic applications in the energy infrastructure market; and Spaceloft Subsea used in pipe-in-pipe applications in offshore oil production. The company also provides Spaceloft that is used in the building and construction market; and Cryogel X201, which is used in cold system designs, including refrigerated appliances, cold storage equipment, and aerospace systems where space is at a premium.
- Quartzene® by Svenska Aerogel AB[402] (Gävle, Sweden) is a silica aerogel which has excellent insulation properties and can resist temperatures up to 650°C due to the material's porosity. Even though exposed to high temperatures the material will never burn. Quartzene® is a fine and porous silica-based powder. To handle the powder and use its superb insulation capacity it

398 http://www.aerogel.org/
399 Ibid
400 BCC Research (2014), Nanotechnology, a realistic market assessment, p.76
401 www.aerogel.com
402 www.aerogel.se/

has to be made into a more manageable form, such as a board or a blanket. In order for this to happen, a form or a binding agent is needed.

- Fixit 222 Aerogel High-Performance Insulating Plaster by Fixit AG[403] (Holderbank, Switzerland) is another example of a silica aerogel that is specially designed for the retrofitting of the old buildings that are very commonly found in central Europe.

Company snapshot: Svenska Aerogel AB

Svenska Aerogel AB[404] is a Swedish SME that was founded in 2000 as a spin-off from the University of Gävle and the Royal Institute of Technology in Stockholm by two researchers from these institutions. In the first decade of its history, the company focussed on research and development and, in 2010, Svenska Aerogel AB made a breakthrough and started producing different grades of nanoporous silica-based aerogel material, Quartzene®.

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

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

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

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

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

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

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

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

Svenska Aerogel AB grew from two to eleven staff members in 2015, and expects to hire up to four more staff members in the coming year.

The company's future looks bright as the beginning of 2016 is seen as a tipping point. In 2016, the company will invest in production and plans to hire four or five new staff members.

Quartzene® does not consist of nanoscale particles. The product is in the micron range and it

403 www.fixit.ch

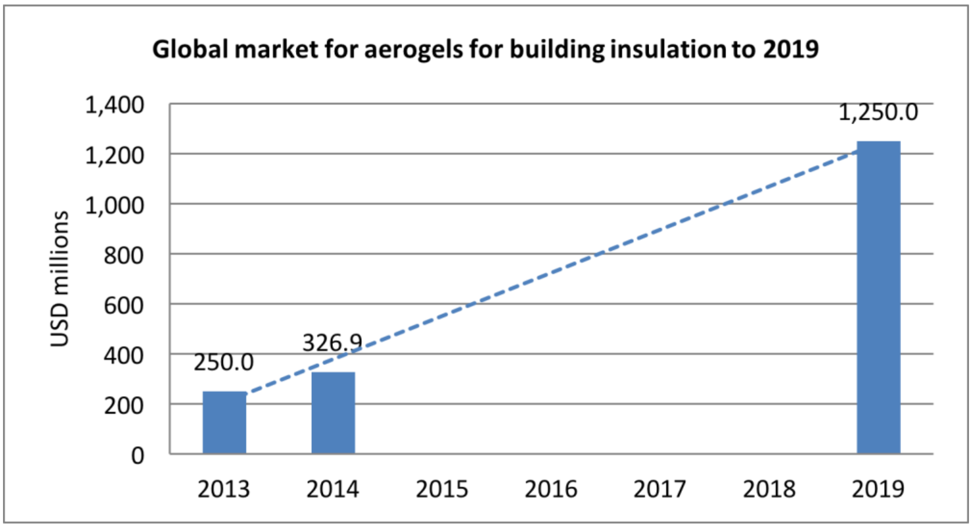
404 http://www.aerogel.se/

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

MARKET DATA AND FORECASTS

The global market for building insulation was estimated at about USD 20 billion in 2013 with aerogel insulation taking about a 1.25% share of that market (USD 250 million). By 2017, it is projected to approach USD 29 billion.

As a benchmark for aerogels' potential market penetration by 2019, cellulose insulation took about 10 years after its introduction in the early 1990s to capture a 15% share of the U.S. market. Forecasters predict that it is unlikely that aerogel insulation sales would show a similar growth rate but a fivefold increase, to some USD 1.2 billion, is seen as potentially achievable (see figure below).



Source: BCC Research, 2014

Figure 7-14: Global market for aerogels in building insulation in 2019

Nanotechnology sees application in energy across areas as diverse as batteries, solar cells, hydrogen storage, fuel additives, insulation and energy recovery systems. It is noticeable that the use of nanotechnology for energy is strongly reliant on its physical properties, as a monolith (in building insulation), as a coating (for wind turbines and PV) or as an additive of some sort (CNT or nanoparticle) as well as in thin-film form.

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

8 THE WIDER ENVIRONMENT FOR NANOTECHNOLOGY AND ENERGY

8.1 Regulation and standards for nanotechnology

Legislative frameworks for energy production and storage do not currently include nano-specific provisions. Nanomaterials used in energy production are nevertheless regulated similarly to other chemical substances in most countries. Nanomaterials may also require registration in country where nanomaterial reporting schemes have entered into force.

8.1.1 European regulations for nanotechnology

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

Table 8-1: Overview of regulations for nanotechnology use in Europe

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

The EU is actively developing a set of regulations around nanotechnology. With the first Regulatory Review on Nanomaterials SEC (2008) 2036 and the Second Regulatory Review on Nanomaterials SWD (2012) 288 final, the EC has given Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) a central role in regulating nanomaterials. "There are no provisions in REACH referring explicitly to nanomaterials. However, nanomaterials are covered by the 'substance' definition in REACH", states the 2008 Communication.

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

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

The definition is the following:

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

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

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

While the European Union has been developing a regulatory framework for nanomaterials under REACH, some European Member States have sought to find additional ways to regulate nanotechnologies. In recent years, databases and reporting schemes for nanomaterials have been developed in Europe. Whilst these are not specific to the market sector covered by this report, they are still relevant to the regulation of nanotechnologies.

Under the Belgian Presidency of the European Union, in 2010, the European Union has opened the discussion on a 'harmonised database of nanomaterials'; it was followed by a 2012 letter to the European Commission calling for a European Reporting Scheme and signed 10 European Member States, plus Croatia. The European institutions are still weighing the pros and cons of such a reporting scheme; nevertheless, some European Member States have been going forward.

In addition, as part of the electoral promises of the 2007 Presidential Elections, the 'Grenelle de l'Environnement', a large environmental debate was organised in France and resulted in major environmental acts: the Grenelle Acts (Lois Grenelle I & II) which enacted the future creation of a mandatory reporting scheme for nanomaterials. France hence took steps towards setting up the first registration scheme for substances at the nano-scale in Europe; in 2012, the Decree[405] on the annual declaration on substances at nano-scale - 2012-232 was published; it came into force on 1 January 2013. It grants to the French Agency for Food Safety, the Environment and Labour (ANSES) the authority to collect *"information from a production, distribution, import of nano-scale substances of 100 grammes"*.

The Belgian FPS (Public Health, Food Chain Safety and Environment) has also been working on a similar scheme: in February 2014, the Belgian Council of Ministers validated the *Royal Decree regarding the Placement on the Market of Substances manufactured at the Nano-scale* (*Koninklijk besluit betreffende het op de markt brengen van als nanodeeltjes geproduceerde stoffen* or *Arrêté royal relatif à la mise sur le marché des substances manufacturées à l'état nanoparticulaire*). The registration of substances will begin from 1 January 2016, while mixtures are to be registered from 1 January 2017.

In June 2014, the Danish Order on a Register of Mixtures and Articles that contain Nanomaterials as well as the Requirement for Manufacturers and Importers to report to the Register - BEK nr 644 came into force. With this Order, the Ministry of the Environment creates a national mandatory database of nanomaterial-containing products that will register the first products for the year 2014 in the year 2015.

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

405 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

reporting scheme and Italy is also considering setting up a similar system.

With these initiatives, EU Member States have been pushing the European Commission to act; the Second Regulatory Review on Nanomaterials of 2012 included an impact assessment of potential transparency measures which include approaches similar to the reporting schemes set in action in several Member States. The *Study to Assess the Impact of Possible Legislation to Increase Transparency on Nanomaterials on the Market was led by a RPA and BiPro;* three reports were published to help the EC decide on an eventual EU-wide registry of nanomaterials. To date, the Commission did not take a decision.

Legislation applying to electronics and that include nano-specific provisions, such as the *Waste Electrical and Electronic Equipment Directive (WEEE) - 2012/19/EU* and the *Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS2) - 2011/65/EU*, may also concern electronic devices used for energy. Under WEEE the European Commission reserves the right to amend Annex VII to eventually apply selective treatment to nanomaterials contained in waste electrical and electronic equipment. With RoHS2, European institutions keep on the possibility to add substances to Annex II – List of Restricted Substances and invited the reviewers of this annex to consider these materials.

8.1.2 Nanotechnology regulation in the rest of the world

In the United States of America, the Toxic Substances Control Act (TSCA) is the main chemical regulation. The US Environmental Protection Agency (EPA) is in charge of adapting this regulation to nanoscale materials (the US authorities have decided not to write a binding definition of a nanomaterial). The latest regulatory initiative was taken by US EPA in April 2015 with the publication of a proposed rule for section 8 (a) of the Toxic Substances Control Act (TSCA). This proposal would introduce reporting and recordkeeping requirements for nanoscale materials as well as a 135-days pre-notification requirement for the manufacturers of ‘chemical substances as discrete nanoscale materials’.

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

8.1.3 Standardisation and nanotechnology

Standards development on nano-enabled energy applications is mostly done via the International Electrotechnical Commission (IEC) technical committee IEC/TC 113 Nanotechnology standardisation for electrical and electronic products and systems.

Several standards on of the IEC series on nano-manufacturing key control characteristics target the production and storage of energy. Cathode nanomaterials for lithium ion batteries are addressed in IEC/TS 62607-4-1, IEC/TS 62607-4-2, and IEC/TS 62607-4-3. IEC/TS 62607-4-4 Nano-manufacturing – Key Control Characteristics – Part 4-4: Nano-enabled energy storage - Thermal characterisation of nanomaterials, nail penetration method is also under development. Photovoltaics will be covered in Part 7 of this IEC series: experts are drafting the document Nano-manufacturing – Key Control Characteristics – Part 7-1: Nano-enabled photovoltaics measurements of the electrical performance and spectral response of tandem cells.

ISO has a number of technical committees dedicated to different types of energy production (e.g. ISO/TC 28 Petroleum and petroleum products, ISO/TC 180 Solar energy and ISO/TC 203 Technical energy systems).

8.2 Environment, health and safety and nanotechnology

Exposure to chemicals in the energy sector may be quite diverse. In this report the safety evaluation will be limited to the engineered nanoparticles intentionally produced. A number of nanoparticles have been identified in the overview of commercially-available products as being used in energy products (see section on Products in Energy). These include Carbon, Copper oxide, Gold, Graphene, Multi-walled carbon nanotube (MWCNT), Nickel monoxide (nickel oxide), Strontium titanate (strontium titanium trioxide) and Titanium dioxide (titania, rutile, anatase).

The basis for the evaluation was "Stoffenmanager Nano" application[406, 407], a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios.

The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in production facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries[408]. 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[409]. However, nanoparticles as such are very unlikely to penetrate the skin[410] and consequently nano-specific systemic toxicity via the dermal route is improbable. Therefore, when evaluating risks from nanotechnology for the respiratory route, the most important aspects of occupational and consumer safety are covered.

8.2.1 Hazard assessment 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 energy sector and their hazard bands, either taken from le Feber et al. (2014)[411] or van Duuren et al. (2012)[412] or derived in this project.

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[406] 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.

[407] Van Duuren-Stuurman, B., Vink, S., Verbist, K.J.M., Heussen, H.G.A., Brouwer, D., Kroese, D.E.D., Van Niftrik, M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritization of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

[408] 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.

[409] Ibid

[410] 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

[411] 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.

[412] M.F.J., Tielemans, E., Fransman, W., 2012. Stoffenmanager Nano version 1.0: a web-based tool for risk prioritization of airborne manufactured nano objects. Ann. Occup. Hyg. 56, 525-541.

Table 8-2: Hazard bands for the specified nanoparticles

Nanoparticles	Hazard band	Source
Carbon	Needs specification, may be carbon black, carbon nanotubes, fullerenes or graphene	
Copper oxide	E	This report
Gold	D	van Duuren et al. (2012)
Graphene	E	This report
Multi-walled carbon nanotube (MWCNT)	E	This report
Nickel monoxide (nickel oxide)	E	This report
Strontium titanate (strontium titanium trioxide)	n/a	This report, no data
Titanium dioxide (titania, rutile, anatase)	B	le Feber et al. (2014)

8.2.2 Exposure assessment

Solar

Based on an overview of commercially-available products, engineered nanomaterials are present in the products as part of a matrix (e.g. coating). No free solids or liquids containing engineered nanomaterials were listed, which can become airborne during the use-phase, were encountered. During the production of these solar products, employees can be exposed to free engineered nanomaterials.

The use of solar products results in an exposure band 1 with respect to nanomaterials (workers and consumers), whereas during the production of solar products an exposure band 4 (workers) is believed to be realistic as spraying of a nano-coating results in the highest relative exposure.

Storage

The identified products in the sub-sector storage are diverse, ranging from nanomaterials that go into final products (e.g. (parts of) batteries). SMEs account for the lion’s share of producers while large private companies (PCO) only play a minor role.

Based on the provided overview of commercially-available products, engineered nanomaterials present in the products may be part of a matrix or be part of free solids or liquids, which subsequently may become airborne during the use-phase.

In conclusion, the use of storage products results in an exposure band 1 (workers and consumers) if nanomaterials are in a matrix, whereas the use of solids or liquids results in an exposure band 2 (workers) due to the relatively low concentrations of engineered nanomaterials as the majority of these products are produced by SMEs.

Hydrogen

In the Hydrogen sector, only two products with nanomaterials were identified; a final product (nanomaterial unknown) and a nanomaterial (copper nanowires) that goes into a final product.

Based on the provided overview of commercially-available products and the limited number of products, we are not able to draw conclusions regarding the exposure assessment for the sub-sector Hydrogen.

Alternatives

Alternative products are for a large part carbon-based nanomaterials that go into final products for the energy market. These nanomaterials include surface coatings and raw materials including graphene and carbon nanotubes.

Based on the provided overview of commercially-available products, engineered nanomaterials present in the products may be part of a matrix or be free solids or liquids, containing engineered nanomaterials which subsequently can become airborne during the use-phase.

In conclusion, the use of Alternatives products results in an exposure band 1 (workers and consumers) if nanomaterials are in a matrix, whereas the use of solids or liquids results in an exposure band 2 (workers) due to the relatively low concentrations of engineered nanomaterials as the majority of these products are produced by SMEs.

OTHER

The items which were not assigned to a sub-sector include only three commercially-available products with a large range of variability, from graphene based materials to thin film coatings for windows.

Based on the provided overview of commercially-available products and the limited number of products, we are not able to draw conclusions regarding the exposure assessment for the sub-sector other.

8.2.3 Risk assessment

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table below. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures ort to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 8-3: Priority bands in the Stoffenmanager system

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Risks based on the hazard and exposure banding applied to the energy sector are listed the table below.

Table 8-4: Priority bands for the energy sector

		Exposure band					
		Solar - production	Solar - use	Alterna-tives - production	Alternatives - use	Storage – production	Storage - use
Nanoparticle	**Hazard Band**						
Carbon	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Copper oxide	E	1	1	1	1	1	1
Gold	D	1	2	2	2	2	2
Graphene	E	1	1	1	1	1	1
Multi-walled carbon nanotube	E	1	1	1	1	1	1
Nickel monoxide	E	1	1	1	1	1	1
Strontium titanate	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Titanium dioxide (titania, rutile, anatase)	B	1	3	3	3	3	3
Zirconium dioxide	A	2	3	3	3	3	3

The high hazard materials are towards the E end of the ranking while the high exposure materials are towards the 4 end of that ranking. Thus the materials with the lowest risk will have hazard A and exposure 1 and those with the highest risk will have hazard E and exposure 4. There are, however, materials of moderate risk and low exposure that are less risk potentially that lower risk materials with high exposure.

The materials copper oxide, graphene, MWCNTs and nickel monoxide have a high priority (1), indicating the need to apply exposure control methods or to assess the risks more precisely. Gold is of medium priority (except in solar energy production) while titanium dioxide and zirconium dioxide showed the lowest priority profiles of the materials considered, being in the lowest priority category (3) for all life cycle stages examined except for the production phase in the solar energy subsector).

This section on hazard, exposure and risk is presented in much greater detail in the Annex.

The section that follows looks at communication on nanotechnology and energy.

8.3 Communication, public attitudes and societal issues

This section looks at nanotechnology and energy in printed and online media, and surveys.

8.3.1 Printed and online media

A search on the web of terms related to nanotechnology and keywords related to energy [413] is summarised in the table below. News sites only were searched using the Google News search tool. A second search, using Google Scholar[414], was done 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.

While these data are approximate, they may be useful in identifying where the public can find the most information, relatively speaking, on a given nanotechnology topic. The number of news items is an indication of where the media perceive that the interest of the public lies.

Table 8-5: Frequency of articles on the web, in the news for nanotechnology energy topics

Select energy keywords	Web, thousands	News, thousands	News / Web, %	Scholar, 1000s	Scholar / Web, %
Energy	93,700	88	0.1	2,250	2.0
Nanotechnology and energy	409	8.1	2.0	8.9	2.0
Solar energy	1,020	6.3	0.6	201	20
Energy Storage	695	9.1	1.3	102	15
Hydrogen	31,800	12	0.0	2,020	6
Alternative energy	464	5.9	1.3	18	4

There is only one major journal that specialises in energy related aspects of nanotechnology, Nano Energy (Elsevier, NE), however many general nanotechnology journals feature energy related articles. For example, over 35 % of the articles in the June 2015 edition of Nano Letters (ACS, USA) were relevant to energy. Similarly, nanotechnology based articles can be found in journals specialising in energy such as Energy Storage Materials (Elsevier, NE) and Advanced Energy Materials (Wiley-VCH, De).

Over a quarter of the top news items related to nanotechnology in energy feature on websites focused on a non-specialist audience, as shown in the figure below. Of those only about 10 of the websites discuss nanotechnology while the rest report on businesses involved in nanotechnology for energy applications. Also, two-thirds of the news items classed as being on a nanotechnology or energy focused website are from nanowerk.com, the highest ranked nanotechnology related website.[415]

[413] The search was carried out using the keywords in quotation marks, coupled with the term nano*, so all words beginning with nano are included.

[414] 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.)

[415] According to Alexa Internet Inc. (http://www.alexa.com/topsites/category/Top/Science/Technology/Nanotechnology)

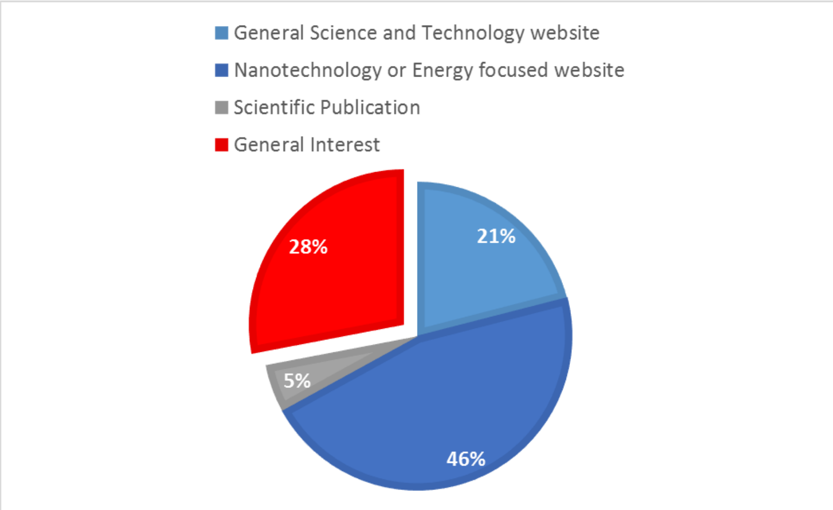

Figure 8-1: Type of website for top 100 new items
found using Google and the search term 'nano* energy' June 29, 2015

The Google Scholar search engine and Google Trends tool were used to measure the popularity of the search term "nano* energy" for academics and on the internet in general respectively, see figure below. The popularity of the term amongst academics has decreased since 2011, perhaps supplanted by more specific or descriptive terms as new specialities developed within the field. According to Google Trends there was a large increase in the frequency of web results associated with the search term in 2008 and the popularity since 2011 has been relatively constant.

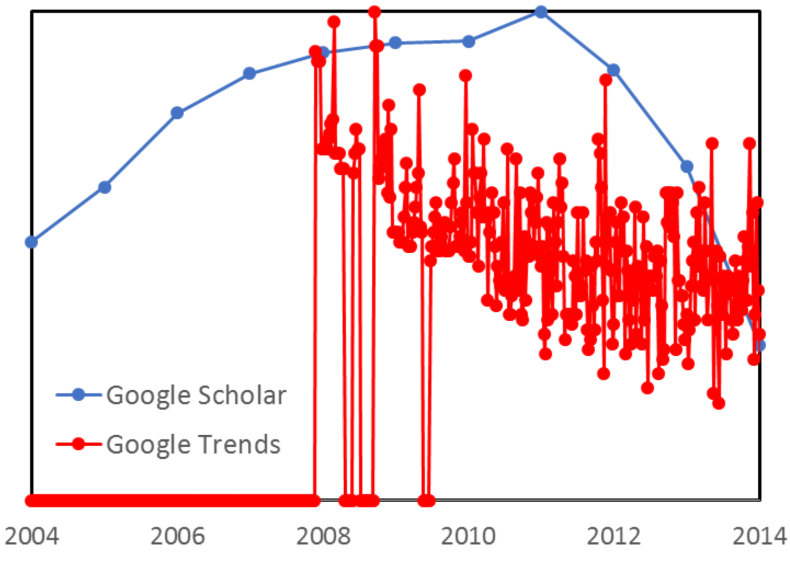

Figure 8-2: Normalised web terms for the search term 'nano energy'
Note: Google scholar was used to chart academic interest and google trends to chart general interest on the web.

More than 200 scientific journals regularly publish articles on nanotechnology[416]. 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.

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

Table 8-6: Bibliometric data for nanotechnology

Title of journal	SJR	h-5 index 2010-14[417]	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 8-7: 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.

8.3.2 Surveys of the public

More rigorous measures of public awareness, attitudes and communication can be seen through surveys. Although not representative for the 'average' EU-citizen, the results provide some indications of trends in attitudes.

NanOpinion was an FP7 project, which ran from 2012 to 2014, focused on monitoring public opinion on nanotechnology in Europe[418]. An online hub, social media, education and information booths in public spaces and special events were used to develop a dialogue with the general public about nanotechnology. Over 1,500 questionnaires were completed in which participants answered questions designed to gauge their understanding and opinions on nano.

Analysis of the responses revealed that Europeans in general have little understanding of nanotechnology but are generally interested in and positive about it. Respondents expected information on nanotechnology to be honest and balanced and wished there was more information available, particularly in the popular media. Across all educational backgrounds, they would be interested in buying products containing nanomaterials, including food containers, clothing and sun creams. However, they would like to see nano-containing products labelled with detailed information and the testing and regulation of these products carried out by independent national or international bodies rather than profit-oriented companies. Their main policy recommendations were to promote consistent and detailed product labelling carried out by an independent body, to update teachers'

[417] h-5 index is the largest number h such that h articles published in 2010-2014 have at least h citations each
[418] www.nanopinion.eu

knowledge of nanotechnology and to encourage more interdisciplinary science, technology, engineering and mathematics curricula.

The objectives of *NanoDiode*, an FP7 project running from mid-2013 to mid-2016, is to develop a co-ordinated and innovative strategy to engage EU civil society in a dialogue about responsibility around nanotechnologies[419]. As part of their approach, they reviewed the experiences and outputs of previous European projects on nanotechnology dialogue and outreach to identify best practices they could adopt for educational workshops and other activities[420]. 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 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)[421], as well as a survey among young people conducted within the framework of the NANOYOU project (NANOYOU, 2010)[422] and a recent survey in the USA (Shipman, 2010)[423]. OECD work on public engagement with nanotechnology has led to the production of a guide to assist policymakers (OECD, 2010)[424].

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)[425,426].

Table 8-8: Assessments by the public of various applications of nanotechnology
From German online discourses and a questionnaire survey (Böl et al. 2010)

Application	Ratio of positive to negative assessments	
	Online discourses	Population survey
Cancer therapies	90 : 10	(not asked)
"Other serious medical applications"	88 : 12	87 : 13
Surface treatment (textile & vehicle)	67 : 33	93 : 7 (paints) 91 : 9 (textile)
Cosmetics (excl. sunscreens)	59 : 41	51 : 49
Textile; other than surface treatment	56 : 44	76 : 24
Food packaging	25 : 75	81 : 19 (detection) 64 : 36 (foil quality)
Foodstuffs	10 : 90	25 : 75 (lump prevention) 10 : 90 (appearance)
Sunscreen products	10 : 90	78 : 22
Dietary supplements	0 : 100	not asked

419 www.nanodiode.eu
420 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)
421 Zimmer, R., Hertel, R., Böl, G.F., 2009, "Public perceptions about nanotechnology: Representative survey and basic morphological-psychological study", Bundesinstitut für Risikobewertung (BfR)
422 Nanoyou, 2010 http://cordis.europa.eu/publication/rcn/15319_fr.html
423 Shipman, M., 2010, "Hiding risks can hurt public support for nanotechnology", News Services NCSU
424 http://www.oecd.org/sti/biotech/49961768.pdf
425 Böl, G.F., Epp A., Hertel, R., 2010, "Perception of nanotechnology in internet-based discussions", Bundesinstitut für Risikobewertung (BfR)
426 Fleischer, T., Jahnel J., Seitz S.B., 2012, "NanoSafety – Risk governance of manufactured nanoparticles", European Commission

9 CONCLUDING SUMMARY

Nanotechnology has the potential to contribute to energy sustainability by reducing energy consumption, improving the infrastructure for energy and offering new ways of producing energy. To achieve this, it needs to have a solid research base on energy and nanotechnology; routes for the technology to be further developed and commercialised; and a market open to nanotechnology energy products, in the context of appropriate regulation and standards.

Nanotechnology for energy is being supported through measures at national and European levels to enable researchers to produce publications and engage in projects that increase knowledge that is being patented and commercialised into products. At European level, there are specific actions that are aiming to support this – ERA-NETs, ETPs and JTIs, as well as clusters.

Throughout Framework Programme projects, publications and patents, it is seen that researchers, organisations and companies from a small number of countries prevail. For the EU28, actors in Germany, the United Kingdom and France lead the way. Large and well-resourced organisations, like the countries just mentioned, lead in project, publication and patent outputs with some specialising in certain areas (the Fraunhofer-Gesellschaft (DE) in projects) while others also excel in publishing (Imperial College and the University of Cambridge (UK)) and others in all three areas (CNRS (FR)). Looking at the trend in publication numbers, over 140,000 relate to nanotechnology and energy. Almost 46% relate to solar and 29% to storage. 14% relate to hydrogen.

Germany, the United Kingdom and France lead the way for the EU28 also in the patent filings but overall it is in the US, Japan and Korea where the most activity takes place.

The search for products has revealed 168 energy nanotechnology products that are on the market at this time. The commercial applications of nanotechnology in the field of energy include: photovoltaic solar cells and their components, nanotubes and particles for use in capacitors and batteries, and nanomaterials for applications in the field of alternative energy production.

The global nanotechnology energy market has a forecast value of EUR 3 billion in 2019. Growth is strong in solar and storage applications in particular.

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[427] (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'.

[427] 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.

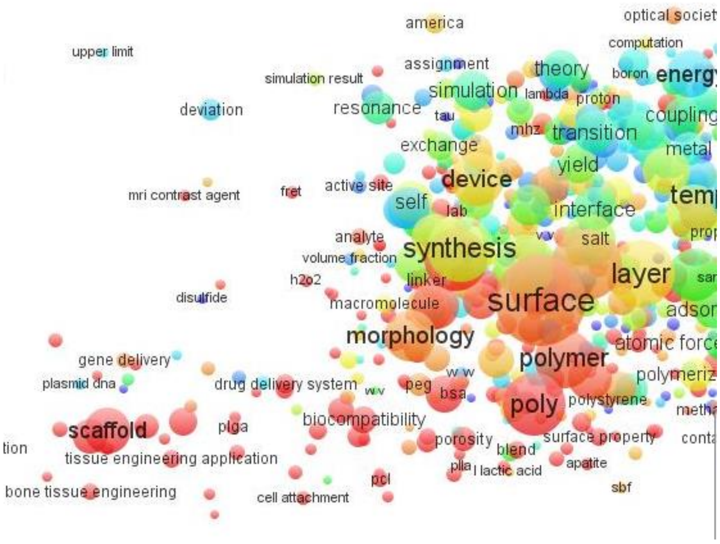

Figure A: Partial VOSViewer map for nanotechnology and health

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[428]	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[429]	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.

[428] In FP6 these were called Priorities and in FP7 Work Programmes.
[429] 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'[430] in the title or abstract of the project. 3,544 projects were selected in this way[431], 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.

[430] 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".

[431] 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[432], 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.

[432] 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)[433].

[433] 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.

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.

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+[434].

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[435]**	United Kingdom
EL[436]	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[437].

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

[434] Data was also analysed from countries outside of the EU28 namely Iceland (IS), Israel (IL), Norway (NO), Switzerland (CH) and Turkey (TR).
[435] GB is also used
[436] GR is also used
[437] 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[438]. 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[439] 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[440] as well as existing market reports[441]. 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[442], Nanowerk[443], the consumer products inventory of the Project on Emerging Nanotechnologies[444], the product database of understandingnano.com[445], the Nanoinformationsportal of the Österreichische Agentur

[438] 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.

[439] http://www.iso.org/iso/country_codes

[440] E.g. Nanomedicine: Nanotechnology, Biology, and Medicine 9 (2013) 1–14, Hessen Nanotech (2008) Applications of Nanotechnologies in the Energy Sector.

[441] See BCC Research www.bbcresearch.com

[442] http://www.azonano.com/

[443] http://www.nanowerk.com/

[444] http://www.nanotechproject.org/cpi/

[445] http://www.understandingnano.com/nanotechnology-product-suppliers.html

für Gesundheit und Ernährungssicherheit GmbH[446], the Danish Inventory of Nanoproducts[447] and the nanowatch.de database[448]. 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[449], 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[450], the Nano-Map of the German Federal Ministry of Research[451], the database on photonic companies compiled by EPIC, the members directory of SEMI[452], and the Nano-Bio Manufacturing Consortium (USA)[453], 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, and public database. European Patent Office[454], PRODCOM[455] and patentlens[456] 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

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[446] http://nanoinformation.at/produkte.html
[447] http://nanodb.dk/
[448] http://www.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank/
[449] http://www.ema.europa.eu/
[450] http://www.nanora.eu/
[451] http://www.werkstofftechnologien.de/en/
[452] http://www.semi.org/en/Membership/MemberDirectory/
[453] http://www.nbmc.org/members-only/
[454] https://www.epo.org/searching.html
[455] http://ec.europa.eu/eurostat/web/prodcom
[456] https://www.lens.org/lens/search?n=10&q=nanotechnology&p=0

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[457]. 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
- 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);

[457] 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.

- 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: ENERGY KEYWORDS

Each keyword is associated with either the overall sector (EN) or one of the four sub-sectors as follows:

AL: Alternative energy sources
HY: Hydrogen generation and storage
SO: Solar/ photovoltaics
ST: Storage/ batteries/ capacitors

In the analysis, where data falls into the energy sector (HT) but not into one of the sub-sectors, it is here marked as HT and usually categorised in the report as Other (OTH).

Asterisks are used to indicate that part of a word is missing. For example, the search for "thermoelectric*" would identify data related to "thermoelectric", "thermoelectrics", "thermoelectrical" and "thermoelectricity". Thus, one search term was used to cover each of the words with multiple possible endings.

Note that common words such as 'battery', 'electrode', 'anode', 'membrane' etc. are found throughout all of science and technology and are not sufficiently specific to energy to be used in the search process used to identify projects, publications, patents, etc.

Aeoli*	AL
Aerofoil-Powered Generator	AL
Alternative Energy	AL
Biofuel*	AL
Cadmium Telluride	SO
CDTE	SO
CIGS	SO
Coal Liquef*	OTH
Copper Gallium Selenide	SO
Copper Indium Gallium Selenide	SO
Crystalline Silicon Solar Cell	SO
CuGaSe2	SO
Direct Methanol Fuel Cell*	ST
DMFC	ST
Electrolyser	HY
Energy Insulation	OTH
Energy Storage	ST
Eolian	AL
Gas Turbine*	OTH
Green Energy	AL
Heat Exchange*	OTH
Heat Insulation	OTH
HFC	HY
Hydroelectric*	AL
Hydro-Electric*	AL
Hydrogen Adsorption	HY
Hydrogen Economy	HY
Hydrogen Fuel Cell*	HY
Hydrogen Generation	HY
Hydrogen Storage	HY
Hydrogen Vehicle	HY
Hydropower	AL
Hydro-Power	AL
LSCF	ST
Marine Energy	AL
Microbial Fuel	AL
Microbial Fuel Cell*	ST
Nano Fuel Cell	ST
Nanobatter*	ST
Nanocapacitor*	ST

Nanodielectric*	OTH
Nanohydro	AL
Nano-Hydro	AL
Nuclear Energy	OTH
Nuclear Fission	OTH
Nuclear Fusion	OTH
Ocean Energy	AL
PEM	ST
Photovoltaic*	SO
Piezoelectric Energy Harvesting	ST
Polymer Electrolyte*	ST
Proton Exchange Membrane*	ST
PV	SO
QD Solar	SO
Quantum Dot Solar	SO
Redox Flow Batter*	ST
Renewable Energy	AL
Shale Gas	OTH
Silicon Thin Film Cell	SO
SOFC	ST
Solar Cell*	SO
Solar Thermal	SO
Solid Oxide Fuel Cell*	ST
Supercapacitor*	ST
Superconducting Cable*	OTH
TEG	OTH
Thermoelectric*	OTH
Tidal Energy	AL
Tidal Power	AL
Water Splitting	HY
Wave Energy	AL
Wave Energy Converter	AL
Wave Power	AL
Wave Turbine	AL
WEC	AL
Wind Energy	AL
Wind Farm	AL
Wind Generator	AL
Wind Park	AL
Wind Power	AL
Wind Turbine*	AL

ANNEX 3: ABBREVIATIONS

Abbreviation	Definition
AEBIOM	European Biomass Association
ANSES	French agency for food safety, the environment and labour
AL	Alternative energy sub-sector (in the NanoData project context)
BEUC	Bureau Européen des Unions de Consommateurs
bn	Billion
CAGR	Compound annual growth rate
CBRNE	Chemical, biological, radiological, nuclear and explosive
CEN	European Standardisation Committee
CMC	Chemistry, manufacturing and controls
CNT	Carbon nanotubes
COD	Co-decision procedure
CSP	Concentrating solar power
DFG	Deutsche Forschungsgemeinschaft
EACH	Executive Agency for Energy and Consumers
EC	European Commission
EEB	European Environmental Bureau
EERA	European Energy Research Alliance
EFTA	European Free Trade Agreement
EGEC	European Geothermal Energy Council
EII	European Industrial Initiatives
EIT	European Institute of Innovation and Technology
EN	Energy nanotechnology (in the NanoData project context)
EoL	End of life
EPA	Environmental Protection Agency
EPR	Enhanced permeation and retention
ESFRI	European Strategic Forum on Research Infrastructures
ESTIF	European Solar Thermal Industry Federation
ESTTP	European Solar Thermal Technology Platform
ETP	European Technology Platforms
ETUC	European Trade Union Confederation
EU	European Union
EuMaT	European Technology Platform for Advanced Engineering Materials and Technologies
EUREC	Association of European Renewable Energy Research Centres
EUROBAT	Association of European Automotive and Industrial Battery Manufacturers
Eurofound	European Foundation for the Improvement of Living and Working Conditions
EWI	European Wind Initiative
FCH	Hydrogen and Fuel Cells Initiative (a Joint Technology Initiative, JTI)
FDA	Food and Drug Administration
FFDCA	Federal Food, Drug and Cosmetic Act
FP7	Seventh European Framework Programme

Abbreviation	Definition
HSE	Energy Safety Environment
HT	Energy nanotechnology
HY	Hydrogen energy sub-sector (in the NanoData project context)
IPC	International Patent Classification
IPR	Intellectual property rights
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
JTI	Joint Technology Initiative
KET	Key Enabling Technology
KIC	Knowledge and Innovation Community
MAPP	Manual of policies and procedures
MEMS	Micro electro-mechanical system
MNBS	Micro- and Nano-Bio Systems
MWCNT	Multi-walled carbon nanotubes
NACE	Nomenclature statistique des activites economiques dans la communauté européenne
NGO	Non-governmental organisation
NIH	National Institute of Energy
NIR	Near infrared
NIR-II	Near-infrared-ii imaging
NP	Nanoparticles
NST	Nanoscience and nanotechnology
NT	Nanotechnology
OSHA	European Agency for Safety and Energy at Work
OSH-professional	Occupational safety and energy professional
OT	Other energy (i.e. not included in the four NanoData energy sub-sectors)
PATSTAT	European Patent Office worldwide patent statistical database
ppm	Parts per million
PV	Photovoltaics
QD	Quantum dot
R&D	Research and development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RHC	Renewable Heating and Cooling
RTD	Research and Technological Development
SFERA	Solar Facilities for the European Research Area
SFT	Norway Pollution Control Authority
SME	Small or medium-sized enterprise
SNAP	Strategic Nanotechnology Action Plan
SO	Solar energy sub-sector (in the NanoData project context)
SOPHIA	Solar Photovoltaic European Research Infrastructure
ST	Storage: energy sub-sector (in the NanoData project context)
STOA	Science and technology options assessment
SWCNT	Single walled carbon nanotubes
TPWind	European Wind Energy Technology Platform (ETP)

Abbreviation	Definition
TT	Technology transfer
US/ USA	United States of America
US EPA	US Environmental Protection Agency
US NIOSH	US National Institute for Occupational Safety and Energy
USA	United States of America
UV/Vis/IR	Ultraviolet / visible / infra-red
VC	Venture capital
WEEE	Waste electrical and electronic equipment
WEC	World Energy Council

ANNEX 4: TERMINOLOGY

Word/phrase	Definition/explanation
Carbon Nanotubes	Allotropes of carbon with a cylindrical nanostructure.
Dendrimers	Nanostructured synthetic molecules having evenly spread branching structure originating out of a central core.
Liposomes	An artificially-prepared vesicle composed of a lipid bilayer
Nanobiosensors	Biosensor at nano-scale: measurement system for detection of an analyte that combines a biological component with a physiochemical detector
Nano-biotechnology	Intersection of nanotechnology and biology, the ways that nanotechnology is used to create devices to study biological systems, this is different from bionanotechnology
Nanocapsule	Nano-scale shells made of non-toxic polymer
Nanocarrier	Nano-object or objects, which are at a larger scale but which carry nanoscale payloads able to transport a diagnostic or therapeutic agent either on its surface, within its bulk structure or within an internal cavity
Nano-coatings	Applying a coating of nano-scale structures to a surface.
Nanocrystal	Nano-object with a crystalline structure
Nanodiagnostics	Application of nanotechnology in molecular diagnostics
Nanoemulsion	Nanodispersion with a liquid matrix and at least one or more liquid nano-objects
Nano-enabled	Products, systems, devices integrating, using, enabled by nanotechnology
Nano-fibres	Nano-object with two external dimensions in the nanoscale and the third dimension significantly larger
Nano-indentation	Variety of indentation hardness tests applied to small volumes. For testing the mechanical properties of materials (hardness).
Nanomaterials	Materials the single units of which is sized (in at least one dimension) between 1 and 1000 nanometres (10^−9 meter) but is usually 1—100 nm (the usual definition of nano-scale).
Nanomedicine	Medical application of nanotechnology
Nanometres	One billionth of a metre
Nano-needles	Conical or tubular needles in the nanometre size range, made from silicon or boron-nitride with a central bore of sufficient size to allow the passage of large molecules
Nanoparticle	Small object that behaves as a whole unit with respect to its transport and properties, between 1 and 100 nanometres in size.
Nanopolymers	Nanostructured polymers
Nanoproducts	Any product containing nanoparticles
Nanorod	One morphology of nano-scale objects, produced by direct chemical synthesis.
Nano-scale	Refers to structures with a length scale applicable to nanotechnology, usually cited as 1–100 nanometres, also called nanoscopic scale
Nanoscience	The study of the fundamental and functional properties of matter on the nano-scale (~10^-9m).
Nanosensor (proteomic, gold)	Any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world
Nanoshells (plasmon)	This is also called nanoshell plasmon, is a type of spherical nanoparticle consisting of a dielectric core, which is covered by a thin metallic shell (usually gold).

Word/phrase	Definition/explanation
Nano-specific	Refers to a system or response that is sensitive to nanomaterials
Nanostructures	An object of intermediate size between microscopic and molecular structures
Nanosuspensions	Submicron colloidal dispersions of nanosized drug particles 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[458]), 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)[459] and the Federal Ministry for Transport, Innovation and Technology (BMVIT)[460]. The largest share of direct support for R&D is channelled through three funding agencies: The Austrian Science Fund (FWF)[461] that focuses on funding academic research; the Austrian Research Promotion Agency (FFG)[462] specialising in funding applied industrial research and the co-operation between the higher educational sector and industry; and the Austria Economic Service (AWS)[463] 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**"**[464]** was adopted by the Federal Government. The NANO initiative was a response to regional activities in the Austrian Bundesländer (such as NanoNet Styria [for more information, see later in this Annex]) that sought to identify existing competences and to formulate potential themes for large-scale co-operative projects.

An important motivation in the establishment of such a national research programme was the expectation that its creation would strengthen the national research community in specific fields thereby better linking them to international communities. At that time, most Austrian peer countries (Germany, Switzerland, UK, and Finland), as well as the European Framework Programmes, were using the label nanotechnology for framing focused research programmes.

The NANO initiative aimed to address the following issues: What would be the best way for Austria to harness the opportunities in nanotechnology (for instance, in environmental and energy technology and new resource-saving products or for small- or medium-sized enterprises)? How could Austria contribute to ensuring the safety for its citizens of nanotechnology applications?

NANO had the following objectives: to increase networking among actors to achieve critical mass; to open up ways to exploit the benefits of nanotechnology for industry and society; and to ensure proper support for qualified personnel. To achieve these objectives it had two programme action lines:

1. National co-operative RTD Projects (Research and Technology Development in Project Clusters (RPCs) and
2. Transnational co-operative RTD Projects (Research and Technology Development in Transnational Projects).

A key aspect of the **Nanotechnology Action Plan** to implement the NANO initiative was to

[458] https://rio.jrc.ec.europa.eu/
[459] http://www.en.bmwfw.gv.at/
[460] https://www.bmvit.gv.at/en/
[461] https://www.fwf.ac.at/en/
[462] https://www.ffg.at/en
[463] http://www.awsg.at/
[464] https://www.bmlfuw.gv.at/dam/jcr:00058164-0320-4544-b6a4-320325dcfd86/Austrian%20Nanotechnology%20Action%20Plan.pdf

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[465], 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)[466] 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**[467]**,** 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**[468], 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)[469]**:** Styria's Economic Strategy 2020 is a successor to the State Government's previous economic strategy 2006. The 2006 strategy identified so-called economic and technological strong-points ("Stärkefelder") of the region, on which innovation policy activities were focused: material sciences; mechanical engineering/automotive and transport technologies; chemical and process engineering; human technology; information and communication technologies; environmental technologies; energy; building services engineering (including timber construction); nanotechnology; computer simulation and mathematical modelling. The 2011 strategy bundles activities in these fields under three major leading themes: i) mobility, ii) eco-technology, and iii) health technology. The central aim is to focus on future activities and to establish Styria as a "European benchmark for the structural change towards a knowledge based production-society".

BELGIUM

Since its two regions play a central role in Belgian policy making, the main nanotechnology activity in the country is carried by the regional government of Flanders, with a number of institutions working in the area of nanotechnology.

Strategische onderzoekscentra[470] **(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

[465] http://www.sozialministerium.at/cms/site/attachments/6/1/7/CH2120/CMS1371046721712/umsetzungsbericht_2012_en.pdf
[466] https://www.ffg.at/en
[467] http://www.bionanonet.at/about-bionanonet
[468] http://www.bionanonet.at/about-nanotoxicology?lang=english
[469] http://www.wirtschaft.steiermark.at/cms/beitrag/10430090/12858597
[470] http://www.ewi-vlaanderen.be/wat-doet-ewi/excellerend-onderzoek/strategische-onderzoekscentra

business worlds. Each of the institutes have their own specific focus.

- Imec[471] is a leading European independent research centre in micro- and nanoelectronics, ***nanotechnology,*** design methods and technologies for ICT systems. It carries out research that runs three to ten years ahead of industrial needs. The world's top integrated device manufacturers, equipment and material suppliers, system houses and electronic design automation (EDA) vendors participate in the research conducted there. Work at Imec has a strong connection to nanotechnology given its use in electronics and as the next generation technology for electronics and ICT.
- VIB[472], 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[473], 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[474] is an independent research institute that stimulates innovation in information & communication technology (ICT) and broadband. This research is interdisciplinary and demand-driven, and takes place in close collaboration with businesses and governments, both local and international. Its aim is to provide solutions to complex problems and thus help meet society's future challenges.

In 2003, the Regional Government of Wallonia launched a nanotechnology program in order to support research projects in that field which led to the creation of **NanoWal**[475], 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[476]. It included four different sub-programmes in the areas of: nanoparticles, nanofibres and nanocomposite materials; nanobiology and nanomedicine; nano-macro interface; and new phenomena and materials for nanoelectronics, with specific priorities in all of them. The programme was planned to end in 2012.

Other general programmes with a less specific mention to nanotechnology came from the Grant Agency of the Czech Republic, the Ministry of Education, Youth and Sports and the Ministry of Industry and Trade.

In the National Research, Development and Innovation Policy document of the Czech Republic in 2009-2015[477], nanotechnology is addressed under the **Materials Research** priority, where it is set as an area to be supported by national budget in order to increase the global competitiveness of the Czech economy through products with high added-value.

Denmark

In Denmark, the Ministry of Higher Education and Science[478] 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

471 http://www2.imec.be/be_en/home.html
472 http://www.vib.be/en/Pages/default.aspx
473 https://vito.be/en
474 https://www.iminds.be/en
475 www.nano.be/
476 http://www.csnmt.cz/getfile.php?type=file&IDfile=24
477 http://www.vyzkum.cz/FrontClanek.aspx?idsekce=1020
478 http://ufm.dk/en

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[479]). The last phase of the foresight programme was closely linked to the establishment of the Danish National Advanced Technology Foundation[480] 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[481]** 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[482].

Since 2009, the Danish National Advanced Technology Foundation has channelled funding for projects in high-tech sectors, such as nanotechnology, biotechnology and ICT.

Support for nanotechnology research has been managed through a number of sources. The Danish Council for Strategic Research, part of the Danish Agency for Science, Technology and Innovation is one of these, although the council itself did not authorise funds for research, dependent instead on the Programme Commission, which covers Nanoscience, Biotechnology and IT (NABIIT). The Strategic Research Programme for the Interdisciplinary Applications of NABIIT technologies supported the establishment of networks and research initiatives. Research support also came from the Danish National Research Foundation, the Danish Ministry of the Interior and Health's inter-ministerial working group on Nanotechnology and Human Health, and the Danish National Advanced Technology Foundation. Latterly, also under the Danish Council for Strategic Research, the Programme Commission on Strategic Growth Technologies has had annual calls of total annual value approximately EUR 10 million for research projects on nanotechnology, biotechnology and information- and communication technology. In 2013, The Danish government and five political parties decided to revise the research and innovation system, agreeing to merge the Danish National Advanced Technology Foundation, the Danish Council for Strategic Research and the Danish Council for Technology and Innovation into a new innovation foundation. Thus, the new organisation Innovation Fund Denmark[483] (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

[479] Danish Nano-science and Nano-technology for 2025, Foresight Brief No. 032
[480] http://www.tekno.dk/about-dbt-foundation/?lang=en
[481] http://ufm.dk/en/publications/2004/technology-foresight-on-danish-nanoscience-and-nanotechnology
[482] http://www.nano-vaccine.org/
[483] 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

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[484]. Its objective was to build know-how, multi-disciplinary infrastructure and linkages between fundamental and applied research. The programme also established a new form of co-operation using joint funding between Tekes and the Academy of Finland. The total value of the programme was EUR 7 million (Tekes EUR 4m, the Academy of Finland EUR 3 m).

FinNano, the Finnish nanoscience and nanotechnology programme, was established in 2005. The programme was co-ordinated jointly by Tekes and the Academy of Finland and covered the whole innovation chain from basic research to commercial products. The aim of the programme was to strengthen Finnish nanotechnology research in selected focus areas and to accelerate the commercial development of nanotechnology in Finland. The key objective was to boost internationally recognised high-level research and competitive business based on nanotechnology.

In addition to FinNano, the Ministry of Education provided funding to develop nanoscience education and infrastructure in Finnish universities and the Nanotechnology Cluster Programme was initiated in 2007 with the Centre of Expertise Programme. In total, Finnish public funding for nanotechnology during 2005–2010 was approximately EUR 235m.

In practice, the FinNano programme was executed in two parts: Tekes' FinNano – Nanotechnology Programme (2005–2009) and the Academy of Finland's FinNano – Nanoscience Programme (2006–2010). The Programme had a total value of approximately EUR 70m, including EUR 25m in research funding and EUR 20m in corporate financing from Tekes. The original programme plan defined three main focus areas:

1) Innovative nanostructure materials;
2) Nanosensors and nanoactuators; and
3) New nanoelectronics solutions.

In 2007, the aims of the programme were redefined as being for:

- Society: Renewal of industry clusters and production, environment and safety;
- Applications: Electronics, forest cluster, chemical sector, health and well-being; and
- Technologies: Nanostructured and functional materials, coatings and devices; Measurement methods, production and scalability.

According to a programme's interim evaluation in 2008, the main successes of FinNano were to activate companies in research and product development, to map all the existing nanotechnology infrastructure and to create cross-cutting networks of nanotechnology professionals.

In 2011, the final report on FinNano was published, showing the results of the Programme[485]. 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

[484] http://www.tekes.fi/globalassets/julkaisut/research_and_technology.pdf
[485] http://www.tekes.fi/globalassets/julkaisut/finnano_loppuraportti.pdf

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*[486] in Grenoble (centred in Minatec);
- The *Laboratoire d'Analyses et d'Architectures des Systemes*[487] (LAAS) in Toulouse ;
- The *Laboratoire de Photonique et de Nanostructures*[488] (LPN) in Marcoussis ;
- *The Institut d'Électronique Fondamentale*[489] *(IEF) Orsay,* in Minerve; and
- The *L'Institut d'Electronique, de Microélectronique et de Nanotechnologie* [490] (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 **Nanosciences 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**[491]) 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**[492] (Investments for the Future) was launched at the end of 2009. Within that context and since 2011, nano-bio-technology has been one of the priority areas for funding under the ANR, with a particular focus on health and environmental research. The package aims to support scientific research, accelerate its transfer to a pilot stage and to consolidate knowledge about toxicology and nanomaterials, the programme is funding therapies, imaging, diagnostics and medical devices base on nanotechnology and biotechnology.

GERMANY

As far back as 1998, the Federal Ministry of Education and Research (BMBF) increased collaborative project funding for nanotechnology. In addition, an infrastructure plan was put in place in the form 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**

[486] http://www-leti.cea.fr/en/
[487] https://www.laas.fr/public/
[488] http://www.lpn.cnrs.fr/fr/Commun/
[489] http://www.ief.u-psud.fr/
[490] http://exploit.iemn.univ-lille1.fr/
[491] http://www.agence-nationale-recherche.fr/suivi-bilan/historique-des-appels-a-projets/appel-detail1/programme-national-en-nanosciences-et-nanotechnologies-pnano-2005/
[492] http://www.gouvernement.fr/investissements-d-avenir-cgi

Markets[493]" 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**[494] in 2006. This was done through the **Nano Initiative—Action Plan 2010**[495], 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**[496], outlining the strategy for responsible development, innovation and public dialogue for the period 2010-2015. The plan included proposals for developing nanotechnology in five main areas (climate/energy, health/food and agriculture, mobility, communication and security). In parallel, a new funding instrument was launched - **Innovation Alliances** - to provide funding for strategic co-operation between industry and public research in key technology areas that demand a large amount of resources and a long time horizon, but promise considerable innovation and economic impacts. Public funds and funding from the industry is combined in a typical proportion of 1:5 (public: private). Innovation was supported with special emphasis on SMEs and development of value chains. Risk assessment was incorporated as well as an improvement of boundary conditions such as educating the workforce, and addressing issues of legislation, norms and standards. The public dialogue on nanotechnology was intensified, including information and dialogue with citizens as well as stakeholders and NGOs.

Innovation alliances were launched as a successor to the leading edge innovation programmes. They were planned as an instrument of public support to ground-breaking industrial innovation, providing support funding for strategic co-operation between industry and public research in high-potential technology areas that require high levels of funding and long lead times. Through a public-private partnership, the Federal Government provided funding for R&D and other innovation-related activities for specific, long-term co-operative R&D projects. R&D activities could range from fundamental research to prototype development. Public funds were complemented by private money from industry, typically at a proportion of 1:5 (public: private). Each innovation alliance was set up through an industry initiative, organised as a long-term co-operative research project and involving 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

[493] http://d-nb.info/97392179x/34
[494] http://www.research-in-germany.org/en/research-landscape/r-and-d-policy-framework/high-tech-strategy.html
[495] http://www.cleaner-production.de/fileadmin/assets/pdfs/Nano_initiative_action_plan_2010.pdf
[496] http://www.lai.fu-berlin.de/homepages/nitsch/publikationen/Germany_ActionPlanNanotechnology_2015.pdf

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)[497]: The Bavarian cluster policy was initialised in 2007 and focused on 19 branches/technologies with high importance for the future of Bavaria. These were organised into five fields:
  - materials engineering (including ***nanotechnologies***, materials engineering, chemical industries);
  - mobility (including automotive, rail, logistics, aerospace and satellite navigation);
  - life sciences and environment (including biotechnology, medical technologies, energy technologies, environmental technologies, forestry and food);
  - IT and electronics (ICT, high-performance electronics, mechatronics and automation); and
  - service and media (financial services, media).

After a positive evaluation in 2010, the State Government announced some changes in the future organisation of the overall initiative: A major change is that the (nonetheless successful) clusters high-performance electronics, logistics, biotechnology and medical technologies would be restructured into networks, while future funding would be focused on the other clusters, where funding so far was most successful in generating additionality.

- Research Strategy of Thuringia (2008): Main objectives of Thuringia's research policy were to strengthen regional universities and non-university research institutes and regional companies in their research and development efforts in order to achieve scientific excellence, to initiate knowledge and technology transfer as well as innovation. The document described outstanding research areas of the state and measures to strengthen and relate the regional research landscape to target fields in the regional economy: micro and nano technologies, microelectronics; information and communication technologies; media and communication; health research and medical technology; microbiology and biotechnology; optical technologies, photonics; materials and production technologies; environmental and energy technologies, infrastructure; and cultural and social change. Main fields of activity of regional research policy were (i) to support competitiveness, (ii) to strengthen networks, (iii) to support young researchers, and (iv) to invest in infrastructure.

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)[498]**. Since its foundation in 2003, CRANN has become a research institute of international standing with 17 Principal Investigators (PIs) across

[497] https://www.cluster-bayern.de/en/
[498] http://www.crann.tcd.ie/

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[499] itself launched a report on **'Ireland's Nanotechnology Commercialisation Framework 2010 – 2014'**. The report presented a national framework to position Ireland as a knowledge and innovation centre for certain niche areas of nanotechnology. It highlighted that Ireland's nanotechnology players should focus on three main technology areas (advanced materials, "More than Moore" and nanobiotechnology) and four application areas (next generation electronics, medical devices & diagnostics, environmental applications, and industrial process improvements).

The BioNano Laboratory in CRANN (mentioned above) is dedicated to interdisciplinary research at the interface between the physical and life sciences including nanotechnology and diagnostics, nanotoxicology and nanomedicine. The group investigates molecular, cellular and physiological interactions using novel biophysical tools such as cell actuators, and magnetic and ultrasound fields. Members of the BioNano Laboratory are also members of the **Integrated Nanoscience Platform for Ireland (INSPIRE)[500],** 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)[501]** 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

[499] Forfás ceased to exist in 2015 and was, in part, subsumed under the Department of Jobs, Enterprise and Innovation.

[500] http://www.crann.tcd.ie/Research/Academic-Partners/testt.aspx

[501] http://ambercentre.ie/

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[502]), Delft University of Technology (with the **Else Kooi Laboratory**[503], previously called Dimes research centre on nanoelectronics) and the University of Groningen (with **BioMaDe**[504] focused on bio-nanotechnology). The early 2000s, these formed the core of **NanoNed** - the Nanotechnology R&D initiative in the Netherlands[505]. 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**[506]. The plan, prepared by the Interdepartmental Working Grou #p on Nanotechnology (ION) and building on the 2006 vision document, incorporated the most up-to-date scientific findings, and reflected information and agreements from European Union and other international initiatives. Four generic themes were defined on the basis of the central theme impact on society and risk analysis, i.e.: bio-nano-technology, beyond Moore, nanomaterials, and nano production (including instrumentation and characterisation). In addition, four application areas were singled out: clean water, energy, food and "nanomedicine".

The Dutch systematic approach to nanotechnology strategy resulted in the development of stable research groups, centres, department and laboratories. On the national level, **NanoLab NL**[507] 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**[508] 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

[502] https://www.utwente.nl/mesaplus/
[503] http://ekl.tudelft.nl/EKL/Home.php
[504] http://www.biomade.nl/
[505] However, four other universities, and TNO, the Netherlands Organisation for Applied Scientific Research, are also represented.
[506] http://www.rritrends.res-agora.eu/uploads/27/8079721-bijlage%281%29.pdf
[507] http://www.nanolabnl.nl/
[508] http://www.nanonextnl.nl/

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**[509], 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**"[510]. The areas to be supported were nanoscale phenomena and processes, nanostructures, nanomaterials and nanoscale devices on the one side and nano-analytics/nano-metrology and manufacturing processes and devices for nanotechnology on the other. The priority of the strategy of nanosciences and nanotechnologies was the development, co-ordination and management of the national system of research, education and industry in this field in the short-, medium-, and long-term perspective. Other main objectives to be achieved by 2013 were the development of high added-value nanotechnology products, the creation and commercialisation of manufacturing devices for the production of nanomaterials, the development of the education system in the field of nanotechnology, educating about 20-30 doctors yearly in the specialisation of nanotechnology, building specialist laboratories, establishing co-operation networks of research and industrial units, financial institutions, etc. and integrating dispersed activity of research units in a joint programme of nanotechnology development.

In 2014, the Government approved the **National Smart Specialisation Strategy** as an integral part of the Enterprise development Programme, setting "Multifunctional materials and composites with advanced properties, including nano-processes and nano-products" as a horizontal smart specialisation area in Poland.

PORTUGAL

In 2005, the Portuguese and Spanish Governments decided to jointly create the **International Nanotechnology Laboratory (INL)[511]** 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

[509] http://topsectoren.nl/english
[510] www.bioin.or.kr/fileDown.do?seq=5186
[511] http://inl.int/

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, nano-electronics, nano-machines & nano-manipulation and environment monitoring, security and food quality control can be found.

Further information on the policies and programmes of Spain is given below.

SPAIN

The Minister of Economy and Competitiveness is responsible for the design of the national innovation strategy in Spain. An Inter-ministerial Commission on Science and Technology (CICYT) has the role of co-ordinating the actions of the different bodies involved in innovation policy in a complex governance structure. The regions of Catalonia, the Basque Country and Valencia are especially active in S&T policy.

The 2004-2007 R&D plan was the first Spanish national R&D plan containing a specific cross-programme action regarding nanoscience and nanotechnology. The **Strategic Action (SANSNT)** was designed for the overall enhancement of Spanish industry competitiveness through the implementation of deep changes in several industrial sectors by generating new knowledge and applications based on the convergence of new technologies, where nanotechnology plays a central role. The SANSNT included seven thematic lines among which the first one is "***Nanotechnologies*** applied in materials and new materials within the field of health". Also included are systems biology, synthetic biology and *nanobiotechnology*. The Strategic Action encompassed the development of activities within the six Instrumental Lines of Action (human resources; projects; institutional strengthening; infrastructures; knowledge use; and articulation and internationalisation of the system).

Nanoscience and nanotechnology were included as a **Strategic Action** of both the 2004-2007 National Plan for Research, Development and Innovation (R+D+I) and the funding set aside within this Plan for the Industrial Sector (PROFIT Programme), with the aim of promoting the development of industrial projects (carried out by companies) with nanotechnology-focused objectives.

During the 2004-2007 periods, around 40 projects were funded as a result of this Strategic Action, receiving a total of EUR 2 million in subsidies and EUR 8.5 million in associated investments. All the projects were coordinated by industrial companies, although universities and technological centres were involved in the development of many of them either on a collaborative basis, or were subcontracted by the company carrying out the project.

In 2005, the Government of Spain launched the strategic programme **INGENIO 2010**[512] 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

[512] http://www.ingenio2010.es/

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**[513] was implemented by the Ministry of Economy and Competitiveness. This policy measure was part of the National Plan for R+D+I 2008-2011[514] 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 the 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[515] and in the State Plan of Scientific and Technical Research and Innovation 2013-2016[516] (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)[517]: In order to promote the implementation of micro and nanotechnologies in the Basque companies, the Basque Government designed a strategy called NanoBasque in 2007. On December 3 2008, the Department of Industry, Trade and Tourism of the Basque Government launched the nanoBasque Strategy in the framework of the Basque Science, Technology and Innovation Plan 2010. The nanoBasque Strategy was an initiative designed to develop a new economy sector enabled by nanotechnology. It was created with the purpose of covering three main areas of action, namely: company, knowledge and society. One of the objectives was to create a new model of relations to involve both national and international companies, scientific, technological, political and social agent. The expected result were targeting the efficiency and the integration of the ecosystem of innovation that was clearly aimed at the market, based on the co-operation between all parties. The launch of the nanoBasque Strategy was accompanied by the creation of a dynamic support agency, the nanoBasque Agency, with the mission of coordinating and managing the development of the Strategy. The 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,

[513] http://www.idi.mineco.gob.es
[514] Ibid
[515] http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_Strategy_Science_Technology.pdf
[516] http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/Spanish_RDTI_Plan_2013-2016.pdf
[517] http://www.nanobasque.eu/aNBW/web/en/strategy/index.jsp

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[518]. It supports SMEs with high growth potential, manages the Small Business Research Initiative[519] 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**[520] which recognised that investment in nanotechnology was increasing rapidly worldwide. Following the Taylor Report, an announcement was made by Lord Sainsbury of GBP 90m of funding for the Micro and Nano Technology Manufacturing Initiative. This funding was committed between 2003 and 2007. **Micro- and Nano-technology Manufacturing Initiative** (MNT Initiative) were joint investments by the Government, the Regional Development Agencies (RDAs) and the devolved administrations of Wales and Scotland. The Initiative was launched to help the industry build on the expertise of the UK science base and win a share of this developing market, harnessing the commercial opportunities offered by nanotechnology.

Approximately one third of this investment went to Collaborative R&D MNT Projects, and two thirds to capital infrastructure. Generally built on existing university or business expertise, the twenty-four facilities were targeted at addressing a broad range of key application areas where micro/nano scale activity was considered key to future UK industry capability and where the UK had some strength. Micro/nano technologies were included within relevant broader collaborative R&D competitions, principally in the materials, medicine and electronics areas. In 2007 the **Nanotechnology Knowledge Transfer Network (NanoKTN)[521]** was created with the objective of supporting the exploitation and commercialisation of MNT through informing, linking and facilitating innovation and collaborations between users and suppliers of nanotechnology in order to build a strong MNT community in the UK. The centres were grouped into four main themes: nano-metrology; nanomaterials (including health and safety); nanomedicine; and nanofabrication. Between its creation and 2014 the NanoKTN secured about £82million for UK industry, mainly focussed on SMEs, providing a good return investment on the initial input of £3million. In 2014, NanoKTN was merged with another 15 KTN in the new organisation KTN Ltd.

In 2006, the Engineering and Physical Sciences Research Council issued its **Report of the Nanotechnology Strategy Group[522]** 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-

[518] https://www.gov.uk/government/organisations/innovate-uk
[519] https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative
[520] http://webarchive.nationalarchives.gov.uk/20130221185318/http://www.innovateuk.org/_assets/pdf/taylor%20report.pdf
[521] https://connect.innovateuk.org/web/nanoktn
[522] https://www.epsrc.ac.uk/newsevents/pubs/report-of-the-nanotechnology-strategy-group/

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**[523]", 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**[524] 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**[525]. 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)**[526] in order to facilitate discussion and engagement between Government and stakeholders in matters referred to the responsible advancement of the UK's nanotechnologies industries. The NSF is an advisory body formed by *ad hoc* expert with a membership drawn from industry, regulators, academia and NGOs (non-governmental organisations and it is jointly chaired by the Minister of State for Universities and Science (BIS) and the Parliamentary Under-Secretary for DEFRA and is supported by a small secretariat based in DEFRA.

The UK **Enabling Technologies Strategy 2012-2015**[527] also addressed 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.

[523] https://www.epsrc.ac.uk/newsevents/pubs/nanotechnology-programme/
[524] http://www.nibec.ulster.ac.uk/uploads/documents/nanoscaletechnologiesstrategy.pdf
[525] http://www.steptoe.com/assets/htmldocuments/UK_Nanotechnologies%20Strategy_Small%20Technologies%20Great%20Opportunities_March%202010.pdf
[526] https://www.gov.uk/government/groups/nanotechnology-strategy-forum
[527] https://www.gov.uk/government/publications/enabling-technologies-strategy-2012-to-2015

ANNEX 6: NANOTECHNOLOGY AND ENERGY COMPANIES – ADDITIONAL INFORMATION

There are no complete overviews of the size of the nanotechnology and energy industry in terms of numbers of enterprises and employees. Data on the number of enterprises differ substantially between the various sources depending on definitions and how the data has been collected. Some databases do not distinguish between manufacturers that sell commercial products, suppliers (that do not manufacture), producers (that manufacture but do not sell at a commercial level, if at all) and those that are active in nanotechnology (potentially users rather than producers). In addition, some databases are not quality controlled but rely on organisations to identify themselves, this being sufficient for them to be added to the database. In the NanoData project, only companies that manufacture and sell nano-related products were identified, via searches of published information including company websites. The information was checked against additional sources whenever there was any uncertainty.

A short summary of data available on the Nanora and Nanowerk databases follows.

Both Nanowerk and Nanora have databases with nanotechnology firms. Nanowerk identifies 71 companies as being active in energy related applications of nanotechnology worldwide[528]. Of these only 11 were located in the EU. The largest proportion of companies (47) is located in the US. Nanora identifies 18 large firms as being active in the application of nanotechnology for the energy sector in the Nanora regions (Belgium (Wallonia), France (Nord-Pas-de-Calais), Germany (Hessen and Saarland), The Netherlands (Southern Netherlands), Ireland and United Kingdom (North West England)). 16 of these 18 large firms were located in Germany, the other two in Belgium. In addition, 8 SMEs were identified, all based in Germany[529].

Nanothinking was a study commissioned by the International Electrochemical Commission (IEC) and undertaken by the Fraunhofer Institute for Systems and Innovation Research (ISI-Fraunhofer). It presented a roadmap for nanotechnology in solar energy and in energy storage[530]. The report discusses developments in nanotechnology applications in solar energy and energy storage and presents some details of markets and key players for various technologies, applications and products.

The application of *nanocomposite technologies* depends to a large extent on global developments in the energy sector. Efficient energy storage solutions, to which nanocomposites are essential, are needed in smart grids with a large share of renewable energies. Increases in the efficiency of specific nanocomposite applications, such as dye-sensitised solar cells, whose efficiency is still lagging behind other technologies, are very important for market competitiveness.

Nanoelectrodes are highly relevant in energy storage and solar energy applications, but also in fuel cell technologies; combined heat and power; storage connected to wind generation; and smart grids. Lithium ion batteries for consumers are mainly produced in Asia, while capacitors are mainly manufactured in the US (with some exceptions in Europe). Developing nanoelectrodes is R&D intensive and the market size for such products is expected to be small market size in the short- and medium-term.

Nanocoatings are used on the surfaces of PV cells, especially in DSSCs (dye-sensitised solar cells), in Li-ion batteries, solar thermal systems and in hydrogen tanks. Large scale production of nanocoatings is still difficult and expensive. It is expected that nanocoatings in thermal applications and batteries are heading for real market entry, but PV applications can take longer to mature.

Carbon nanomaterials can be used for electrodes in batteries and for catalyst support of membranes in fuel cells. Carbon nanotube films can be used as transparent electronic materials for solar cell applications (conductive ink for printed solar cells), or for coating wind turbine blades (e.g. for making lighter and de-icing purposes). Again, reliable large-scale production is a main challenge.

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[528] http://www.nanowerk.com/nanotechnology/nanomaterial/products_plist.php?subcat1=ene

[529] http://www.nanora.eu/tinca?field_tags_tid_op=and&field_tags_tid%5B%5D=1654&field_region_tid=All&items_per_page=50&=Apply

[530] Seitz, R. et al (2013) Nanotechnology in the sectors of solar energy and energy storage, study prepared for the IEC Market Strategy Board by the Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany

Nanoscale *printed electronics* can be used in both energy harvesting and storage devices. Organic conductors and metals can be printed to form electrodes in transparent photovoltaic cells. Printed electronics could also be used in disposable batteries. Performance and product lifetimes of printed electronics are still unsatisfactory compared with conventional electronics. Improvements in scalability and manufacturing techniques, along with better integration of printed components with other circuit components, will hopefully address these issues in the future.

Nanocatalysts are widely applied in the energy sector. In oil and gas generation they are used for cracking, cleaning up oil spills, desulphurisation and biodiesel/ethanol production. In fuel cells, nanocatalysts are used to produce hydrogen for compact fuel cells. Moreover, nanocatalysts help to improve cleaner combustion and are also used in polymer solar cells and fuel cells. Nanocatalysts' inferior stability and activity over time, along with their relatively high production costs, are challenges facing their wider uptake.

The main relevance of *nanofluids* is to solar thermal applications, but nanofluids are also applied in photobioreactors and thermal energy storage systems. Nanofluids are in a very early stage of development, especially for applications in the energy sector.

The IEC study also identified some key players in developing nanotechnology materials and applications relevant to the energy sector. It should be noted that some may not be producers and some may no longer operate as independent companies as the report is from 2013 and the research may pre-date that.

Table: Companies active in nanotechnologies and nanomaterials for the energy sector worldwide

Nanomaterial	Type of application	Companies
Nanocomposites	Coatings for solar absorbers	Alanod-Solar GmbH, 3M ESPE, DSM Somos, Elementis Specialties Inc, Inframat
	DSSC- Dye-sensitised solar cell	Merck & Dyesol Limited
	Other energy sectors (wind)	Arkema Group, Evonik Degussa GmbH
	Energy storage (battery applications)	eSpin Technologies Inc, Nanophase Technologies Corporation, Powdermet Inc
Nanoelectrodes	Nanobatteries	Nexelion by Sony Corp, SCIB by Toshiba Corp, Altair Nanotechnologies Inc
	LIB (Lithium in batteries)- manufacturing	Panasonic Sanyo, ENAX (JP), Mitsubishi Chemicals (JP), NEC (JP), Samsung SDI (KR), SK Innovation (KR), LG Chem (KR), Johnson Controls (USA), Lishen (CN), BAK (CN), BYD (CN), Evonik Degussa (DE), Li-Tec Battery (DE), Varta Microbattery (DE), Leclanché (Ch), Saft (FR)
Nanocoatings	PV coatings	Advent Solar[531], Philips Research (NL)
	Other types of coatings such as lubricant coatings, protective coatings, safety coatings and functional coatings	Tufftek, Buehler AG (CH), AS&M (USA), Cetelon Nanotechnik GmbH (DE), Nanovere Technologies, Diamon-Fusion International Inc., TopChim (BE), Hyperion Catalysis International
Carbon nanomaterials	General	XG Sciences, Targray, Avanzare, Samsung, Nokia, Vorbeck Materials, Angstrom Materials, Graphene Laboratories, CVD Equipment Corporation, Bayer MaterialScience GmbH, AMO GmbH, Showa Denki (CN), Nanocyl (BE), Future Carbon (DE)
Printed electronics	General	Oxford Photovoltaics, Magnolia Solar (USA), Innovalight Inc. (USA), 3M (USA), Anwell

[531] Taken over by Applied Materials in 2009

		Technologies Limited (HK), Tera-Barrier Films (SG)
Nanocatalysts	Oil refining	Headwaters NanoKinetix, Oxonica nanomaterials (UK), ThalesNano, Catalysts and Chemicals Co. Industries Ltd.
	Batteries, emissions reduction, fuel cells, and hydrogen generation	QuantumSphere Inc.
	Regenerative fuel production	Avoyelles Renewable Fuels Group
	Fuel cell catalysts	Antaira
	Chemical and petrochemical applications	Symyx Technologies
	Hydrogen production	Nanoptek
	Biofuel conversion	Sasol, Dioxide Materials, Albermarle Corporation, Green Power Inc.
	Hydrogen conversion	Ultracell LLc

Source: Seitz, R. et al (2013) Nanotechnology in the sectors of solar energy and energy storage, study prepared for the IEC Market Strategy Board by the Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany

ANNEX 7: PRODUCTS FOR NANOTECHNOLOGY AND ENERGY

This Annex is divided largely into the same categories as used in the main body of the report:

1. Photovoltaics (solar cells);
2. Storage
   a. Lithium-ion batteries;
   b. Super-capacitors;
3. Fuel cells
   a. Fuel cells;
   b. Fuel cell membranes;
4. Alternatives
5. Other products

1 PHOTOVOLTAICS (SOLAR CELLS)

Product Name	Description	Producer
AcuraCoat on-line CVD systems	Chemical vapour deposition (CVD) of high performance energy efficiency films.	AcuraCoat
Catalysts	ADParticles is working in the development of catalysts for gas emissions control and bulk chemical products. Its technology controls the structure of catalyst particles and therefore their catalytic function. ADParticles achieves a uniform and controllable dispersion of nanoparticles and an exposed structure, with a strong anchoring of nanoparticles to the substrate.	Advanced Dispersed Particles
MIRO-SUN®	MIRO-SUN® solar mirrors, with a total solar reflectivity of between 85% and 95%	ALANOD® GmbH & Co.KG
Mirotherm®	Mirotherm® is one of the selective absorptive layer systems for solar collectors and has revolutionised solar thermal applications.	
Elpox	Electrically conductive silver-epoxy flexible pastes, may be used in manufacturing membrane switches and flexible printed circuits.	Amepox Sp. z o.o.
Fluxopox	Fluxopox is the name of pastes conducting magnetic flux, but this paste has also anti-radiolocation properties.	
Printopox	Electrically conductive, glass-silver pastes Printopox for firing (or fusing) into silica type wafers (especially for Solar Cell applications) and or to other type of ceramics.	
Thermopox	Thermally conductive and electrically insulating pastes. Amepox is currently working on materials with the highest conductivity with special prepared and nano-size fillers.	
TCO Film	Transparent Conductive Oxide (TCO) film for thin film silicon photovoltaic devices	Asahi Glass

CPV Triple Junction Solar Cell - Type 3C42C	As the key component of a photovoltaic system, solar cells significantly contribute to the total costs of a CPV power plants. To further reduce manufacturing costs, AZUR SPACE is transferring its existing 100mm wafer technology to 150mm.	AZUR SPACE Solar Power GmbH
Triple Junction Solar Cell – Type 3T34C	The triple-junction solar cell initially developed for space operations and then optimised for terrestrial AM1.5 conditions (air mass 1.5) has reached efficiencies of over 34 % without any sunlight concentration. This solar cell is now available in large-scale production under the names of 3T34C or 3T34A as an assembly with interconnectors and cover glass.	
Triple Junction Solar Cell Assembly – Type 3T34A		
Triple Junction Solar Cell 3G28C	Space Solar Cells offer high efficiencies, starting from the 28% class and ending in the high-end cell class of 30% - Advanced. The solar cells are equipped with an integrated bypass diode to protect the adjacent cell in the string.	
Triple Junction Solar Cell 3G30C-Advanced		
Silicon Solar Cell S32		
Organic Photovoltaic Cells	Organic Photovoltaic Cells	BELECTRIC OPV GmbH
nAERO	Beneq aerosol A-R coatings for solar PV and CSP applications.	Beneq Oy
Solar Brush	Bloo’s Solar Brush™ increases the amount of sunlight converted into electricity through superior light trapping, driving the cost of energy below grid parity.	Bloo Solar
SLR-160	Blue Nano's proprietary SLR-160 conductive film allows for up to 38% greater efficiency due to light trapping and conductivity gains. The SLR-160 can be applied to most types of solar cells including thin-film photovoltaic, crystalline silicon photovoltaic, and concentrator solar panels. The SLR-160 is deposited onto the emitter surface during normal solar cell manufacturing processes.	Blue Nano
CENTROSOL HiT C TE ≥ 96%	This product group comprises low-iron special glasses made from float glass or structural glass, which are in addition given the companies' Nano-Power anti-reflective coating on one or both sides.	Centrosolar Glas GmbH & Co.KG
CENTROSOL HiT C+ TE ≥ 97%		
CENTROSOL HiT CST TE ≥ 95%		
CENTROSOL HiT MM TE ≥ 96%		
CENTROSOL HiT SM TE ≥ 96%		
SANTE Nanoparticle Coating	Self-Aligning Nano Technology for Electronics (SANTE™) Nanoparticle Coatings are Cima NanoTech's first commercial applications of an advanced nanoparticle and coating combination for use where high visible light	Cima Nanotech

	transmittance and low resistivity is needed.	
QDEC (Quantum Dot Enhanced Cell)	Advanced quantum dot nanotechnology high efficiency Concentrator Photovoltaic (CPV) cells.	Cyrium Technologies Incorporated
Innovalight™ Silicon inks	The DuPont Innovalight selective emitter platform is a patented silicon ink based solution for quick transition to >19% efficient mono crystalline solar cells.	DuPont
Dye-sensitised solar cells	Dye-sensitised solar cells	Dyesol
Organic Solar Cells	Organic solar cells	Eight19
Customised Solar Cells	Customised solar cells. The DSSC manufacturing process means GCell can be precisely manufactured with customised solar cells available in custom lengths and sizes for high volume OEM integration.	G24 Power Ltd
Indoor Solar Cells	The GCell brand of Dye Sensitised Solar Cell (DSSC) is an efficient indoor solar cell. GCell has been created to work in a wide range of indoor lighting conditions from extremely low light conditions, to dimly-light living rooms through to brightly-lit supermarkets.	
Gasp nanowire solar	The combined silicon-nanowire solar cell is completed using standard fabrication techniques.	Gasp Solar ApS
Q.PEAK BLK-G3	The third module generation from Q CELLS has been optimised across the board: improved output yield, higher operating reliability and durability, quicker installation and more intelligent design.	Hanwha Q CELLS GmbH
Q.PEAK-G3	The Q.PEAK-G3 of the third module generation is our champion among monocrystalline solar modules and impresses with its high performance coupled with its elegant design.	
Q.PLUS-G3	The new high-performance module Q.PLUS-G3 is the ideal solution for all applications thanks to its innovative cell technology Q.ANTUM. The cell design was developed for high performances under real conditions - even with low radiation intensity and on clear, hot summer days.	
Q.PRO-G4	This polycrystalline high performance module with performance classes up to 265 Wp represents the next evolutionary phase of the polycrystalline solar module. The Q.PRO-G4 provides excellent output values and maximum reliability.	
HeliaFilm	The film is ultra-light and flexible and less than 1 mm thin. It keeps its conversion efficiency in low light conditions and at high temperatures up to 80°C. Modifying the absorber	Heliatek GmbH

	chemistry, different colours can be achieved and even transparent cells are available.	
QRC heater	Sputter targets for thin film solar cells and functional layers for heat insulation glazings.	Heraeus Holding GmbH
Organic Solar Cells	Organic solar cells	infinityPV
Thin-film Solar Cell	Magnolia's thin film solar cells offer substantially lower cost than crystalline solar cells, use less expensive materials, have significant gains in efficiency vs. other thin film cells and modules by application of proprietary nano/micro technologies; and, has the potential for lowest cost/watt solar technology.	Magnolia Solar
HELiA	Coating systems for highest efficiency solar cells: The various HELiA systems form the core components of a production for manufacturing solar cells with heterojunction technology (HJT). The systems are perfectly coordinated technologically and in terms of their gross throughput of 2,400 wafers per hour.	Meyer Burger Technology AG
MAiA®TEX	The MAiA® platform - an enhanced version of SiNA® - provides a range of options for implementing new technological approaches to increasing the efficiency of crystalline silicon solar cells.	
SiNA®/MAiA®	With its SiNA® systems, Meyer Burger's competence centre for coating technologies, Roth & Rau AG, provides SiN coating systems for a host of capacity requirements from pilot production to fully automated mass production.	
ND-SP Ultrasonic Spray Coater	The Ultrasonic Spray Coater ND-SP is a system developed for the fabrication and deposition of thin films via spray. ND-SP has been designed with the objective to perform spray coating techniques, such as sol-gel, which require uniform and very small drop sizes. The ultrasonic spray coating technology can reduce manufacturing costs of solar cells.	Nadetech Innovations S.L.
TA2210	TA2210 is a photo-catalytically-active product for the coating of photovoltaic panels. Surfaces coated with TA2210 have self-cleaning properties. The coating reduces the reflection of sunlight on the module's surface. Accordingly, the light transmission of the glass is improved. The efficiency of the coated photovoltaic panel will increase up to 3 %.	NADICO Technologie GmbH
Advanced Processing Technologies	NanoAmor uses full-scale processing technologies to manufacture a wide	Nanoamor Europe

	range of high-quality nanomaterials with unique properties and enhanced performance.	
CFQD® quantum dots	Cadmium and heavy-metal free quantum dots, called CFQD® quantum dots, are fluorescent semiconductor nanoparticles typically between 10 to 100 atoms in diameter.	Nanoco Technologies Ltd
CIGS and CIS nanoparticles	Nanoco has developed a range of CIGS and CIS (copper indium gallium di-selenide/sulphide, copper indium di-selenide/sulphide) materials that can be deposited much more economically using conventional printing techniques.	
μsurf solar	μsurf solar is a high precision optical measurement solution for the broad range of solar applications in laboratory and production. The optimum flexibility allows all measurement tasks to be performed with nanometre accuracy using the confocal technology.	NanoFocus AG
nanoShell Solar PV	A silane-based nano-coating with hydrophobic and self-cleaning properties for photovoltaic (PV) and solar thermal panels.	nanoShell
Dye-sensitised solar cells	Dye-sensitised solar cells	NANOSOLAR INC.
Chromium sputtering targets	The hard material coatings chromium (Cr) and chromium nitride (CrN) optimally protect engine components such as piston rings against premature wear and consequently extend the useful life of important engine parts. Chromium is used as a bonding layer for DLC coatings (Diamond Like Carbon), for example on bucket tappets.	PLANSEE SE
CuGa sputtering targets	Many CIGS manufacturers use copper-gallium (CuGa) or copper-indium-gallium (CuInGa) sputtering targets for the deposition of the absorber layer. Compared to the co-evaporation method, the sputtering process is more stable, achieves improved material utilisation and makes it possible to produce uniform layers more easily.	
CuInGa sputtering targets	Many CIGS manufacturers use copper-gallium (CuGa) or copper-indium-gallium (CuInGa) sputtering targets for the deposition of the absorber layer. Compared to the co-evaporation method, the sputtering process is more stable, achieves improved material utilisation and makes it possible to produce uniform layers more easily.	
Molybdenum sputtering targets	Molybdenum coatings are the crucial components of the thin-film transistors used in TFT-LCD screens. Molybdenum layers are also used as back contacts in CIGS solar cells.	

Molybdenum-Sodium sputtering targets	Range includes MoNa sputtering targets with a sodium content of 5 % and 10 %. This corresponds to 1.3 and 2.6 % by weight.	
Molybdenum-Tantalum sputtering targets	Both during the production process and as a component in the future displays, these layers are exposed to atmospheric humidity and perspiration from the user's hand. The answer to corrosion: PLANSEE's molybdenum-tantalum solutions.	
Titanium and zirconium coatings sputtering targets	Titanium and zirconium coatings are applied using the reactive magnetron sputtering or the arc evaporation process. We supply both materials as sputtering targets and arc cathodes in all common sizes and formats.	
I30EG-1	Sicrys™ is single crystal nano-metric copper-based conductive ink for inkjet printing of circuits on solar cells (to replace silver ink).	pvnanocell
I40DM-106		
I50DB-114		
I50DM-106		
I50T-11		
I50T-13		
I50TM-115		
I50TM-119		
I60PM-116		
III-V Photovoltaic cells	III-V Photovoltaic cells	QuantaSol
Crystalline Solar Cells	SINGULUS TECHNOLOGIES co-operates with cell manufacturers worldwide and develops processes which improve the efficiency of solar cells and at the same time reduce production costs. Evolutionary improvement in cell concepts like PERC (PERL/PERT), n-type material, IBCcell or heterojunction cells will drive the future of crystalline solar cells.	SINGULUS TECHNOLOGIES AG
Aerotaxy	Gallium arsenide has been used in performance-category solar modules for years because of its high conversion efficiencies. The photonic effect of our nanowires and the low cost of Aerotaxy production of Solfilm™ minimises the cost by dramatically reducing the amount of gallium arsenide and other expensive materials required to generate electricity. The gallium arsenide nanowires in Solfilm™ consist of only a small number of atoms, but are fully-functioning solar cells.	Sol voltaics AB
SolFilm	SolFilm™, a solar panel additive containing gallium arsenide nanowires, promises to dramatically increase the efficiency of silicon solar modules. By adding SolFilm™ on crystalline silicon modules, today's average panel of	

	15.5% conversion efficiency can go beyond the silicon limits of 23-24%.	
Solink™	Solink™, a solar panel additive containing gallium arsenide nanowires, promises to dramatically increase the efficiency of silicon solar modules. By adding Solink™ on crystalline silicon modules, today's average panel of 15.5% conversion efficiency can go beyond the silicon limits of 23-24%.	
Polymer Solar cells	Polymer solar cells	Solarmer Energy, Inc.
Dye Solar Cell technology	Solaronix is developing a new generation of photovoltaic panels based on Dye Solar Cell technology.	Solaronix SA
Solaronix Solar Cell	Their ability to function in diffuse light conditions, coupled with unprecedented possibilities of design, make these solar cells applicable to a variety of novel installations, from building integration to embedded in electronics.	
Quantum dots PVC	Quantum dots PVC	Solterra Renewable Technologies
Multi-junction thin-film silicon cells (Micromorph)	Multi-junction thin-film silicon cells (Micromorph)	TEL Solar Ltd

2 Storage

A Lithium-ion batteries

Product Name	Description	Producer
12V Engine Start Battery	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.	
AHR32113 Cylindrical	Nanophosphate® AHR32113M1Ultra-B: Designed for HEV applications using the 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.	
AMP20 Energy Modules	Nanophosphate® AMP20 Energy Modules: Designed for plug-in hybrid and electric vehicle applications, the automotive class prismatic modules are built to deliver high energy without compromising power performance.	
AMP20 Prismatic Pouch	Nanophosphate® AMP20M1HD-A: A123's AMP20 prismatic pouch cell is built to deliver high energy and power density combined.	

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.	
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.	
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.	
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	
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
CE175-360 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 Li2MnO3) 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 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 GB is developing together with CVD Equipment Corporation. The unique technology GB is developing will not only replace conventional binders in	Graphene Batteries AS

	the battery but will also lead to the fabrication of thicker electrodes which can reduce the cost of batteries per KWh by about 30%.	
LFP/Graphene	GB has developed a composite LFP/Graphene material which has significantly higher conductivity than the reference industrial material. The developed 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 the safety of the battery.	
Silicon/Graphene	Silicon is the next generation of anode material with 10 times the theoretical capacity of presently used graphite. The 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.
CNTs for Li-ion batteries	Nanotube based additive for use in lithium-ion electrodes	NanoAmor
3rd Generation Cathode Materials	Lithium-ion battery using nanocomposite electrodes using technology developed at Argonne National Laboratory	NanoeXa Corporation
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
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

B Super-capacitors

Product Name	Description	Producer
NanoCap	NanoCap is a revolutionary 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 ™ product line consists of the industry's thinnest, patternable supercapacitor devices at voltages designed to match battery and system operating voltages.	
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.	

3 Fuel cells

A 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 minimise 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.	
CAT-110 Fuel Cell Catalyst	Blue Nano's porous catalyst technology increases reactive surface area, minimising 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
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.	Tagray

	Vor-charge Anode-HE: High energy storage capacity, Short recharge times, Good cycle life.	
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

B 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 patented proprietary cathodes and anodes and Dupont Nafion.	Bing Energy
Nafion	Nanoporous fuel cell membranes	E. I. Dupont De Nemours and Co.
SiMION	SiMION: composite and nanocomposite ion exchange materials, proton (H+) exchange materials.	SiM Composites

4 Alternatives

Product Name	Description	Producer
Alpha Nano Solutions	Coatings for wind turbine blades	Alpha Nano Solutions
Hybtonite®	The system is a low viscosity solvent free 100 % reactive CNT modified epoxy system tailor-made for composites industry. It is suitable for RTM, fi lament winding, laminating, pultrusion and many other applications	Amroy Europe Oy
Baytubes®	Carbon nanotubes for increased power yields and ability to withstand hurricane-strength wind speeds –basis of the wind power systems Hybtonite® manufactured by Eagle Wind Power, Finland.	Bayer Material Science AG
ConsERV	ConsERV is the best fixed-plate ERV on the market worldwide, as validated by third-party rating agencies. Our product raises the amount of indoor fresh air to meet ventilation building codes while saving up to 30% of energy costs, offering the potential to reduce the size of	DAIS analytics

	heating and cooling equipment by 1/3rd, while also reducing harmful CO2 emissions by 1.95 lbs per hour per ton of use avoided for the heating and cooling equipment.	
Small wind turbines	Wind power systems made of Hybtonite®	Eagle Wind power
Carbon spar caps	Fiberline manufactures pultruded profiles with consistent longitudinal strength that reinforces the blade. Profiles are available in both carbon fibre, GFRP or a combination.	Fiberline Composites
Bladeshield	The Bladeshield solution contains material that utilises nanotechnology and is applied by mixing it with the blade's paint. In addition to preventing ice formation, it can also boost the paint's resistance to erosion.	Gamesa
Rotorblades	Made of nanotube enforces resins	LM Wind Power Group
REWITEC Nanocoating	Thanks to the coating of metallic surfaces subjected to friction, REWITEC Nanocoating offers ideal protection for wind turbine transmission and bearings, even under the most extreme environmental conditions. The metal-silicate layer created improves tribological properties, reduces pitting and grey staining, increases the scuffing load capacity, reduces the need for replacement components, extends operational lifecycles and, thereby, increases system profitability.	REWITEC

5 Other products

Product Name	Description	Producer
Airglass	Silica based aerogel	Airglass
Cryogel	Foam-like hydrophobic aerogel	Aspen Aerogels Inc.
Pyrogel	Foam-like hydrophobic aerogel	
Spaceloft	Foam-like hydrophobic aerogel	
ConFINE Fines Fixing Agent	ConFINE treatments use advanced nanoparticle technology with high surface-force attractions to capture migrating fines in a frac pack.	Baker Hughes
YBCO 2G HTS Superconductors	YBCO 2G HTS wire products to enhance the reliability and efficiency of electrical power grids and large energy demanding applications.	Bruker
Nanogel Thermal Wrap	Silica based aerogel	Cabot Corporation
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.

LitwWire	LiteWire is a carbon nano-tube conductor in wire form. LiteWire is a direct replacement for copper wire. It also replaces any other metallic conductor used today. CurTran, in conjunction with its partners, NanoRidge Materials and Rice University, discovered alternate methods of producing carbon nano-tubes in wire form. This research and development resulted in a nearly pure carbon conductor that can be produced on an industrial scale. The capabilities of LiteWire exceed that of copper and compete at the same pricing point. LiteWire is produced in filaments and then processed to form any standard wire size. LiteWire can be delivered in any AWG standard sizing and processed in the same equipment as copper wire.	CurTran
DuraSeal Nanocoatings	Applied to pipes, tubing, couplings, valves and other specialty items, DuraSeal's specialty coatings provide customised solutions to abrasion and corrosion problems that have plagued the oil and gas industry for decades.	Duraseal
Evirox	Cerium oxide-based nano-catalyst for diesel fuels	Energenics Pte Ltd.
Fixit 222 Aerogel High-Performance Insulating Plaster	Silica based aerogel	Fixit AG
NPD Solutions Fracturing Fluid	NPD® Solutions features stable nanoparticle dispersions to accelerate recovery of hydrocarbons and stimulation fluids from reservoirs and near-wellbore regions. This high-tech solution replaces traditional surfactant systems, using nanoparticles to create complete water 'wetness' in a formation.	FTS International
NANOGEL	A new material, solid state; 90 to 99.8% of its composition is air. NANOGEL properties: Low refractive index. Low density, 1000 times less dense than glass and 3 times denser than air. Excellent thermal insulator. High mechanical strength, supports more than 1000 times its own weight.	Graphendis
NANOPERM®	NANOPERM® is a rapidly quenched iron based alloy with a fine crystalline microstructure. The typical grain size is only 10 nm, making it 'nanocrystalline'. This fine material structure is the reason for extraordinary soft magnetic properties which can be controlled in a wide range by an annealing process under the presence of external magnetic fields.	MAGNETEC GmbH
Aerogel	Silica based aerogel	MarkeTech International Inc.
HP-150	VIP-based aerogel	NanoPore

HT-170	VIP-based aerogel	
Aerogel	Silica based aerogel	SEPAREX S.A.
Eolys PowerFlex®	cerium oxide-based nanocatalyst for diesel fuels	Solvay
Quartzene®	Silica based aerogel	Svenska Aerogel AB
Thermoskin	Silica based aerogel	Vinzenz Harrer GmbH
XSnano fuel additive	NANO fuel additive, info on nano particles not disclosed	XSNANO LTD
NanoSphere ZLnano	Nano-spheres are very small particles of proprietary composition that are used to enhance the recovery of oil within a wide range of reservoir conditions. This is accomplished by adjusting the permeability of the reservoir.	ZL Petrochemicals

ANNEX 8: INDUSTRY AND NANOTECHNOLOGY FOR ENERGY

OVERVIEW OF THE ENERGY INDUSTRY

The energy sector in general covers extraction, production and distribution of energy. In 2013, 2.3 million people were employed in the sector in the EU28. It added EUR 309 billion to the European economy in 2012, corresponding to 5% of the value added of the European non-financial business economy[532]. There were over 70,300 energy enterprises in 2012, generating a total turnover of EUR 2.27 trillion[533]. The figure below presents an overview of the energy sector.

Table A: Overview of basic economic data for the energy sector in the EU28

Sub-sectors	Value added at factor cost	Total employees	Number of enterprises	Turnover
	MEUR [534]	'000s		MEUR
	2012	2013	2012	2012
Mining of coal and lignite	9,458.7	329.0	214	15,314
Extraction of crude petroleum and natural gas	51,010.9	97.7	397	173,009
Mining of uranium and thorium ores				
Extraction of peat	500.8	12.4	862	1,941
Support activities for petroleum and natural gas extraction	6,489.7	52.2	935	14,721
Manufacture of coke and refined petroleum products	20,194.0	208.1	1,153	626,196
Electricity, gas, steam and air conditioning supply	221,412.5	1,621.5	66,750	1,439,488
Total	**309,066.6**	**2,230.9**	**70,311**	**2,270,669**

Source: Adapted from: Eurostat Structural Business Statistics and EU Energy in figures, Statistical Pocket Book 2014

The energy storage sector is not included in the general energy sector overview of economic indicators. However, one specific part of energy storage, the manufacturing of batteries and accumulators, is included in Eurostat statistics as part of the manufacturing of electrical equipment. Economic data is shown in the overview table below.

Table B: Summary statistics for manufacturers of batteries and accumulators, EU28, 2012

Value added at factor cost in MEUR (2011)	Number of employees in thousands	Number of enterprises	Turnover in MEUR
1,733.1	300	500	9,000

Adapted from: Eurostat Structural Business Statistics

OVERVIEW OF FOUR SUB-SECTORS IN ENERGY

This section of the report discusses some economic indicators for the four sub-sectors identified for this report: solar energy (Solar), energy storage, batteries and capacitors (Storage), hydrogen energy (Hydrogen) and alternative energy generation technologies (Alternatives). These economic indicators are presented for the four sub-sectors in general and not specifically for the application of nanotechnology in these four sub-sectors, because of lack of data.

532 Eurostat, Structural Business Statistics
533 EU Energy in figures, Statistical Pocket Book 2014
534 MEUR = millions of euro

SOLAR ENERGY

Solar energy includes solar thermal and solar power. Solar thermal refers to the conversion of sunlight into heating and cooling. Solar power refers to conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar thermal power (CSP).

In 2014, the connected and cumulative *photovoltaic* capacity in the European Union (EU28) amounted to over 87,000 MWp[535], generating over 91,000 GWh[536,537,538]. The worldwide market is continuing to expand (to almost 40 GWp in 2014), but the European market is declining. In 2014, 6.9 GWp (gigawatt power) was installed and connected, a drop of 32.2% on 2013 and almost 70% less than in 2011 (see below). Significant reasons are the declining demand for energy due to the economic recession, changing support and incentives schemes from governments, as well as changes in the taxing and electricity distribution cost rate structures, making self-consumption[539] less advantageous. Hence, Europe no longer leads the world market for solar photovoltaic power.

In 2013, the European solar photovoltaics industry (EU28) generated a turnover of EUR 22 billion with a workforce of around 159,000 jobs. This was a substantial decrease of over 30%[540]. According to EU ProSun, an industry initiative striving for fair global competition in the photovoltaic industry, there are more than 130 European solar manufacturers[541].

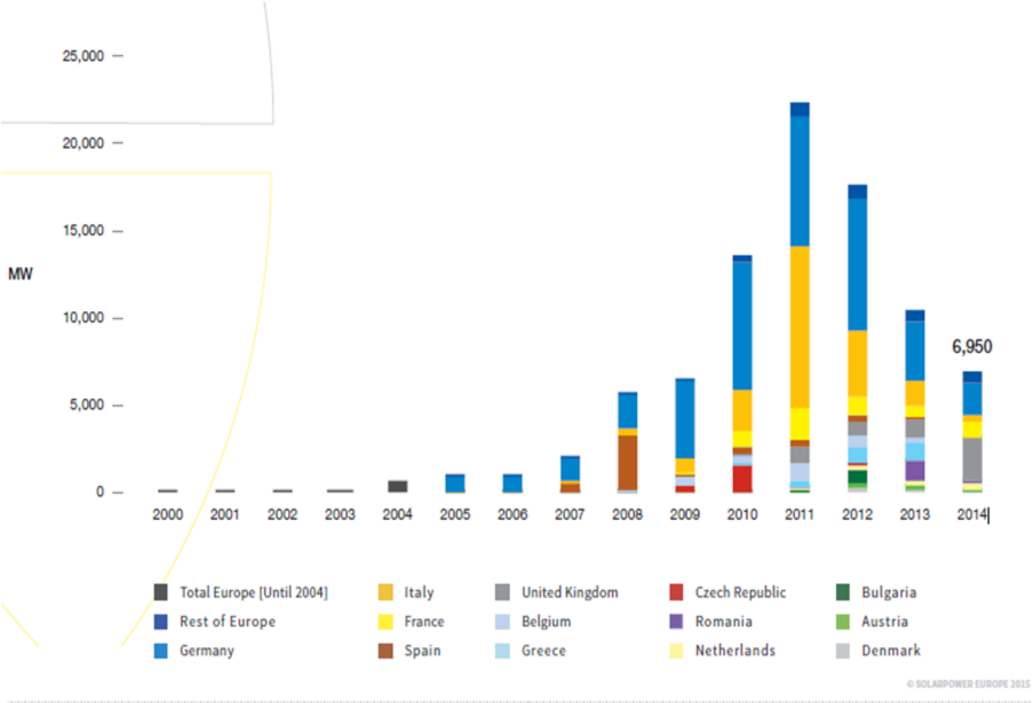

Figure A: Evolution of European solar PV annual installed capacity 2000-2012

Source: SolarPowerEurope (2015) Global Market Outlook for Solar Power / 2015 – 2019

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535 Megawatt peak, the maximum output of a power plant
536 Gigawatt hours, 1GWh = 1000 MWh
537 EurObserv'ER (2015) Photovoltaic Barometer, April 2015 http://www.eurobserv-er.org/pdf/press/2015/EurObservER-Press-Release-Photovoltaic-Barometer-2015-EN.pdf.
538 EurObserv'ER is a consortium of six European observatories, research centres and institutes monitoring the development of the various sectors of renewable energies in the European Union. http://www.eurobserv-er.org/
539 Production and consumption by the same country/ producer
540 EurObserv'ER (2012), 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe: http://www.eurobserv-er.org/
541 http://www.prosun.org/en/about/fact-sheet.html

Table C: Overview of the main manufacturers of photovoltaic modules worldwide

Company	Technologies	Country	Locations of the production lines	Modules delivered in 2014 (in MWp)
Trina Solar	Wafers, Crystalline (mono) cells, modules	China	China	3 660
Yingli Green Energy	Wafers, mono and multi crystalline cells, modules	China	China	3 361
Canadian Solar	Lingots, wafer, cells, modules, PV systems	Canada, China	Canada, China	3 105
Jinko Solar	Crystalline ingots, wafers, cells, and mono- and multi-crystalline PV	Chine	China	2 944
JA Solar	Mono-Crystalline, Silicon Module, Poly-Crystalline, Silicon Module	China	China	2 407
Renesola	Poly silicon wafers and modules, micro inverters	China	Poland, South Africa, Inde, Malaysia, South Korea, Turkey, Japan	1 970
Sharp Corporation	Crystalline (mono, multi)/Thin Film (a-Si, mc-Si)	Japan	Japan, USA	1 900
Motech	Crystalline (mono, multi) cells, modules and inverters	Taiwan	Taiwan, China, Japan, USA	1 632
First Solar	Thin film modules (CdTe)	USA	Malaysia, USA	1 500
Sun Power	Crystalline (mono, multi)cells, modules	USA	USA, Philippines	1 254

Source: EurObserv'ER 2015 (according to financial reports).

The Asian market dominates the worldwide market for solar photovoltaic and the main photovoltaic module manufacturers in the world are Chinese as shown in the table below. China is the world's largest producer of solar panels, most of Chinese production being exported to the EU and US markets. The European PV industry is concerned that China is producing to export, creating over capacity in the market, heavily supported by the government, and able to sell solar cells at very low prices. Official investigations resulted in EU measures against subsidised imports from China until the end of 2015. However, EU ProSun is concerned that Chinese manufacturers have failed to comply and has therefore asked for an extension of the trade measures[542].

In 2014, the cumulative capacity of *thermal solar collectors* installed in the European Union (EU28) amounted to 47.1 million m^2, generating 32.98 GWh[543]. For six years on a row, the annual installation capacity decreased. In 2014, 2.9 million m^2 was newly installed, 3.7% less than in 2013. Main reasons for this decline concern the drop in house sales, the construction sector suffering from the economic crisis and changes in investment support policies from the governments[544].

Concentrated solar power includes technologies that transform the radiation from the sun into very high temperature heat. This thermal energy can be used to produce electricity or to supply industrial processes that require high temperature levels.

In 2014, Europe's concentrated solar power capacity amounted to over 2,300 MW, similar to 2013. Most of the concentrated solar power plants in Europe are located in Spain (50). Italy and France have two plants each, and Germany has one. In Italy in particular, new concentrated solar power plants are under development (see table). The European industry for concentrated solar power has a solid base, also generating business in the main emerging markets (South Africa, Saudi Arabia, Chile etc.).

[542] http://www.prosun.org/en/component/downloads/downloads/242.html
[543] Includes glazed and unglazed collectors
[544] EurObserv'ER (2012) 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe; EurObserv'ER (2015) Concentrated solar power and solar thermal Barometer, May 2015. http://www.eurobserv-er.org/

Table D: Overview of CSP plants under development at the beginning of 2013

Project	Location	Capacity (MW)	Technology	Commercial date of operation
Italy				
Flumini Mannu	Villasor, Cagliari (Sardegna)	55	Parabolic Trough	2017
Gonnosfanadiga	Gonnosfanadiga, Nuoro (Sardegna)	55	Parabolic Trough	2017
CSP San Quirico	San Quirico, Oristano (Sardegna)	10.8	Parabolic Trough impianto ibrido	2017
Banzi	Banzi, Potenza (Basilicate)	50	Parabolic Trough	2017
Mazara Solar	Mazara del Vallo, Trapani (Sicily)	50	Central receiver (power tower)	2017
Archimede	Melilli, Siracusa (Sicily)	1	Parabolic Trough	2015
Lentini	Lentini, Siracusa (Sicily)	55	Parabolic Trough	n.a.
Reflex Solar Power	Gela, Caltanissetta (Sicily)	12.5	Parabolic Trough	2016
Solecaldo	Aidone, Enna (Sicily)	41	Linear Fresnel	2016
Michelangelo	Palermo (Sicily)	3	Linear Fresnel	n.a.
Bilancia 1	Palermo (Sicily)	4	Linear Fresnel	2016
Bilancia 2	Palermo (Sicily)	4	Linear Fresnel	n.a.
Calliope	Trapani (Sicily)	4	Linear Fresnel	n.a.
Zeronovantuno 2	Trapani (Sicily)	4	Linear Fresnel	n.a.
Jacomelli	Trapani (Sicily)	4	Linear Fresnel	2016
Porthos	Trapani (Sicily)	4	Linear Fresnel	n.a.
Stromboli Solar	Trapani (Sicily)	4	Linear Fresnel	n.a.
Total Italy		361.3		
France				
Alba Nova 1	Ghisonaccia (Corsica)	12	Linear Fresnel	2016-2017
eLLo	Llo (Pyrénées-Orientales)	9	Linear Fresnel	2016-2017
Total France		21		
Cyprus				
Helios Power	Larnaca	50.8	Dish Stirling	n.a.
Total Cyprus		50.8		
Greece				
Maximus Dish project	Florina	75	Dish Stirling	n.a.
Hyperion 1	Crète	70	Parabolic Trough	n.a.
Total Greece		145		
Spain				
PTC50 Alvarado	Alvarado, Badajoz	50	Central receiver (power tower) - Biomass	n.a.
Total Spain		50		
Total European Union		628.1		

Source: EurObserv'ER 2015

Source: EurObserv'ER (2015) Concentrated solar power and solar thermal Barometer, May 2015

In 2013, the European *solar thermal sector and concentrated solar power sector* (EU28) generated a turnover of EUR 3.7 billion, and employed 41,650 people[545]. The tables present an overview of the main European solar thermal collector manufacturers and the main European CSP project developers in 2014.

[545] 14th EurObserv'ER Report, Edition 2014, The State of Renewable Energies in Europe

Table E: Overview of representative European solar thermal collector manufacturers

Company	Country	Activity	Production 2012/2013 (collector area in m²)	Turnover 2014 (in M€)	Employees 2014
GREENoneTEC *	Austria	Flat plate and vacuum tube collector	634 000	82	280
Bosch Thermotechnik *	Germany	Heating equipment supplier / Flat plate collector manufacturer	310 000	2.800 ***	12.900 ***
Viessmann *	Germany	Heating equipment / solar thermal	240 000	2.200 ***	11.500 ***
Vaillant Group *	Germany	Heating equipment supplier / solar thermal	170 000	2.400 **	12 000
BDR Thermea Group *	Netherlands	Heating equipment supplier / solar thermal	160 000	1.800 ***	6.500 ***
Dimas *	Greece	Flat plate collector manufacturer	130 000	n.a.	n.a.
Riposol	Austria	Flat plate collector manufacturer	125 000	n.a.	n.a.
Wolf *	Germany	Heating equipment supplier	120 000	337 **	1.810 **
Nobel Xilinakis *	Greece	Flat plate collector manufacturer	115 000	n.a.	80
Cosmosolar *	Greece	Flat plate collector manufacturer	70 000	n.a.	n.a.
Ariston *	Italy	Flat plate collector manufacturer	60 000	1.340 ***	6.600 ***

* No ranking - representative overview of European companies in the Solar thermal sector. Estimations based on company information and Sun and Wind Energy 10/2014 (Solar Thermal World Map 2014). Note: There may be substantial uncertainties due to the different collector types and OEM inputs. ** 2013. *** Entire group. **Source: EurObserv'ER 2015**

Table F: Overview of representative European solar thermal collector manufacturers

Company	Country	Activity	MW developed or under construction	Turnover	Employees
Ibereolica	Spain	Engineering - EPC - O&M - Project developer	960	n.a.	n.a.
Abengoa	Spain	Promoter - Project developer - EPC - Engineering - O&M - Components	651	7.151 *	24.748 *
Magtel Renewables	Spain	Promoter - Project developer - EPC - O&M - Engineering - Consulting	1 050	n.a.	n.a.
ARIES ingenieria y sistemas	Spain	Promoter - Project developer - EPC - O&M - Engineering - Consulting	500	n.a.	n.a.
Cobra	Spain	Promoter - Project developer - EPC - Engineering - O&M	500	4.200 *	26.000 *
Acciona Energy	Spain	EPC - Project developer - Promoter	314	2.200 **	2.300 **
Torresol Energy	Spain	Promoter - Project developer - O&M - Engineering	119	n.a.	n.a.
FCC Energia /Enerstar	Spain	Promoter - Project developer	100	6.334 *	80.000 *
Hyperion	Spain	Promoter - Project developer - O&M	103	n.a.	n.a.
Samca	Spain	Promoter - Project developer - O&M	100	850 *	3,500 *
Sener	Spain	Components - Engineering - Project developer	100	1.218 *	5.570 *

* Entire group, not only solarthermal or renewable division. ** Energy Division.
Source: EurObserv'ER 2015 (based on company information and CSP-World: http://www.csp-world.com/guide).

Source: EurObserv'ER (2015) Concentrated solar power and solar thermal Barometer, May 2015

In 2013, asset financing for *utility-scale*[546] photovoltaic capacity significantly decreased compared to 2012. In 2013 the EU-wide investment in new utility-scale PV capacity amounted to almost EUR

546 Asset financing covers all investment into renewable energy generation at *utility scale*. It includes balance-sheet finance, non-recourse project finance, and bonds and other approaches. In the PV sector, the largest share in PV installations are small-scale investments as rooftop installations.

3.1 billion, a drop of almost 60%. The number of projects dropped as well, by 34% to 234 projects in 2013. The average investment into solar PV power plants was EUR 13 million in 2013. When the asset financing is related to the associated capacity, it becomes clear that the average investment per one MW has decreased substantially from EUR 2.42 million in 2012 to EUR 1.37 in 2013, reflecting the sharp decrease in prices for PV[547]. The figure presents an overview of asset financing of PV at utility-scale in various EU Member States.

Table G: Overview of asset finance in photovoltaic sector in the EU member states in 2012 and 2013 (PV plants)

	2012			2013		
	Asset Finance - New Built (mln. €)	Number of Projects	Capacity (MWp)	Asset Finance - New Built (mln. €)	Number of Projects	Capacity (MWp)
United Kingdom	1 139.78	87	485.0	1 732.02	119	1 320.5
Romania	276.67	21	120.0	447.62	34	325.3
France	1 389.88	30	537.7	385.90	27	251.4
Italy	512.69	40	209.1	262.34	16	172.0
Germany	2 962.35	85	1 252.0	163.14	19	112.9
Spain	92.15	10	33.6	38.55	9	32.0
Greece	219.21	22	93.9	15.53	5	11.45
Poland	0.00	0	0	6.65	1	4.0
Czech Republic	5.30	1	2.3	3.98	3	3.3
Austria	0.00	0	0	3.92	1	1.0
Belgium	10.86	2	4.7	0	0	0
Bulgaria	904.82	53	366.9	0	0	0
Denmark	2.57	1	1.1	0	0	0
Netherlands	3.50	1	1.5	0	0	0
Portugal	41.10	1	17.6	0	0	0
Slovakia	2.33	1	1	0	0	0
Total EU	7 563.20	355	3 126.3	3 059.65	234	2 233.8

Source: EurObserv'ER 2014

EurObserv'ER presents data on small-scale PV investments as well. These figures clearly show that financing for small-scale PV installations is more than four times higher than asset finance for PV power plants (see table below).

Table H: Renewable energy investment and capacity in Europe, 2012 and 2013

	2012		2013	
	Investment (MEUR)	**Capacity (MW)**	**Investment (MEUR)**	**Capacity (MW)**
Commercial	7,563.20	3,126.3	3,059.65	2,233.8
Residential	25,921.28	8,437.25	9,964.7	4,780.72
Total EU	33, 484.48	11,563.55	13,024.35	7,014.52

Source: EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe

[547] EurOberv'ER (2014) The state of renewable energies in Europe – 2014 edition

In 2013, no asset financing for concentrated solar power plants was reported. In 2012, there was asset financing for four CSP power plant projects (see table below).

Table I: Overview of asset finance in CSP sector in the EU Member States in 2012 and 2013

	2012			2013		
	Asset Finance - New Built (mln. €)	Number of Projects	Capacity (MW)	Asset Finance - New Built (mln. €)	Number of Projects	Capacity (MW)
Spain	915.78	4	173.5	0.00	0	0
Total	915.78	4	173.5	0.00	0	0

Source: EurObserv'ER 2014

Source: EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe

Not only asset financing but also venture capital and private equity investment in PV and CSP decreased between 2012 and 2013. There were less deals as well as a lower average size of the deals. According to EurObserv'ER (2014), a total amount of just under EUR 75 million venture capital / private equity was invested in PV in 2013, a decline of EUR 21 million compared with 2012. There was no venture capital or private equity invested in CSP in 2013, while in 2012 this amounted to EUR 4.4 million[548].

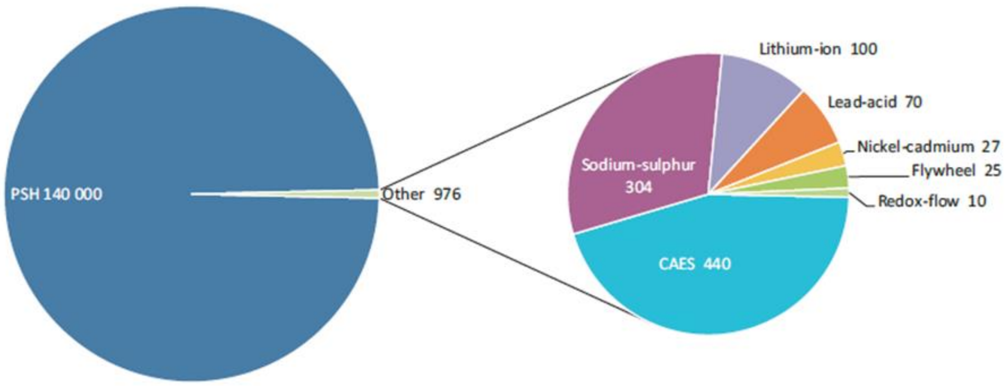
ENERGY STORAGE

Energy storage fulfils three functions: to charge, to store, and to discharge energy. Energy storage is considered to be an essential element in developing sustainable energy systems, especially because energy storage can help to integrate discontinuous renewable energy sources; to improve resource use efficiency; to reach higher levels of end-use sector electrification; to support access to energy; to bring the production of energy where it is consumed; and to improve the stability, flexibility, reliability and resilience of the electricity grid[549].

Energy storage is applied in various products and markets, such as consumer products (consumer electronics), stationary energy storage (e.g. home solar, isolated grids) and transport (electric vehicles). The technologies applied in energy storage can be differentiated into electrochemical energy storage (e.g. lithium-ion, flow/high-temperature batteries and aqueous systems), electrical energy storage (e.g. super-capacitors), chemical energy storage (e.g. chemical or liquid hydrogen, synthetic natural gas), mechanical energy storage (e.g. compressed air energy storage, flywheels, pumped hydro), and thermal energy storage [550].

Current installed energy storage capacity is not easy to define. Lack of accessible data, as well as conflicting definitions, prevent a comprehensive and detailed overview of current installed storage capacity. The International Energy Agency (IEA, 2014) estimates the current worldwide energy storage capacity installed in electricity grids to be 140 gigawatts (GW) worldwide. Of this, 99% is in pumped hydro energy storage (PSH). The other 1% includes a mix of battery technologies, compressed air energy storage (CAES), flywheels, and hydrogen storage, as shown below (figures in megawatts (MW)).

[548] 14th EurObserv'ER Report, Edition 2014, The State of Renewable Energies in Europe
[549] IEA (2014) Technology Roadmap – Energy Storage; FCH-JU & McKinsey & Company (2015) Commercialisation of energy storage in Europe – Final Report, March 2015
[550] IEC (2014) Nanotechnology in the sectors of solar energy and energy storage, Technology Report for the IEC Market Strategy Board by the Fraunhofer Institute for Systems and Innovation Research ISI; http://www.ease-storage.eu/technologies.html



Source: IEA analysis and EPRI (Electric Power Research Institute) (2010), "Electrical Energy Storage Technology Options", Report, EPRI, Palo Alto, California.

Figure B: Current global installed grid-connected electricity storage capacity (mw)

The IEA roadmap for Energy Storage (2014) estimates that, based on a scenario in which variable renewable electricity reaches between 27% and 44% of electricity production in 2010, 310 GW of additional storage would be needed in China, India, the EU and the US in 2050 (these regions being expected to make up 85% of the electricity demand in 2050).

There are few data on the size of the energy storage sector in terms of number of enterprises, value added, turnover or employment. EUROBAT, the Association of European Automotive and Industrial Battery Manufacturers, estimates that the European battery industry employs over 30,000 employees. EUROBAT has 47 members including 31 battery manufacturing plants and 16 R&D centres and represents 90% of European automotive and industrial battery manufacturers. The companies realised a turnover of EUR 6 billion in 2013, according to EUROBAT[551]. The data presented by EUROBAT diverge from Eurostat data (presented earlier in this section), which could be explained by there being a much broad sector definition, also including accumulators other than batteries, and also including manufacturing of batteries for consumer markets.

According to an IDTechEx Market Survey (2013) only 7% of global manufacturers of electro-chemical capacitors (supercapacitors) are located in Europe[552].

EASE, the European Association for Storage of Energy has developed an Energy Storage Database including current storage projects, both demonstration and commercial, all over Europe. The database includes 82 projects (see table below) across twelve European countries, the majority being either electro-chemical or mechanical by technology type.

Table J: Energy storage projects, demonstration and commercial, in Europe

Country	Organisation	Technology type
Austria	Verbund	Mechanical - Pumped Hydro
	KELAG (2)[553]	
	Voralberger Illwerke (2)	
	Verbund Hydro Power (6)	
Belgium	Electrabel (2)	Mechanical - Pumped Hydro
Czech Republic	ČEZ Group (2)	Mechanical - Pumped Hydro
Denmark	Technical University of Denmark (Risø DTU)	Electrochemical - Flow Battery - Vanadium Redox
	GO Development	Mechanical - Pumped Hydro
France	Saft	Electrochemical - Classic Battery - Lithium Ion
	Christophe HUBERT	Electrochemical - Classic Battery - Lithium Ion Phosphate
	Gas de France (GDF) - Suez	Mechanical - Diabatic Compressed Air
	Électricité de France (EDF) (11)	Mechanical - Pumped Hydro

[551] Eurobat Infographic, http://www.eurobat.org/sites/default/files/eurobat_infographic_2014_posterweb.pdf
[552] Referred to in EASE/EERA recommendations for European energy storage technology development roadmap towards 2030 – Technical Annex (2014), page 45
[553] Number in brackets indicates number of projects developed by the company

Country	Organisation	Technology type
	CNIM	Thermal - Heat
Germany	EnBW	Chemical - Hydrogen
	E.ON - Swissgas	Chemical - Hydrogen
	EnBW - ODR	Electrochemical - Classic Battery - Lithium Ion
	EnBW	Electrochemical - Classic Battery - Lithium Ion
	ads-tec	Electrochemical - Classic Battery - Lithium Ion
	Wemag	Electrochemical - Classic Battery - Lithium Ion
	E.ON Hanse	Electrochemical – Classic & Flow Battery - Lithium Ion & Vanadium Redox
	EnBW	Mechanical - Adiabatic Compressed Air
	Hydrogenics	Mechanical - Adiabatic Compressed Air
	E.ON Kraftwerke	Mechanical - Diabatic Compressed Air
	Vattenfall (5)	Mechanical - Pumped Hydro
	Statkraft	Mechanical - Pumped Hydro
	EnBW	Mechanical - Pumped Hydro
	E.ON (2)	Mechanical - Pumped Hydro
	Stadtwerke Reutlingen	Mechanical - Pumped Hydro
	Stadtwerke München (2)	Mechanical - Pumped Hydro
	DRL	Thermal - Heat
Ireland	Glen Dimplex	Thermal - Smart Electrical
Italy	BYD	Electrochemical - Classic Battery - Lithium Ion
	ENEL (2)	Electrochemical
	ENEL (3)	Electrochemical - Classic Battery - Lithium Ion
	FIAMM	Electrochemical - Classic Battery - Sodium Nickel Chloride
	Cellstrome	Electrochemical - Flow Battery - Vanadium Redox
Spain	Endesa - ENEL	Electrical - (Ultra)capacitors
	Endesa - ENEL	Electrochemical - Classic Battery - Sodium-Sulphur
	CENER	Electrochemical - Flow Battery - Vanadium Redox
	Endesa - ENEL	Electrochemical - Flow Battery - Zinc Bromine
	SENER (2)	Thermal - Molten Salt
Sweden	Falbygdens Energi	Electrochemical - Classic Battery - Lithium Ion
Switzerland	EKZ	Electrochemical - Classic Battery - Lithium Ion
	Electric Power Company	Electrochemical - Classic Battery - Lithium Ion Phosphate
United Kingdom	UK Power Networks (2)	Electrochemical - Classic Battery - Lithium Ion
	Mitsubishi Power Systems Europe (MPSE)	Electrochemical - Classic Battery - Lithium Ion
	Gigha Island Community	Electrochemical - Flow Battery - Vanadium Redox
	Highview Power Storage	Mechanical - Cryogenic
	National Grid	Mechanical - Pumped Hydro
	First Hydro Company	Mechanical - Pumped Hydro
	Scottish & Southern Energy (SSE)	Thermal - Smart Electrical

Source: http://www.ease-storage.eu/demonstrator.html, visited 3 July 2015

HYDROGEN [554]

Hydrogen can be produced from various energy sources, such as biomass and natural gas, and from water by using electricity to split it into its components, hydrogen and oxygen. Fuel cells are used to convert hydrogen to power and heat energy.

In 2013, global hydrogen usage as a feedstock for industry to convert raw materials into chemical or refinery products amounted to a total of 7.2 EJ[555] (2,000 TWh)[556]. Around 48% of the hydrogen was produced from natural gas, 30% as a fraction of petroleum during the refining process, 18% from coal, and the balance (4%) is electrolytic hydrogen[557]. The use of hydrogen as an energy carrier is beginning to emerge, in mobility applications as well as in energy storage applications. So far, hydrogen for energy usage has mainly been seen in demonstration projects, with some commercial applications starting to emerge.

In transport, fuel cell electric vehicles (FCEVs) are electric vehicles using hydrogen stored in a pressurised tank and with a fuel cell for on-board power generation. There are about 500 FCEVs running in demonstration projects around the world (see table below).

Hydrogen-based transport depends on the existence of refuelling stations. Currently there are an estimated 80 refuelling stations worldwide (see second table below).

Materials handling vehicles (fork lifts) using fuel cells are commercially deployed, mostly in the US, with over 8,200 deployed there since 2009 (IEA, 2015).

Stationary fuel cell systems in the range of several kilowatts to multiple megawatts, used for remote power and back-up power applications, account for almost 90% of total fuel cell shipments (IEA, 2015).

Table K: Overview of existing FCEV fleet and targets set by demonstration projects

Country or region	*Running FCEVs*	*Planned FCEVs on the road*	
		2015	*2020*
Europe	192	5 000	~350 000
Japan	102	1 000	100 000
Korea	100	5 000	50 000
United States	146	~300	~20 000

Sources: Weeda et al. (2014), *Towards a Comprehensive Hydrogen Infrastructure for Fuel Cell Electric Cars in View of EU GHG Reduction Targets*; personal contact with US Department of Energy; Japanese registration number from database of Japan Automobile Dealers Association (JADA, March, 2015).

Source: IEA (2015) Technology Roadmap Hydrogen and Fuel Cells

[554] IEA (2015) Technology Roadmap Hydrogen and Fuel Cells, http://www.iea.org/publications/freepublications/publication/technology-roadmap-hydrogen-and-fuel-cells.html

[555] 1 Exa-Joule = 10^{18} Joules = 1 Mega Tera Joule. 1 kWh = 3.6 x 10 6 J

[556] Suresh, B. et al. (2013), Chemical Economics Handbook, IHS Chemical. See also: http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf

[557] Decourt, B. et al. (2014), Hydrogen-Based Energy Conversion, More Than Storage: System Flexibility, SBC Energy Institute, Paris. See also: http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf

Table L: Overview of existing and planned refuelling stations

Country or region	Existing hydrogen refuelling stations	Planned stations	
		2015	2020
Europe	36	~80	~430
Japan	21	100	>100
Korea	13	43	200
United States	9	>50	>100

Sources: Weeda et al. (2014), *Towards a Comprehensive Hydrogen Infrastructure for Fuel Cell Electric Cars in View of EU GHG Reduction Targets*; HySUT (2014), *Fuel Cell Vehicle Demonstration and Hydrogen Infrastructure Project in Japan*; FFC (2015), *Fuel Cell Commercialisation Conference in Japan (FCCJ)*, http://fccj.jp/hystation/index.html#hystop; personal contact with US Department of Energy.

Source: IEA (2015) Technology Roadmap Hydrogen and Fuel Cells

Combined heat and power (or cogeneration) systems are being developed and installed to use at household level, particularly in Japan[558]. The electricity is generated by refrigerator-sized 'energy farms', or 'home ene-farms' manufactured by companies including Panasonic and Toshiba and sold by utility companies such as Tokyo Gas. More than 100,000 Japanese households have installed generators that use hydrogen since sales began in 2009. Japan has set a target of 5.3 million hydrogen-powered homes, roughly 10 percent of Japan's total, by 2030 and are subsidising their purchase.

A study commissioned by the U.S. Department of Energy (DOE) estimates total fuel cell industry sales at USD 1.3 billion in 2013[559]. These revenues grew by 35% over 2012, especially in North America and Asia, while Europe showed a slight decline in fuel system revenues (see figure below).

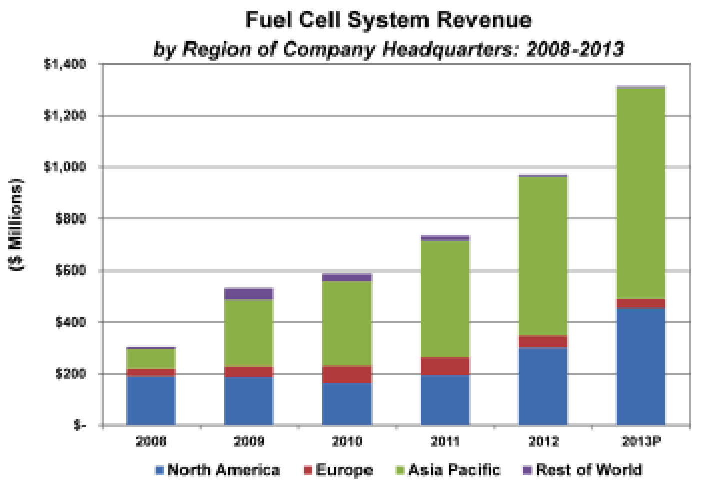


Figure C: Fuel cell industry revenues 2008-2013

Source: US Department of Energy (2014) 2013 Fuel Cell Technologies Market Report, Fuel Cell Technologies Office, November 2014

558 http://www.bloomberg.com/news/articles/2015-01-15/fuel-cells-for-homes-japanese-companies-pitch-clean-energy and IEA (2015) Technology Roadmap Hydrogen and Fuel Cells

559 US Department of Energy (2014) 2013 Fuel Cell Technologies Market Report, Fuel Cell Technologies Office, November 2014

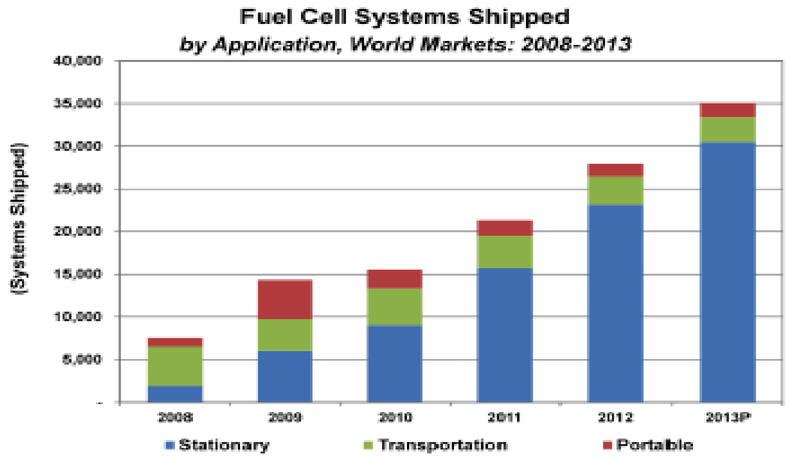


Figure D: Fuel cell systems shipped 2008-2013

Source: US Department of Energy (2014) 2013 Fuel Cell Technologies Market Report, Fuel Cell Technologies Office, November 2014

The U.S. Department of Energy study estimates that in 2013 approximately 35,000 fuel cell systems were shipped, an increase of 26% compared to 2011. These shipments represent 165 MW worldwide (see figure above).

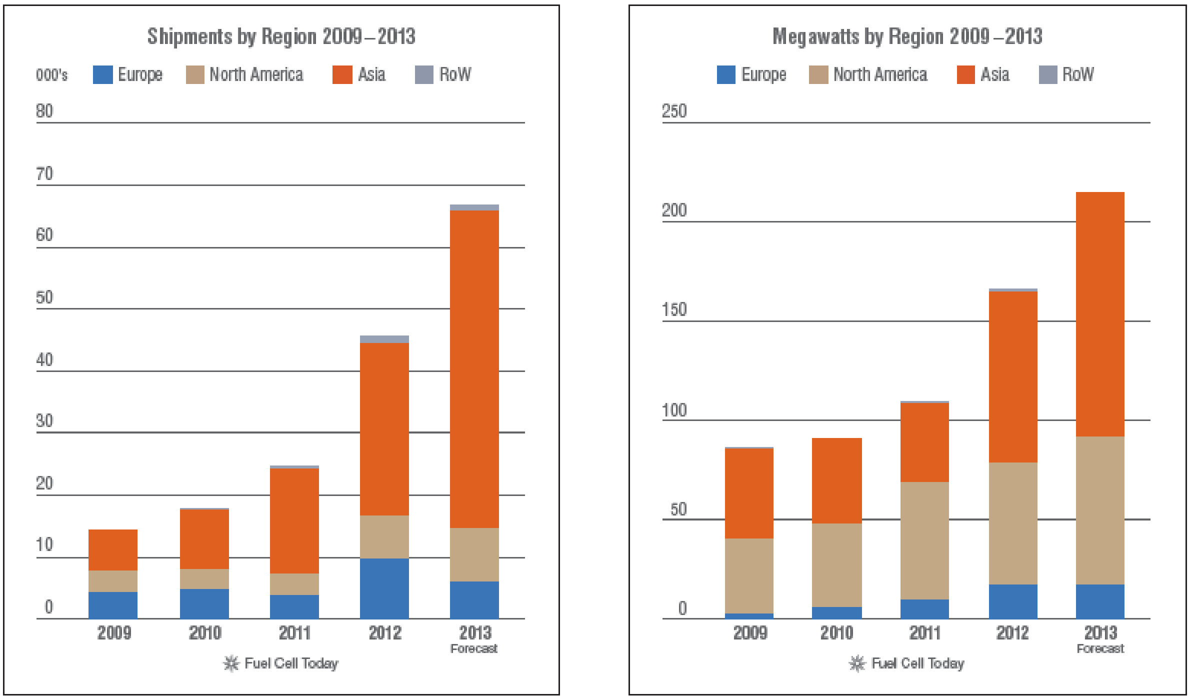


Figure E: Annual shipments of fuel cells by region in 2009-2013

Source: Fuel Cell Today (2013) The Fuel Cell Industry Review 2013

Fuel Cell Today reports[560] substantially larger numbers of shipments. They estimate 45,700 fuel cell shipments worldwide in 2012 (excluding toys and education kits), an increase of 86% on 2011, mainly led by growing numbers in the stationary fuel cells. In terms of megawatts, these shipments generate a total of 166.7 MW (see figure above). Asia dominates the global shipments, with a share of 61%. Fuel cell shipments for Europe amounted to 9,700 units in 2012, a share of 21%. Fuel Cell

[560] Fuel Cell Today (2013) The Fuel Cell Industry Review 2013, http://www.fuelcelltoday.com/media/1889744/fct_review_2013.pdf

Today forecast that the global shipments would increase to 66,800 units in 2013, with the shipments from Asia doubling to 51,100 units, while European shipments would decrease to 6,000.

The Fuel Cells and Hydrogen Joint Undertaking commissioned a survey[561] of the European fuel cells and hydrogen sector (2013). 154 respondent companies reported that, on average, their annual turnover increased by 10% in the previous 5 years, R&D expenditures by 8% and market deployment expenditures by 6%. Moreover, they estimated that the total number of jobs has been increasing by about 6% per year since 2007, to approximately 4,000 FTE. The respondents expect turnover to increase by 35% year on year to 2020, while R&D expenditure is expected to increase by 12% p.a. and employment by 9% p.a., reaching about 8,000 FTE in 2020.

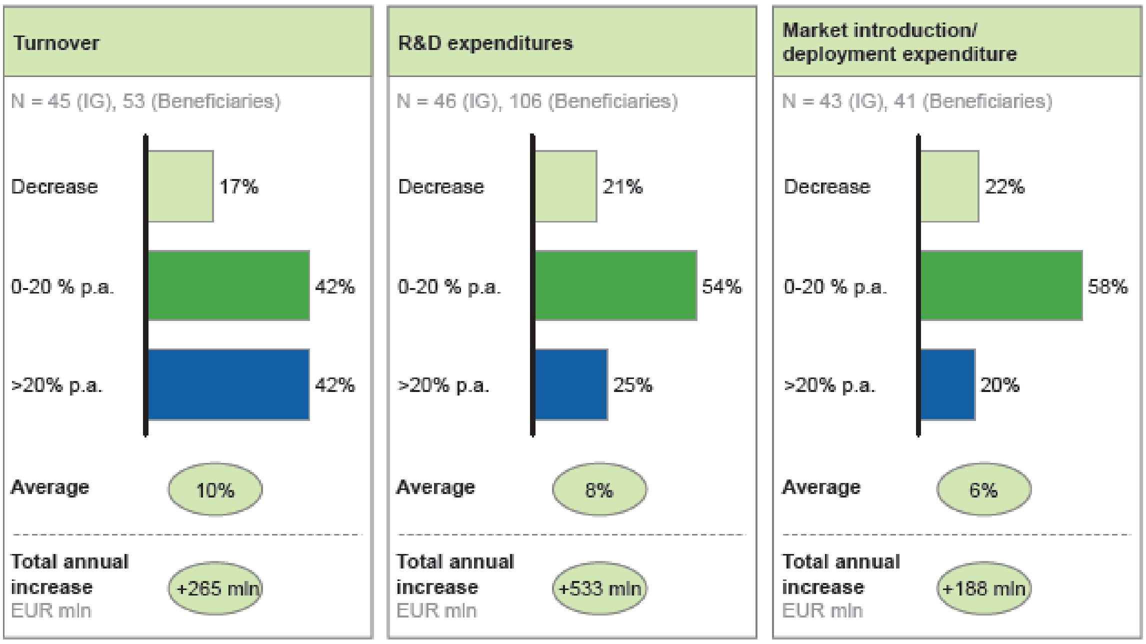


Figure F: Estimated annual growth in the fuel cells and hydrogen sector, 2007-2011/12

Source: Fuel Cells and Hydrogen Joint Undertaking, Trends in investments, jobs and turnover in the fuel cells and hydrogen sector

Between 2011 and 2013, the total cumulative global investment in fuel cell companies (venture capital, private equity, over-the-counter and private investment) was estimated at more than USD 1.038 billion, growing from USD 853.6 million between 2010 and 2012 (see figure below).

[561] Fuel Cells and Hydrogen Joint Undertaking (2013) Trends in investments, jobs and turnover in the fuel cells and hydrogen sector, http://www.fch.europa.eu

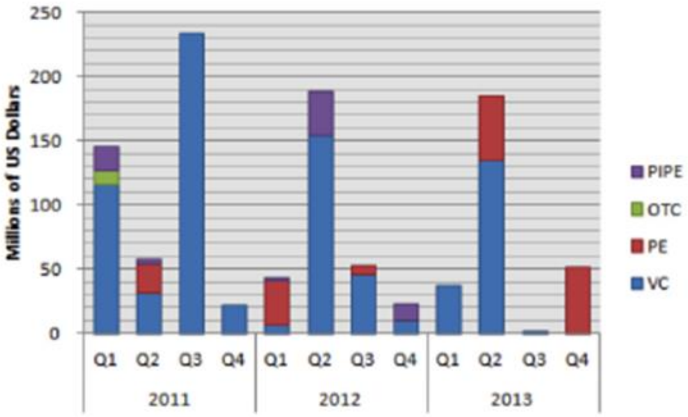


Figure G: Global investments in fuel cell companies, 2011-2013

Source: US Department of Energy (2014) 2013 Fuel Cell Technologies Market Report, Fuel Cell Technologies Office, November 2014[562]

Over 90% of the reported global investment in fuel cell companies during the period 2000 through 2013 comes from the top ten investor countries. The table below presents an overview of the top ten fuel cell investors and the top ten countries with the highest levels of private investment in fuel cells in the period 2000 through 2013.

Table M: Top ten venture capital and private equity investors in fuel cells by company and by country (cumulative 1/1/2000-12/31/2013)

Top Ten Fuel Cell Investors		Top Ten Countries with Highest Levels of Private Investment in Fuel Cells	
Company	Amount (million USD)	Country	Total All VC and PE Investment (million USD)
Credit Suisse (Switzerland)	136.2	U.S.	789.9
Kleiner Perkins Caufield & Byers (U.S.)	105.7	U.K.	243.1
New Enterprise Associates (U.S.)	71.0	Switzerland	156.5
Mobius Venture Capital, Inc. (U.S.)	68.2	Canada	73.8
GSV Capital Corp. (U.S.)	54.2	Singapore	50.0
DAG Ventures LLC (U.S.)	54.2	New Zealand	50.0
Rolls-Royce Holdings PLC (U.K.)	50.0	Germany	42.5
Enertek Services Pte Ltd (Singapore)	50.0	Sweden	23.6
Superannuation Fund (New Zealand)	50.0	Russian Federation	21.0
Meditor Capital Management (U.K.)	36.7	Denmark	20.0
Subtotal (top 10 only)	**$676.2**	**Subtotal (top 10)**	**$1,470.4**
TOTAL (All Companies and Countries)			**$1,577.4**

Source: Source: US Department of Energy (2014) 2013 Fuel Cell Technologies Market Report, Fuel Cell Technologies Office, November 2014[563]

[562] Based on data from Bloomberg New Energy Finance and New Zealand Superannuation Fund, Worldwide Venture Capital (VC), Private Equity (PE), Over-the-Counter (OTC), and Private Investment in Public Equities (PIPE)

[563] Based on data from Bloomberg New Energy Finance and New Zealand Superannuation Fund

ALTERNATIVES

In addition to solar energy and hydrogen-based energy, there are several other categories of renewable energy sources, including wind power, hydropower, geothermal energy, heat pumps, biogas, biofuels, renewable urban waste, solid biomass, and ocean energy.

In 2014, according IRENA, the International Renewable Energy Agency, total renewable energy capacity in Europe amounted to 471,989 MW, an increase of 4.75% since 2013. These figures include capacities for 40 European countries and cover hydro power (large and small plants), heat pump, marine energy, geothermal energy, solar photovoltaic, concentrated solar power, wind power, solid biomass and waste, biogas, and biofuels.

EurOberv'ER also provides capacity data for several renewable energy sources for EU28 Member States (see table below). Bioenergy is omitted as only primary energy production figures are available. Wind power has the largest share in EU28 renewable energy source capacity, followed by photovoltaic power.

Table N: EU28 capacity and cumulative capacity installed in 2012 and 2013 by renewable energy source

Renewable energy source	Capacity installed in 2012	Capacity installed in 2013	Cumulative capacity installed in 2012	Cumulative capacity installed in 2013
Wind power	Not available	Not available	106,552 MW	117,741 MW
Photovoltaic	17,519 MW	10,673 MW	68,956 MW	79,623 MW
Solar thermal	2,440 MW	2,115 MW	29,657 MW	31,389 MW
Small hydro (net capacity)	NA	Not available	13,732 MW	14,050 MW
Geothermal energy (net capacity)	782 MW	795 MW	2,738 MW	2,866 MW
Concentrated solar power plants	Not available	Not available	1,961.2 MW	2,312 MW

Source: EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe

Capacity for and production of renewable energy is increasing, as seen in the figure below. In 2013, gross renewable electricity production[564], totalled 853 TWh, an increase of 11% compared with 2012. While the EU's overall electricity consumption was stable at 3,306 TWh 2013, the share of renewable energy in total electricity consumption rose to 25.8% from 2012 to 2013. Hydraulic power[565] has by far the largest share (43.3%), followed by wind power (27.5%), biomass (18.4%) and solar power (10.0%). Compared with 2012, the share of wind power and solar power increased somewhat, while other sources reduced[566].

Although the share of renewable energy in the total EU electricity production has increased to more than 25%, the renewable energy sector is finding itself in a downward trend. The turnover of the renewable energy sector in EU28 declined from EUR 143,015 in 2012 to EUR 138,215 billion in 2013. It reflects the decreasing overall investment and installation activities, and is also a response to budget cuts and revisions of renewable energy support schemes. In addition, some renewable energy technologies became more efficient with lower average installation prices, e.g. in solar photovoltaics.

[564] Not normalized for hydro and wind power, hence actual generation.
[565] Hydraulic power is power transmitted by the controlled circulation of pressurised fluid, usually a water-soluble oil or water–glycol mixture, to a motor that converts it into a mechanical output capable of doing work on a load (www.britannica.com)
[566] 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe, http://www.eurobserv-er.org/

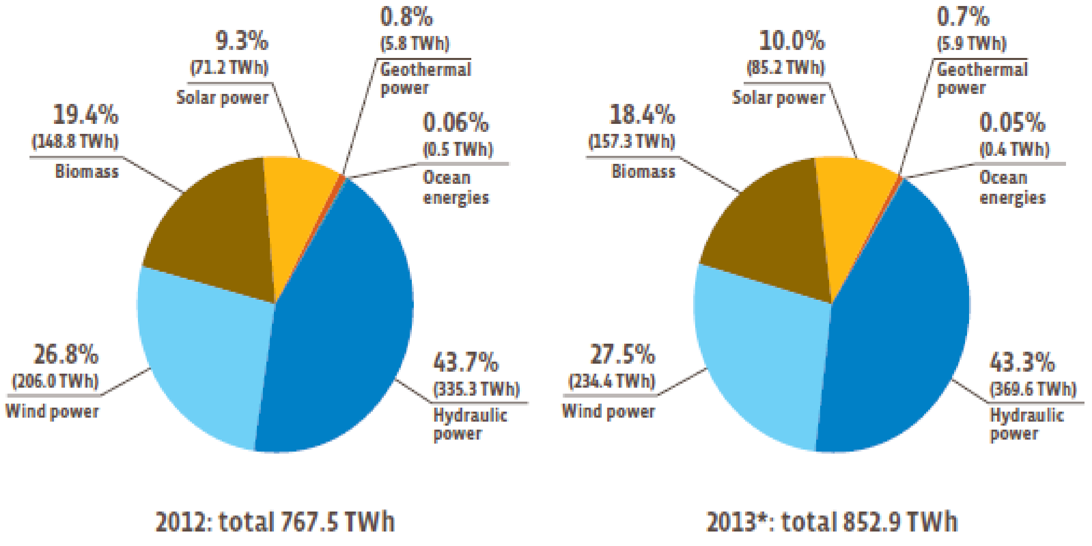


Figure H: Share of renewable electricity generation by energy source in the EU28

Source: EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014: The State of Renewable Energies in Europe

Employment shows a decline as well: between 2012 and 2013, 54,000 jobs were lost. In 2013, 1,148,050 persons were directly or indirectly employed in Europe's renewable energy sector (EU28)[567,568]. The wind power sub-sector has the largest share in the total turnover and the second highest share in employment. Solid biomass follows closely. The solar photovoltaic sector is half the size of the wind power sector in EU28, both in turnover and employment. The figures for turnover and employment in 2013 are presented in the table below.

Table O: Turnover and employment by energy technology sector, 2013

Renewable energy source	Turnover in EUR millions in 2013	Employment in 2013
Wind power	39,750	302,450
Solid bioma2ss	35,950	314,800
Photovoltaic	22,030	158,900
Biofuels	14,340	98,900
Heat pumps	10,390	96,200
Biogas	5,820	65,400
Small hydro[569]	4,985	42,850
Solar thermal	3,680	41,650
Geothermal energy	1,270	11,450
Waste		15,450[570]
Total	138,215	1,148,050

567 Employment data covers both direct and indirect jobs and relates to gross employment, i.e. not taking into account job losses in other industrial sectors or due to expenditure and investment in other sectors. Direct jobs are those directly derived from renewable energy manufacturing, equipment and component supply, or onsite installation and O&M. Indirect jobs are those that result from activity in sectors that supply the materials or components used, but not exclusively so, by the renewables sectors (such as jobs in copper smelting plants part of whose production may be used for manufacturing solar thermal equipment, but may also be destined for appliances in totally unconnected fields).

568 EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe

569 covers plants with capacity up to 10 MW

570 Direct jobs only

Source: EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe

Asset financing for new built capacity in the EU28 declined by 43% from EUR 52 billion in 2012 to under EUR 30 billion in 2013. The solar photovoltaic sector had the largest share (64%) in 2012, but its asset financing fell sharply in 2013, which explains the sharp decline in asset financing for the total renewable energy sector (see table below).

EurObserv'ER used data from Bloomberg New Energy Finance to calculate utility-scale investments in renewable energy, mainly power plants. Asset finance[571] in the table covers all investment in renewable energy projects with a capacity of more than 1 MW or more than one million litres per year. The dates relate to the year of completion of the financing agreement, not the year of installation.

While asset financing relates to the investment in the application of renewable energy technologies (e.g. in power plants), venture capital and private equity relate to the development and production of the technologies themselves (e.g. producing solar modules). Even stronger than for asset financing, the amount of venture capital and private equity in the EU fell drastically by 83% between 2012 and 2013. Despite this dramatic decline in the total sum invested, the drop in the number of deals was less severe by 30%. This implies that the average size of the deal decreased from EUR 37 million in 2012 to EUR 9 million in 2013[572]. If the data for the renewable energy sector are compared with the overall venture capital and private equity investments in the EU in all sectors, it becomes clear that the renewable energy sector is in a more difficult situation compared to all other sectors. Data from the European Private Equity and Venture Capital Association (EVCA) show that overall investment in the EU stabilised between 2012 and 2013[573].

Table P: Asset financing and venture capital / private equity in renewable energy sectors, 2012 and 2013, EU28

	2012		2013	
	Asset finance	Venture capital / private equity MEUR	Asset finance	Venture capital / private equity MEUR
Wind power	14,234	979	13,591	222
Photovoltaic (commercial & residential)	33,484	96	13,024	75
Geothermal	124	0	0	0
Biogas (biogas plants & biomethane)	99	186	52.93	15
Biofuels (biodiesel & bioethanol	938	124	117	51
Renewable urban waste	705	834	1618	16
Solid biomass	1,725		1,355	
Concentrated solar power plants	916	4.4	0	0
Small hydro	na	25.84	na	0.00
Total EU28	**52,225.18**	**2,249**	**29,758.08**	**408.73**

Source: EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014: The State of Renewable Energies in Europe

[571] Asset finance covers balance-sheet finance, non-recourse finance and bonds.
[572] EurObserv'ER (2014) 14th EurObserv'ER Report Edition 2014, The State of Renewable Energies in Europe
[573] http://www.evca.eu/media/385581/2014-european-private-equity-activity-final-v2.pdf

ANNEX 9: HUMAN HEALTH AND SAFETY

INTRODUCTION

Exposure to chemicals in the energy sector may be quite diverse. In this report the safety evaluation will be limited to the engineered nanoparticles intentionally produced.

The products in the solar sub-sector cover applications around photovoltaic cells, testing devices, and nanomaterials for the production of photovoltaic cells and whole systems. By far the most of the nanoproducts are nanocoatings with silicon dioxide used for its photocatalytic and self- cleaning properties. The nanoparticles that are used the energy sector are listed in Table 2. Furthermore, five sub-sectors were identified. Since no information was available on which nanoparticles are produced in which sub-sector, all combinations of nanoparticles and sub-sector will be evaluated.

The basis for the evaluation will be the "Stoffenmanager Nano" application developed by TNO (Van Duuren-Stuurman, et al. 2012). In short, Stoffenmanager Nano is a risk-banding tool developed for employers and employees to prioritise health risks occurring as a result of respiratory exposure to nanoparticles for a broad range of worker scenarios. This tool combines the available hazard information of a substance with a qualitative estimate of potential for inhalation exposure. "Stoffenmanager Nano" does not contemplate the dermal and oral routes of exposure. The respiratory route is the main route of exposure for many occupational scenarios, while the oral route of exposure is considered minor and sufficiently covered, from a safety point of view, by good hygiene practices established in production facilities as prescribed through general welfare provisions in national health and safety legislation in EU countries (ECHA 2012). The dermal route may be the main route of exposure for some substances or exposure situations, and cause local effects on the skin or systemic effects after absorption into the body (ECHA 2012). However, nanoparticles as such are very unlikely to penetrate the skin (Watkinson, et al. 2013), and consequently nanospecific systemic toxicity via the dermal route is improbable. Therefore, when evaluating nanorisks for the respiratory route, the most important aspects of occupational safety are covered.

Currently version 1 of Stoffenmanager Nano is being updated with recent data and insights. The hazard of six metal oxide nanoparticles has been reassessed and their hazard bands have been updated. This revision, which follows the hazard assessment methods established by van Duuren-Stuurman et al. (2012), but makes use of more recent toxicity data, has been published in a TNO-report (Le Feber, et al. 2014). Hazard bands for the nanoparticles, as listed in the table *Hazard bands for selected nanoparticles,* are taken by preference from this report and, if not available in that report, from van Duuren-Stuurman et al. (2012). If a nanoparticle in the list has not been evaluated in either publication, data were collected from public literature to derive its hazard band.

HAZARD ASSESSMENT OF NANOPARTICLES NOT ASSESSED IN STOFFENMANAGER NANO

INTRODUCTION

In "Stoffenmanager Nano" the available hazard information is used to assign specific nanoparticles to one of five hazard bands, labelled A to E (A= low hazard, E= highest hazard). Not for all nanomaterials of importance for the energy sector which are listed in the table, hazard banding has been performed within the context of Stoffenmanager Nano. For those nanoparticles toxicity data have been collected and hazard bands are derived according to the methodology described for "Stoffenmanager Nano" in van Duuren-Stuurman et al. (2012). In essence, it applies the toxicity classification rules of EU Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures. The method is summarised in the figure.

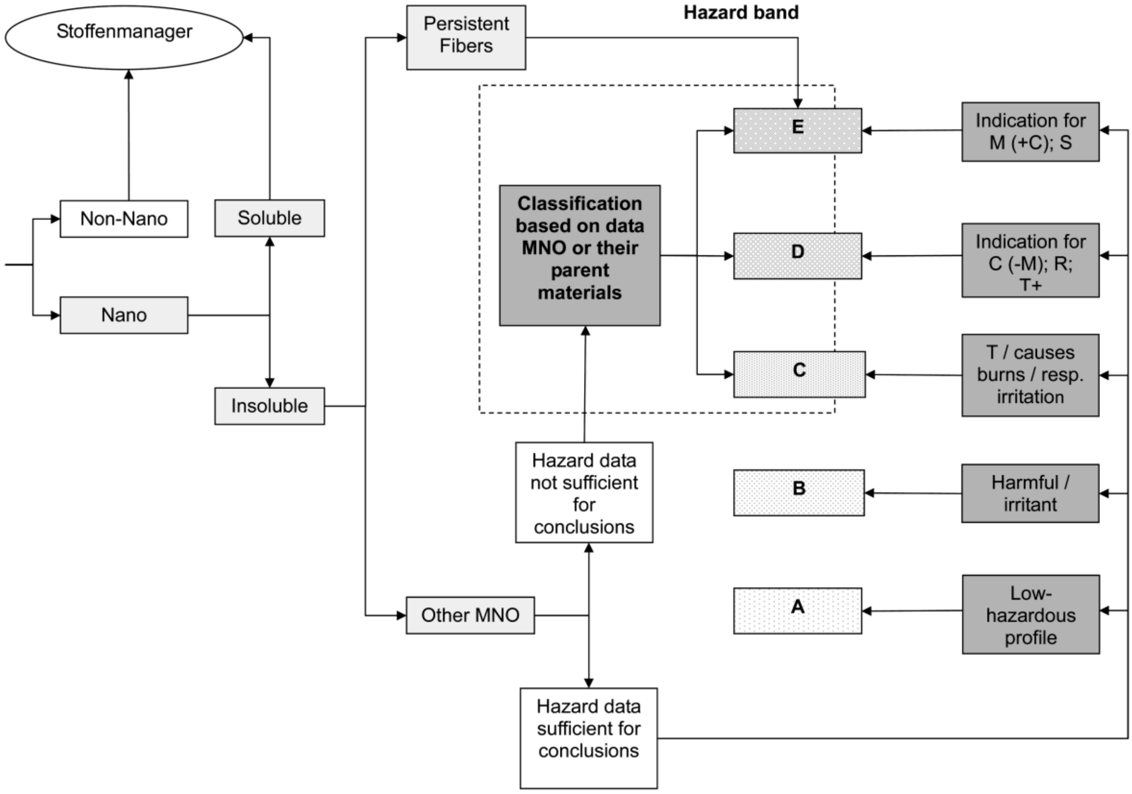


Figure 1: The stepwise approach of hazard banding of Stoffenmanager Nano (Van Duuren-Stuurman, et al. 2012)

C = carcinogenic, +C = and carcinogenic, M = mutagenic, -M = and not mutagenic, MNO = manufactured nanoparticle, R = reprotoxic, resp. = respiratory, T = toxic, T+ = very toxic Stoffenmanager refers to the non-nano version of Stoffenmanager as described by Marquart et al. (2008).

Copper oxide

CuO nanoparticles are positive in an in vitro Comet assay with human skin epidermal (HaCaT) cells, causing a dose dependent increase of tail DNA (Alarifi, et al. 2013). In vivo they induce micronucleated reticulocyte formation in mouse peripheral blood after an i.p. injection of nanoparticles (0, 1 and 3 mg/mouse) (Song, et al. 2012). Soluble copper salts have comparable effects, e.g. copper sulphate induces chromosome aberrations in chick (Bhunya and Jena 1996) and mouse (Agarwal, et al. 1990) bone marrow cells and in mouse spermatocytes (Fahmy 2000).

In public literature, there is still a lively discussion on whether the root cause of CuO nanoparticle cytoxicity is the release of cupric ions (Bondarenko, et al. 2013, Horie and Fujita 2011, Piret, et al. 2012, Privalova, et al. 2014) or a direct effect of the particle (Karlsson, et al. 2008, Midander, et al. 2009). However, cytotoxicity is in vitro firmly established. Bondarenko et al. (2013) made, amongst others, an inventory of CuO cytotoxicity to mammalian cells and derived a median EC_{50} of 25 mg Cu eq./L for CuO nanoparticles, based on 21 tests, while the median value of soluble copper salts is 53 mg Cu eq./L, based on 10 tests.

Comparative *in vitro* testing with mammalian cells showed that CuO nanoparticles are a more potent toxicant than many other metal oxides such as Al_2O_3 (Lanone, et al. 2009), CeO_2 (Lanone, et al. 2009, Rotoli, et al. 2012), $CuZnFe_2O_4$ (Karlsson, et al. 2008), Fe_2O_3 (Fahmy and Cormier 2009, Karlsson, et al. 2008, Sun, et al. 2012), Fe_3O_4 (Karlsson, et al. 2008, Sun, et al. 2012), TiO_2 (Karlsson, et al. 2008, Lanone, et al. 2009, Sun, et al. 2012) and ZrO_2 (Lanone, et al. 2009)), than SiO_2 (Fahmy and Cormier 2009, Sun, et al. 2012), than carbon nanoparticles and multiwalled carbon nanotubes (Karlsson, et al. 2008), and than microsized CuO particles (Cohen, et al. 2013).

All these cytotoxicity tests were executed with particles suspended in the test medium. However, Aufderheide et al. (2013) simulated in vivo respiratory exposure with A549 cells using the CULTEX system, in which the cells are exposed to air-borne particles. The authors tested a.o. copper(II) sulphate, copper(II) oxide, and micro- and nanoparticles. All copper compounds induced cytotoxic effects, most pronounced for soluble copper(II) sulphate. Micro- and nanosized copper(II) oxide also showed a dose-dependent decrease in the cell viability, whereby the nanosized particles decreased the metabolic activity of the cells more severely.

Concluding, in vitro CuO nanoparticles are a more potent cytotoxicant than many other metal oxide nanoparticles and than microsized CuO particles.

Only a few in vivo tests with CuO nanoparticles were available from public literature and none with the occupationally most important route: inhalation.

Sandhya Rani et al. (2013) intratracheally instilled the lungs of rats with phosphate-buffered saline (PBS) or CuO nanoparticles (50 nm, SA 29 m^2/g, crystalline shape, diameter and length <50 nm), or quartz silica particles at a dose of 1 and 5 mg kg^{-1} body weight. CuO produced a transient dose dependant increase of ALP, LDH, and total leucocytes count in BAL fluid. A dose dependant decrease in SOD and catalase values in exposed rats was observed compared to control at all post exposure periods. Histopathological examination of the lungs revealed a dose-dependent degeneration, fibrosis and granuloma formation in the nanoparticles exposed rats, 1 day after instillation. The effects had worsened 1 week after instillation. On all investigated parameters, the effect of quartz nanoparticles (no characterisation provided) was less pronounced than that of copper nanoparticles.

Cho et al. (2010) instilled CuO and other nanoparticles (CeO_2, TiO_2, carbon black, SiO_2, NiO, ZnO) into lungs of rats. All exposures were carried out at equal-surface-area doses. Only CeO_2, NiO, ZnO, and CuO were inflammogenic to the lungs of rats at the doses used (50 and 150 cm^2/rat, equivalent, respectively, to 172 and 515 µg for CuO). Both acute and more chronic effects were observed. The chronic inflammatory responses CuO treatment caused after 4 weeks were fibrotic/granulomatous inflammation.

Based on the available evidence, CuO nanoparticles are genotoxic in vivo, potently in vitro cytotoxic in comparison to many other metal oxide nanoparticles and are able to cause chronic inflammatory responses in in vivo instillation tests, a property they share with other metal oxide nanoparticles. The importance and severity of these effects when animals or humans are exposed via relevant routes (e.g. inhalation) cannot be assessed due to lack of data. Since there clear indications of mutagenicity, it is assigned to hazard band E.

GRAPHENE

Graphene is composed of sp^2-hybridised carbon atoms arranged in a two-dimensional structure. The various forms of graphene include few-layer graphene, reduced graphene oxide, graphene nanosheets and graphene oxide (GO) (Seabra, et al. 2014).

The UK government body, the Medicines and Healthcare Products Regulatory Agency (MHRA), and the US Food and Drug Administration (FDA) are now reviewing all forms of graphene and functionalised graphene oxide (GO) because of their poor solubility, high agglomeration, long-term retention, and relatively long circulation time in the blood (Begum et al. 2011 cited in Nezakati, et al. 2014).

Currently, limited information about the in vitro and in vivo toxicity of graphene is available (Seabra, et al. 2014). The toxicity profiles of graphene and graphene oxide (GO) nanoparticles remain difficult to separate, since their characterisation, bulk and chemical composition are very similar at the nanometre length scale (Nezakati, et al. 2014).

In vitro graphene has been demonstrated to be cytotoxic, be it overall to a lesser degree than carbon nanotubes (Seabra, et al. 2014). However, the reliability of this conclusion can be doubted since Seabra et al. stated that graphene showed an inverse dose-relationship, being more cytotoxic than carbon nanotubes at low concentrations. The only elaborate comparative study reported by Seabra et al., refers to genotoxicity towards human fibroblast cells. GO proved to be the most potent genotoxic agent compared to iron oxide (Fe_30_4), titanium dioxide ($Ti0_2$), silicon dioxide ($Si0_2$), zinc oxide (ZnO), indium (In), tin (Sn), core—shell zinc sulphate-coated cadmium selenide (CdSe (3) ZnS), and carbon nanotubes.

Intratracheal instillation of 50 µg GO in mice caused severe pulmonary distress after inhalation causing excessive inflammation, while the amount of non-functionalised graphene instilled did not

(Duch et al. 2011). Single intravenous (i.v.) injection of graphene oxide into mice at a dose of 10 mg/kg bw accumulated in the lung resulting in pulmonary oedema and granuloma formation, with NOAEL of 1 mg/kg bw (Zhang, et al. 2011). Furthermore, surface functionalised graphene (PEGylated) appears to be far less toxic: no toxic effects after single i.v. injection of 20 mg/kg bw (Yang, et al. 2011). In mice, PEGylated GO materials showed no uptake via oral administration, indicating limited intestinal absorption of the material, with almost complete excretion. In contrast, upon i.p. injection in mice, PEGylated GO was found to accumulate in the liver and spleen (Yang, et al. 2013 (cited in Seabra, et al. 2014)).

The toxicity of graphene is dependent on the graphene surface (the chemical structure or the nature of the functionalised coatings), size, number of layers, cell type, administration route (for in vivo experiments), dose, time of exposure, and synthesis methods (Seabra, et al. 2014). Generalisations are therefore hard to make, but graphene nanostructures are not fibre-shaped and theoretically may be assumed to be safer than carbon nanotubes (Seabra, et al. 2014).

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

MULTI-WALLED CARBON NANOTUBES (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 (El-Ansary, et al. 2013).

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 MWCNTs in rodents, no tumours were reported. Cellular responses and gene expressions in these studies showed significant effects associated with lung cancer (Zhao and Castranova 2011).

Several studies have shown the potential for MWCNTs to act like the persistent fibres of asbestos, causing thoracic inflammation and fibrosis (NIOSH 2013, USEPA 2013). Additionally, MWCNT have been shown to penetrate into the alveolar region of the lung and to cause inflammation due to accumulation of alveolar macrophages. These biological events have been shown to lead to mesothelioma, although MWCNT have not been demonstrated to *de facto* cause mesotheliomas. Still the weight-of-evidence for certain types of MWCNT (e.g., those with high aspect ratios) is increasing: mice injected with long (> 15 μm) MWCNT or asbestos showed significantly increased granulocytes in the pleural lavage, compared with the vehicle control at 24 hours post exposure. Long MWCNT caused rapid inflammation and persistent inflammation, fibrotic lesions, and mesothelial cell proliferation at the parietal pleural surface at 24 weeks post exposure. Chronic *in vitro* exposure (4 months) of human mesothelial cells to MWCNT induced proliferation, migration and invasion of the cells similar to those observed with crocidolite asbestos as well as a similar up-regulation of a key gene involved in the process of cell invasion (matrix metalloproteinase-2) (Lohcharoenkal, et al. 2013). As a matter of fact, at the same mass exposure (0.02 μg/cm^2) MWCNT caused a higher fold increase in cell migration and invasion than crocidolite asbestos (c. 3- and 2-fold, respectively). Also asbestos and rigid, high-aspect-ratio CNT activated the NLRP3 inflammasome to the same extent (Palomäki, et al. 2011). The NLRP3 believed to play a central role in inflammatory diseases (Abderrazak, et al. 2015). Frustrated phagocytosis is believed to be the trigger for the chain of events leading to mesotheliomas; in order to be able to cause this phenomenon fibres need to be biopersistent and longer than 5 μm (Donaldson, et al. 2013). Concluding, flexible, rigid, high-aspect-ratio MWCNT may cause cancer in a similar fashion as asbestos and may be as potent in this respect.

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

NICKEL OXIDE

Horie et al. (2009) investigated the influences of ultrafine NiO particles on cell viability. Ultrafine NiO particles showed higher cytotoxicities toward human keratinocyte HaCaT cells and human lung carcinoma A549 cells than fine NiO particles and also showed higher solubilities in culture medium.

Cellular responses induced by black NiO nanoparticles with a primary particle size of 20 nm, were examined in human lung carcinoma A549 cells. In vivo responses were examined by instillation of

NiO nanoparticles into rat trachea. In vivo and in vitro oxidative stress was induced resulting in activation of antioxidant systems (Horie, et al. 2011).

No clear data on genotoxicity of nanoNiO was encountered in public literature, but the on-line REACH dossier on NiO[574] (presumably non-nano) contains quite a number of positive *in vitro* tests on cell transformation, mammalian cell gene mutation and DNA damage.

Cho et al. (2010) instilled NiO and other nanoparticles (CeO_2, TiO_2, carbon black, SiO_2, CuO, ZnO) into lungs of rats. All exposures were carried out at equal-surface-area doses. Only CeO_2, NiO, ZnO, and CuO were inflammogenic to the lungs of rats at the doses used (50 and 150 cm^2/rat, equivalent, respectively, to 55 and 164 µg for NiO). Both acute and more chronic effects were observed. The chronic inflammatory responses NiO treatment caused after 4 weeks were neutrophilic/lymphocytic inflammation.

Fujita et al. (2009) investigated the pulmonary effects of the inhalation of fullerenes compared with ultrafine nickel oxide particles. Rats were exposed whole-body to ultrafine nickel oxide (Uf-NiO) particles (0.2 mg/m^3; 9.2×10^4 particles/cm^3, 59 nm diameter) during 6 h a day for 4 weeks (5 days a week). Pulmonary response in rats at 3 days, 1 month, and 3 months post-exposure was examined. Ultrafine nickel oxide particles induced high expression of genes associated with chemokines, oxidative stress, and matrix metalloproteinase 12, as well as mild infiltration of inflammatory cells, mainly neutrophils and alveolar macrophages, in alveoli and interstitial tissue at 3 days and 1 month after exposure. No granuloma, emphysematous change, or fibrosis was observed during the observation period. There were no significant differences in body, lung, liver, or brain weight Nodule-like lesions were observed in animals that were exposed to Uf-NiO particles at both 3 days (n = 2/5) and 1month (n = 1/5) post-exposure, but not in the fullerene exposed group. No histopathological abnormalities were observed in the liver, kidney, spleen, cerebrum, cerebellum, testis, or nasal cavity tissues in the exposed or control groups.

Morimoto et al. (2010) conducted a similar experiment on NiO and fullerene nanoparticles in which rats were exposed via installation and compared them to the inhalation study reported by Fujita et al. (2009). The effects observed in both study types were similar to each other. These data from the intratracheal instillation and inhalation studies also suggested that well-dispersed fullerenes do not have a strong potential for neutrophil inflammation (Morimoto, et al. 2010). Micron-sized nickel oxide nanoparticle agglomerates also induced a persistent inflammatory response in an instillation study with rats (Morimoto, et al. 2011).

Carcinogenicity studies reported for conventional NiO in the REACH dossier[574] were clearly positive when administered i.p. or i.m. to mice and rats, while whole body inhalation carcinogenicity studies were equivocal in their results (mice) or slightly positive (rats)

Based on the available evidence NiO nanoparticles may be both mutagenic as well as carcinogenic. Therefore, this metal oxide nanoparticle is assigned to hazard band E.

NANOSTRONTIUM TITANATE

No toxicity studies on nanostrontium titanate were encountered in public literature nor on its bulk parent compound. Therefore, no hazard banding can be derived.

The table below presents an overview of selected nanoparticles of the energy sector and their hazard bands, either taken from le Feber et al. (2014) or van Duuren et al. (2012), or derived in this report (see above).

[574] http://apps.echa.europa.eu/registered/data/dossiers/DISS-a21aae14-ff8a-0613-e044-00144f67d031/AGGR-680c9c02-81e3-4b19-bda5-a664834dee8b_DISS-a21aae14-ff8a-0613-e044-00144f67d031.html#GEN_MAT_ME_HD

Table 1: Hazard bands for selected nanoparticles

Nanoparticles	Hazard Band	Hazard Band Source
Carbon	Needs specification, may be carbon black, carbon nanotubes, fullerenes or graphene	
Copper oxide	E	This report
Gold	D	van Duuren et al. (2012)
Graphene	E	This report
Multi-walled carbon nanotube (MWCNT)	E	This report
Nickel monoxide (nickel oxide)	E	This report
Strontium titanate (strontium titanium trioxide)	n/a	This report, no data
Titanium dioxide (titania, rutile, anatase)	B	le Feber et al. (2014)

EXPOSURE ASSESSMENT

Solar

Based on the provided overview of commercially available products, engineered nanomaterials are present in the products as part of a matrix (e.g. coating). No free solids or liquids containing engineered nanomaterials were listed, which can become airborne during the use-phase, were encountered. During the production of these solar products, employees can be exposed to free engineered nanomaterials.

In conclusion, the use of solar products results in an exposure band 1 with respect to nanomaterials (workers and consumers), whereas during the production of solar products an exposure band 4 (workers) is believed to be realistic as spraying of a nanocoating results in the highest relative exposure.

Alternatives

Alternative products are for a large part carbon-based nanomaterials that go into final products for the energy market. These nanomaterials include surface coatings and raw materials including graphene and carbon nanotubes.

Based on the provided overview of commercially available products, engineered nanomaterials present in the products may be part of a matrix or be free solids or liquids, containing engineered nanomaterials which subsequently can become airborne during the use-phase.

In conclusion, the use of Alternatives products results in an exposure band 1 (workers and consumers) if nanomaterials are in a matrix, whereas the use of solids or liquids results in an exposure band 2 (workers) due to the relatively low concentrations of engineered nanomaterials as the majority of these products are produced by SMEs.

Hydrogen

In the Hydrogen sector, only two products with nanomaterials were identified; a final product (nanomaterial unknown) and a nanomaterial (copper nanowires) that goes into a final product.

Based on the provided overview of commercially available products and the limited number of products, we are not able to draw conclusions regarding the exposure assessment for the sub-sector Hydrogen.

Storage

The identified products in the sub-sector storage are diverse, ranging from nanomaterials that go into final products (e.g. (parts of) batteries). SMEs account for the lion’s share of producers while large private companies (PCO) only play a minor role.

Based on the provided overview of commercially available products, engineered nanomaterials present in the products may be part of a matrix or be part of free solids or liquids, which subsequently may become airborne during the use-phase.

In conclusion, the use of storage products results in an exposure band 1 (workers and consumers) if nanomaterials are in a matrix, whereas the use of solids or liquids results in an exposure band 2 (workers) due to the relatively low concentrations of engineered nanomaterials as the majority of these products are produced by SMEs.

OTHER

The items which were not assigned to a sub-sector include only three commercially available products with a large range of variability, from graphene based materials to thin film coatings for windows.

Based on the provided overview of commercially available products and the limited number of products, we are not able to draw conclusions regarding the exposure assessment for the sub-sector other.

RISK ASSESSMENT

The hazard and exposure bands are combined to yield so called priority bands, according to the scheme depicted in the table *Priority bands in the Stoffenmanager*. A high priority implies that it is urgent to apply exposure control measures or to assess the risks more precisely, and a low priority implies that it is not very urgent to apply exposure control measures or to establish the risk involved with more precision. It should be emphasised that because of the scarcity of available information, the scheme is set in a conservative way (according to the precautionary principle).

Table 2: Priority bands in the Stoffenmanager

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Key:
Hazard: A = lowest hazard and E = highest hazard;
Exposure: 1 = lowest exposure and 4 = highest exposure;
Overall result: 1 = highest priority and 3 = lowest priority (Van Duuren-Stuurman, et al. 2012)

Risks based on the hazard and exposure banding applied to the energy sector are listed in the table. Due to lack of data on production and use, no risk estimates can be presented for the sub-sectors “Hydrogen” and “Others”.

Table: Priority bands nanotechnology energy sector

		Exposure band					
		Solar - produc-tion	**Solar - use**	**Alterna tives – produc-tion**	**Alterna tives - use**	**Storage – produc-tion**	**Storage - use**
Nanoparticle	**Hazard band**						
Carbon	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Copper oxide	E	1	1	1	1	1	1
Gold	D	1	2	2	2	2	2
Graphene	E	1	1	1	1	1	1
Multi-walled carbon nanotube (MWCNT)	E	1	1	1	1	1	1
Nickel monoxide	E	1	1	1	1	1	1
Strontium titanate	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Titanium dioxide (titania, rutile, anatase)	B	1	3	3	3	3	3
Zirconium dioxide	A	2	3	3	3	3	3

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