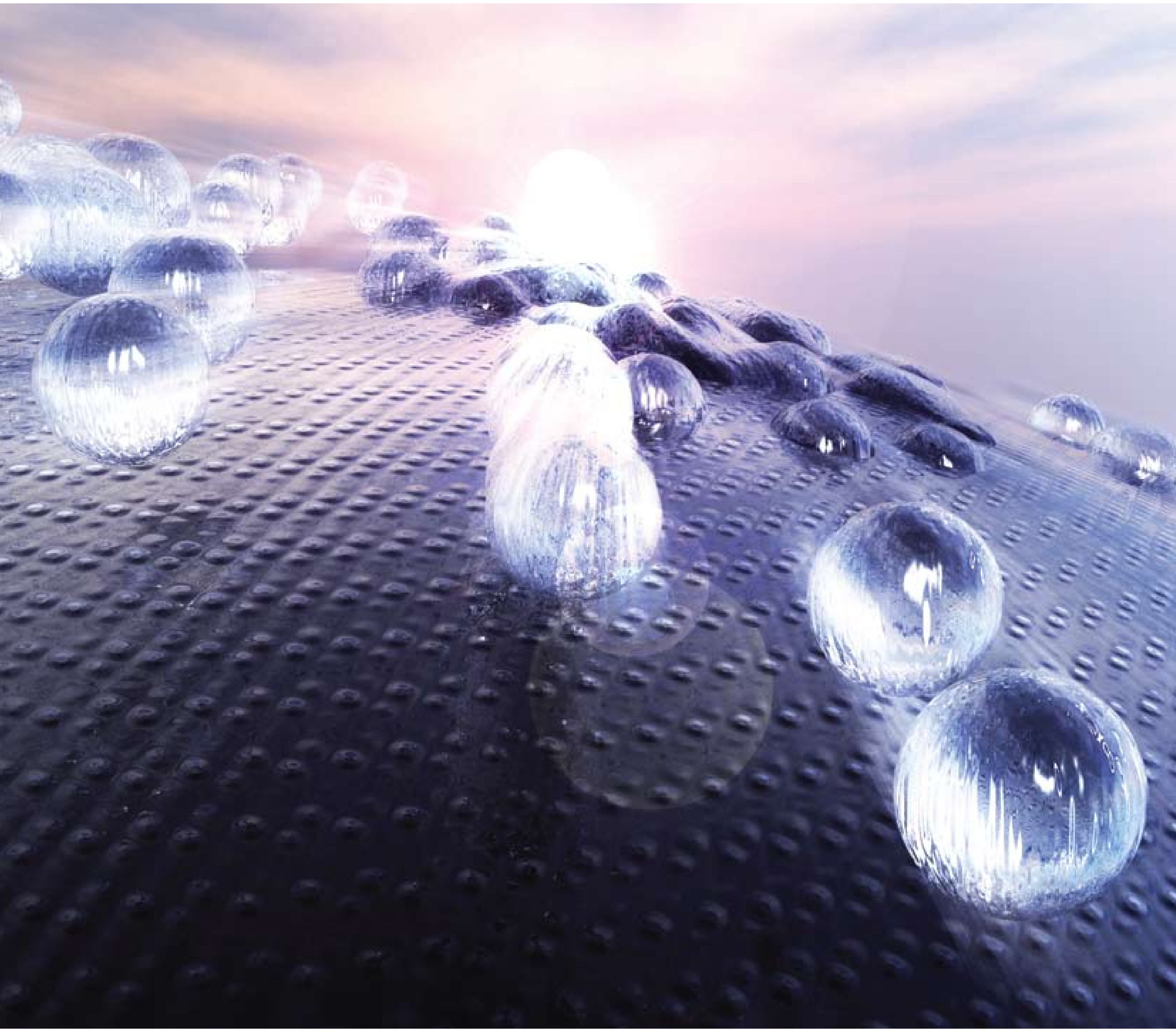
Nanotechnology: a UK Industry View



Knowledge Transfer Networks

Materials UK
Owned by the materials community

Mini Innovation & Growth Team
Nanotechnology

MINI INNOVATION AND GROWTH TEAM

SECRETARIAT

Dr Matthew Thornton	Materials KTN / Materials UK
Dr Robin Young	Materials KTN
Dr Barry Park	Nanotechnology KTN

WITH SUPPORT FROM:

Dr Steve Fletcher	Chemistry Innovation KTN
Darren Ragheb	Chemistry Innovation KTN
Dr Colin Johnson	Materials KTN
Stuart MacLachlan	Materials KTN
Dr Robert Quarshie	Materials KTN / Materials UK
Dr Alec Reader	Nanotechnology KTN
Tiju Joseph	Sensors and Instrumentation KTN

ENDORSEES

Prior to publication of the report, the following people have contacted the secretariat to endorse the report and its recommendations.

Dr Andrew Burgess	AkzoNobel
Dr John Saffell	Alphasense Ltd & Chairman of CoGDEM
Dr Victor Higgs	Applied Nanodetectors Ltd
Dr Alan Smith	AZ-TECH
Dr Matthew O'Donnell	BioCeramic Therapeutics Ltd
Dr Ian Pallett	British Water
Prof Kai Cheng	Brunel University
Dr Bojan Boskovic	Cambridge Nanomaterials Technology Ltd
Dr Roger Pullin	Chemical Industries Association
Dr Didier Farrugia	Corus
Prof Derek Sheldon	Derek Sheldon Consultants Ltd
Dr Brian More	Exilica Ltd
Prof Julian Jones	Heriot-Watt University
David Kent	The Institute of Measurement and Control
Dr Mark Morrison	Institute of Nanotechnology
Del Stark	Institute of Nanotechnology
Dr Paul Reip	Intrinsiq Materials Ltd
Dr Peter Hatto	IonBond Ltd
Andrew Elphick	Iota NanoSolutions Limited
Dr Kevin Matthews	Isogenica Ltd
Dr Sam French	Johnson Matthey
Dr Brendan Casey	Kelvin Nanotechnology Ltd
Simon Allison	Marks & Spencer Plc
Dr Neil Ebenezer	Medicines & Healthcare Products Regulatory Agency
Prof Ben Beake	Micro Materials Ltd
Tom Warwick	NanoInk Inc.
Prof Terence A Wilkins	Nanomanufacturing Institute, University of Leeds
Dr Mike Fisher	Nanotechnology KTN
Dr Neil Harrison	National Physical Laboratory
Dr Piers Andrew	Nokia Research Centre
Dr Gareth Wakefield	Oxford Advanced Surfaces Group plc
Dr Peter Luke	Pfizer
Dr Al Lambourne	Rolls Royce Plc
Neil Gray	Scott Bader Co Ltd
Phil Cooper	Sensors and Instrumentation KTN
Jonathan Foulkes	Smith & Nephew Extruded Films Ltd
Christian Inglis	Technology Strategy Board
Dr Kevin Cooke	Teer Coatings Ltd
Dr Michael Butler	Unilever Research Colworth
Prof Sergey Mikhalovsky	University of Brighton
Dr Neil Bowering	University of Glasgow
Prof David Cumming	University of Glasgow
Prof Ping Xiao	University of Manchester
Prof John Gray	University of Manchester
Prof Peter Dobson	University of Oxford
Prof Julian Gardner	University of Warwick

A full list of the steering and review group is provided in the appendices.

Contents

Executive Summary 2

1. Introduction 5

2. Industry Response to Questionnaire 6

3. Recommendations to Government 8
   - 3.1. Policy and Regulation 8
   - 3.2. Funding 9
   - 3.3. Skills 10
   - 3.4. Engagement 10

4. UK in 10 Years 11

5. International Approaches to Nanotechnology Strategy 12

6. Size of UK Industry 13
   - 6.1. Nanotechnology Support Infrastructure 13
   - 6.2. Nanotechnology Applications 13

7. Diversity of Business 16

8. Investment to Date 17
   - 8.1. International Context 17
     - 8.1.1. Public Funding Ratios for Nanotechnology R&D 17
     - 8.1.2. Corporate Funding for Nanotechnology R&D 18
   - 8.2. UK Government Spend on Nanotechnology over the last 12 years 18
   - 8.3. UK Government Spend on MNT Facilities 19
   - 8.4. FP7 Funding 19
   - 8.5. Research Council Funding 19
   - 8.6. Private Funding Ratios for Exploitation of Nanotechnology 20

9. Opportunities 21

10. UK Capability and Capacity to Exploit 24

11. Barriers to Exploitation 27

12. Funding 29

13. Issues 31
   - 13.1. International Regulation 31
   - 13.2. Codes of Conduct for Responsible Research and Commercialisation 32
   - 13.3. Public Perception 32
   - 13.4. Measurements and Standards 34
   - 13.5. Health and Safety 35
     - 13.5.1. Overview 35
     - 13.5.2 Funding for safe implementation 36
     - 13.5.3 International Efforts 36
     - 13.5.4 Government Position 37
     - 13.5.5 Implications for Insurance 37

Acknowledgements 38

List of Tables and Figures 38

Glossary 39

Appendices 40

References 51

Executive Summary

Nanotechnology is the basis for many products that are in common use and is providing the capability to produce a very wide range of new products that will become commonplace in the near future. The UK, like many other countries, has invested heavily in nanotechnology and has considered, through a series of reports and Government responses, how to manage and fund nanotechnology developments. At the third meeting of the Ministerial Group on Nanotechnology it was agreed that a nanotechnology strategy should be developed for the UK.

As part of the strategy development process, Lord Drayson launched an evidence gathering website on 7th July 2009. Alongside this, four Knowledge Transfer Networks (Nanotechnology, Materials, Chemistry Innovation and Sensors and Instrumentation) with significant industrial interest in nanotechnology agreed that it was necessary for industry to contribute to policy development using the bottom up approach. It is intended that this report with its unique industry led views on nanotechnology will provide a significant contribution to a future overarching UK Government Strategy on Nanotechnology, alongside other input from inter alia the Technology Strategy Board and the Research Councils.

Feedback was sought from industry using a questionnaire and workshop discussions with invited industry leaders and others in the field of nanotechnology to gather information on what they are currently doing and what their future needs are to create enhanced value from nanotechnology. A full review of UK and international strategic approaches was also undertaken. This report considers where the UK currently sits in terms of investment in comparison with its major industrial competitors and reviews the UK's capability to exploit nanotechnology given the organisations and funding bodies currently in place. Future opportunities are also reviewed alongside issues that must be addressed to ensure responsible development of nanotechnology based products.

The following recommendations on Policy and Regulation, Funding, Skills and Engagement have been developed to provide a basis for implementation of the Government Strategy based on this feedback and are listed below. A view is also given of what the UK status on nanotechnology would be in 2020 assuming that the recommendations are followed in the intervening years. These recommendations are in line with the UK Government's strategy for New Industry, New Jobs which is part of Building Britain's Future.

POLICY AND REGULATION

1. Nanotechnology innovation and exploitation is business driven. The department responsible for leading and coordinating nanotechnology activities across Government should be the Department for Business, Innovation and Skills (BIS) to ensure investment provides added value for the UK.
2. The Technology Strategy Board must implement its Nanoscale Technologies Strategy with specific funded calls to deliver commercialisation of value adding nanotechnology based products.
3. Government should address the need for responsible development of all emerging technologies, including nanotechnologies, by putting in place a framework through which product risk assessments can be carried out alongside industry's need to focus on innovation.
4. Defra, other Government Departments, relevant KTNs and trade associations should engage with industry to ensure the effective operation of a simplified Voluntary Reporting Scheme in the UK for nanomaterials and to work with EU regulators to ensure ongoing REACH regulations take account of nanotechnology fully and effectively.

SKILLS

1. Develop world class professional education programmes at all levels covering all aspects of nanotechnology.
2. Improve and promote vocational training in nanotechnology from technician level to develop individuals with the skills and expertise to support commercialisation of nanotechnology in the UK.

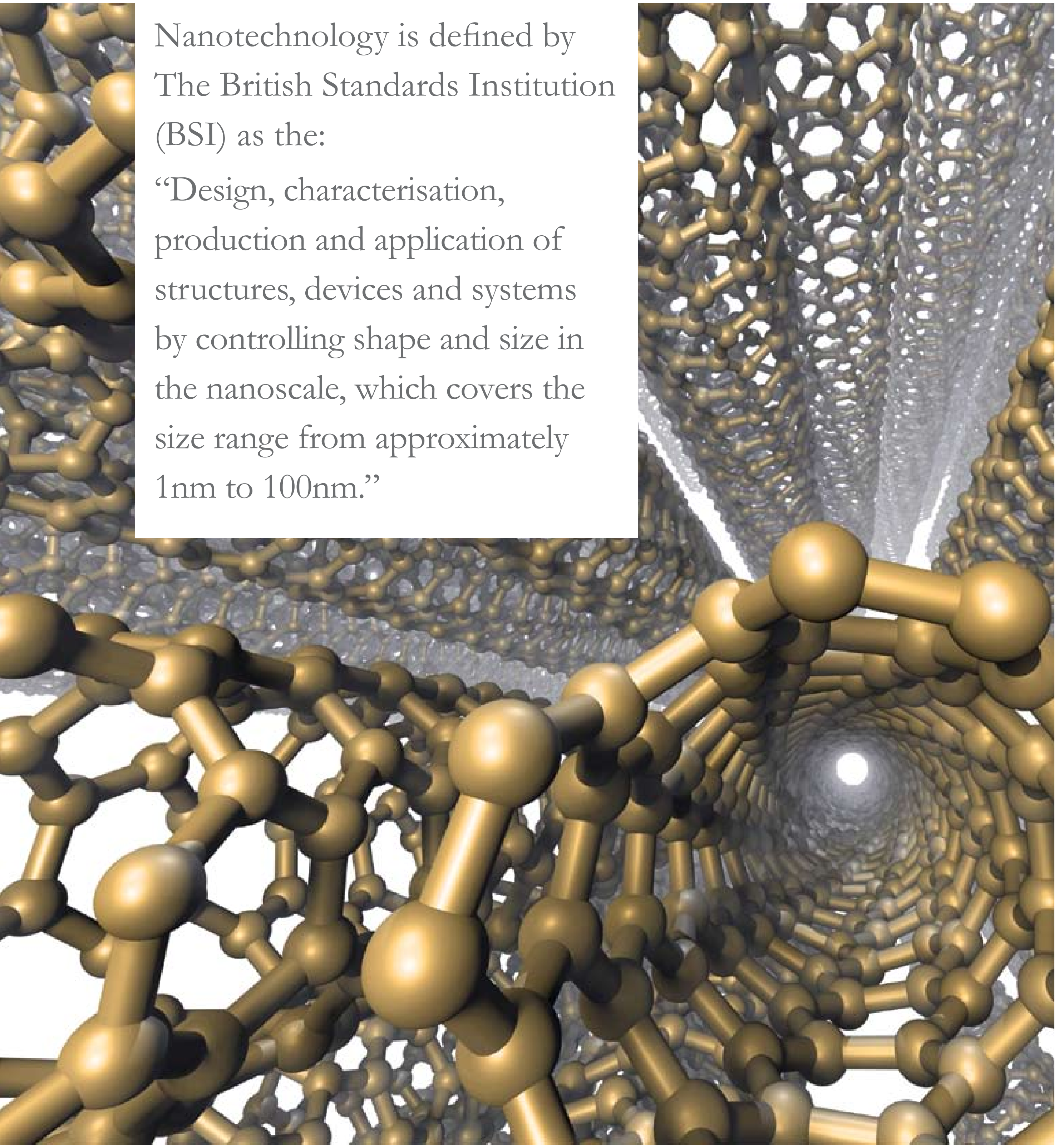
FUNDING

1. Provide more accessible and commercially focussed funding for SMEs as well as larger companies engaged in the development of nanotechnology based products to support innovation in the UK.
2. Invest in key establishments and organisations to build world class capability in nanotechnology product development.
3. Provide funding for cross-sectoral initiatives to apply developments achieved in one sector to other sectors and applications.
4. Continue to invest in standardisation activities to maintain UK leadership in creating international standards for nanotechnology and National Measurement System facilities.
5. Continue to support knowledge transfer activities to deliver innovation in nanotechnology and pull through academic research into commercial applications.

ENGAGEMENT

1. Ensure that the general public is informed of product developments based on nanotechnology.
2. Industry and Government should engage in an evidence based dialogue with the Unions and Non-Governmental Organisations (NGOs).
3. Provide support for two-way international collaboration to gather and share information on nanotechnology.
4. Government and industry should assist banking and insurance companies in understanding nanotechnology to enable sound investments to be made.

These recommendations are discussed in greater detail in this report.



Nanotechnology is defined by The British Standards Institution (BSI) as the:

"Design, characterisation, production and application of structures, devices and systems by controlling shape and size in the nanoscale, which covers the size range from approximately 1nm to 100nm."

1 Introduction

Nanotechnology provides a significant opportunity to address global challenges. This is leading to intense global competition to commercialise different products enabled by nanotechnology. However, UK industry is well placed to capitalise on this opportunity and participate in the development of many new products and services by operating alone or in collaboration with international partners. Success in this area will lead to growth in employment and wealth creation.

Today, nanotechnology is evolving with some mature products and many in the growth and developmental stage. This is not unlike the condition of computer science in the 1960s or biotechnology in the 1980s. Nanotechnology has been applied to the development of products and processes across many industries particularly over the past ten years. Products are now available in markets ranging from consumer products through medical products to plastics and coatings and electronics products.

There have been various market reports estimating the scale of potential future value for products that are "nanotechnology enabled". Details of a number of these are reported in section 8. A report from Lux Research published in 2006 entitled The Nanotech Report 4th Edition[1], notes that nanotechnology was incorporated into more than $30 billion in manufactured goods in 2005. The projection is that in 2014, $2.6 trillion in manufactured goods will incorporate nanotechnology. Even if this is an over-estimate, it is clear that there is a vast market available for nanotechnology based products. It is extremely important to the UK economy that UK companies engaged in nanotechnology participate at each stage of the supply chain.

While companies are moving speedily to develop further and more advanced products based on nanotechnology, they are becoming increasingly aware that there are many challenges to address. It was with this background that a Mini Innovation and Growth Team (Mini-IGT) was formed comprising members of the Nanotechnology KTN and the Materials KTN as the secretariat together with members of the Chemistry Innovation KTN and the Sensors and Instrumentation KTN to prepare a report on nanotechnology on behalf of UK industry. A questionnaire (see Section 2) was sent to the members of the various KTNs to solicit feedback on their views on nanotechnology focussing on their commercial position and also their concerns and issues. This report considers the status of nanotechnology in the UK today and provides recommendations in response to the concerns and issues raised.

While the UK Government has commissioned reports and provided responses over the past decade, in the field of nanotechnology (see Appendices), the UK has not articulated an overarching national strategy on nanotechnology that can rank alongside those from the likes of the US and Germany. It is intended that this report, with its unique industry led views on nanotechnology, together with other strategic documents, including the Nanoscale Technologies Strategy 2009-2012 produced by the Technology Strategy Board, will provide a significant contribution to a future UK Government Strategy on Nanotechnology.

2 Industry Response to Questionnaire

A web based survey was undertaken where answers to eight key questions were solicited to ascertain how important nanotechnology was to UK industry and determine how UK Government can assist in further developing the commercial landscape. The specific questions were:

1. Where does your company fit in the supply chain regarding nanotechnology?
2. What commercial / development products based on nanotechnology do you have?
3. What resources are focussed on nanotechnology based products?
4. What alliances / partnerships do you have to exploit nanotechnology?
5. What percentage of your sales is based on nanotechnology based products?
6. How long has your company been involved in developing and/ or selling products based on nanotechnology?
7. What Governmental funding have you received to support your nanotechnology business?
8. Where should company and Government funding on nanotechnology be focussed for the next ten years?

The questionnaire, together with the outputs from two workshops, has been used to generate the recommendations listed in the following section. This section presents the outputs from the questionnaire. The respondents to the questionnaire covered the entire supply chain, from fundamental research through nanomaterial producers, equipment suppliers, system integrators and end users. They represented the major market sectors important to the UK economy including medical/ pharmaceutical, aerospace and defence, chemical, food and automotive.

The respondents were classified as large, medium or small to medium enterprises, universities or others such as trade associations etc. (see Figure 1). As might be expected the largest segment of responses was from SMEs. However, 20% of the respondents were from large companies representing some of the UK's leading blue chips.

The SMEs generally devoted the majority of their resource to nanotechnology with many calling themselves "a nanotechnology company". With larger companies the emphasis was more on their products or sectors viewing nanotechnology as an enabler to a commercial product serving an established sector with multidisciplinary teams assembled as and when required. Nearly all those who responded either had established relationships or were actively developing networks of partners and alliances; these were most commonly with universities to help develop the fundamental understanding of the products or with the supply chain to help delivery of commercial products.

Most of the respondents had zero or low (less than 25%) sales in nanotechnology related products (see Figure 2). This might be expected from the large number of SMEs who responded, many of which are less than 5 years old and are still in product/ process development and have yet to bring any commercial products to market. However, some 26% of the respondents were significantly or entirely (i.e. 100% of sales) nanotechnology enabled companies. Several of the larger well established companies answering our questionnaire had a significant proportion of their business in nanoenabled products. The maturity of the commercial sales on the whole reflected the time that most companies had been trading in nanotechnology enabled products. Some 34% of all respondents have been involved in nanotechnology for more than 10 years (see Figure 3).

Perhaps of most interest were the responses to question 8: Where should company and Government funding on nanotechnology be focussed for the next ten years? As might be expected there was a wide range of answers. However, several common themes emerged:

1. The UK should continue to support the UK's leading position in driving global standards for nanotechnology.
2. Strategic longer term research programmes focused on employing nanotechnology solutions for larger challenge led societal problems such as ageing population and healthcare, low carbon economy, safety and security, with less emphasis on new nanoparticles or materials.
3. "Joined up" thinking on EHS concerns with managed programmes across the supply chain from university research to actual practice in industry and end of life. An essential component is also providing the public with a balanced picture of the true risks and advantages of nanotechnology.
4. Support for product development, including translational development and knowledge management especially for SMEs.

Some of the comments that were received included:

"E.ON believes that there are great opportunities for the development of nanotechnology-based products particularly in renewable energy systems which will help to create a low-carbon future"

"Addressing market needs through collaborative development and knowledge exchange where companies can work together and/or access the strong UK academic base for new products and processes and where universities can strategically develop research streams based on the commercial needs of industry" Kelvin Nanotechnology

"Investment in product focussed enabling technologies and step change technologies that benefit UK plc and establish the UK as a skills centre for novel, emerging technologies." Rolls-Royce

Figure 1
Classification of respondents to questionnaire

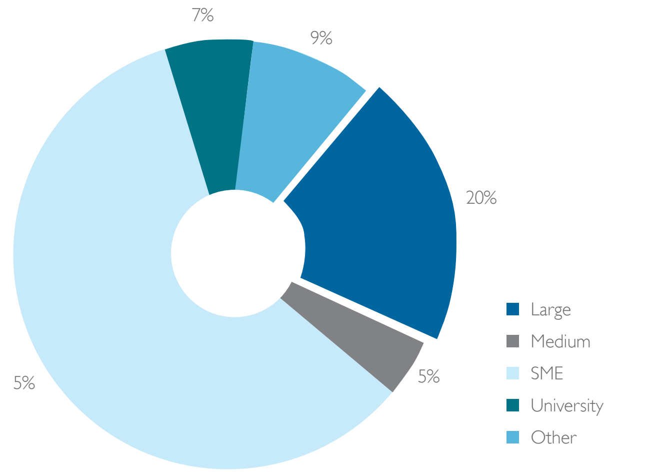


Figure 2
Breakdown of the sales based on nanotechnology enabled products

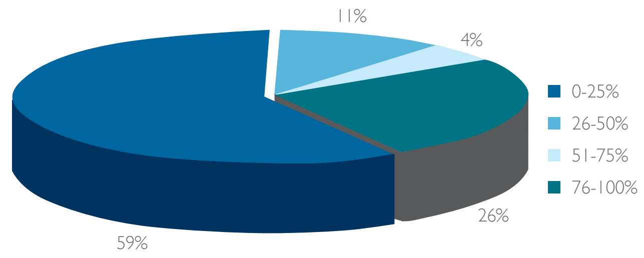
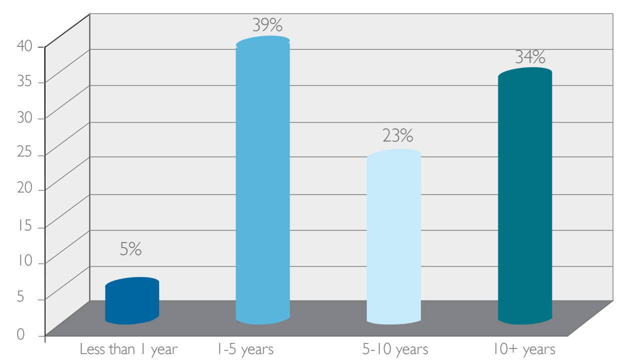


Figure 3
Breakdown of the time companies had been involved with nanotechnology



3 Recommendations to Government

This report, informed and led by the UK's nanotechnology industry, recommends that the following are paramount to the successful exploitation of nanotechnology in the UK. These are listed under four headings and under each heading the recommendations are ranked in order of importance. These recommendations focus on areas where Government can make a significant difference.

3.1 Policy and Regulation

1. Nanotechnology innovation and exploitation is business driven. The department responsible for leading and coordinating nanotechnology activities across Government should be the Department for Business, Innovation and Skills (BIS) to ensure investment provides added value for the UK.

   To ensure commercial success for the UK in nanotechnology, BIS should be the champion for nanotechnology and collaborate with other departments and agencies including Defra, Research Councils, Environment Agency, Health and Safety Executive, Health Protection Agency and Department of Health amongst others.

2. The Technology Strategy Board must implement its Nanoscale Technologies Strategy with specific funded calls to deliver commercialisation of value adding nanotechnology based products.

   Investment in nanotechnology must be industry led and focussed on taking practical, useful and valuable research through to commercialisation i.e. from fundamental research through prototyping and pilot manufacturing to full scale manufacturing. This means that the Technology Strategy Board has to focus on industrial needs, especially those identified within the Grand Challenges, and work alongside other funding bodies including the Research Councils to bring organisations and companies together to exploit novel technologies quickly and effectively.

3. Government should address the need for responsible development of all emerging technologies, including nanotechnologies, by putting in place a framework through which product risk assessments can be carried out alongside industry's need to focus on innovation.

   Concerns about environmental, health and safety issues must be considered as part of the responsible development process. Risk assessment procedures and associated legislation already in use should be used to determine where issues may lie and to define processes and procedures to ensure safe manufacture, use and disposal of nanotechnology based products. SMEs, in particular, may need financial support to conduct risk assessments to comply with product and chemical legislation since these are generally required at a point in the development cycle before revenues have been generated. It should be noted that the chemical legislation REACH (Registration, Evaluation, Authorisation and restriction of Chemicals) has the framework for developing this for nanomaterials during their research and development phase.

   This recommendation is in line with Government's interests in this area as noted in the Statement by the Government about Nanotechnology published in February 2008 where they state its vision for nanotechnologies to be: *"for the UK to derive maximum economic, environmental and societal benefit from the development and commercialisation of nanotechnologies, and to be in the forefront of international activity to ensure there is appropriate control of potential risks to health, safety and the environment".*

4. Defra, other Government Departments, relevant KTNs and trade associations should engage with industry to ensure the effective operation of a simplified Voluntary Reporting Scheme in the UK for nanomaterials and to work with EU regulators to ensure ongoing REACH regulations take account of nanotechnology fully and effectively.

   The Voluntary Reporting Scheme, to monitor and regulate the use of nanotechnology based materials and products, has advantages but needs to be simplified for industry to participate. Imposing a Mandatory Scheme is fraught with difficulties both in terms of definition and in terms of monitoring and policing what has or has not been reported. It will also stifle UK innovation and competitiveness if imports are not required to comply with a UK based mandatory scheme. Sanctions for not reporting would have to be made clear. Further, any scheme has to be EU-wide and subject to EU regulations including REACH.

3.2. Funding

1. Provide more accessible and commercially focussed funding for SMEs as well as larger companies engaged in the development of nanotechnology based products to support innovation in the UK.

   No mechanism exists to ensure continuity of funding developments through to commercialisation. The need for small scale funding is evident from the interest from industry in the recent Technology Strategy Board Beacons call. Larger collaborative R&D funding is not always suitable for pre-product demonstrator or proof of concept to drive research through the Technology Readiness Levels. To complement Technology Strategy Board funding the Research Councils should fund more industrially relevant research in this area. Industry has expressed concern that collaboration with universities leads to very low grant ratios for industry. This is a disincentive for industry and in particular SME/ university collaboration and needs to be addressed as part of the funding processes.

2. Invest in key establishments and organisations to build world class capability in nanotechnology product development.

   Focus on centres capable of delivering world class nanotechnology research and development, risk assessment and characterisation through to manufacturing. Invest in and drive to international success centres that can be (or already are) world class. To do this the UK could learn from the German Fraunhofer model, for example by creating critical mass through consolidation of existing facilities and organisations.

3. Provide funding for cross-sectoral initiatives to apply developments achieved in one sector to other sectors and applications.

   Developments based on nanotechnology in one product area may be transferable to other product areas. Ensuring this happens efficiently can provide significant added value for the UK.

4. Continue to invest in standardisation activities to maintain UK leadership in creating international standards for nanotechnology and National Measurement System facilities.

   This will ensure that the UK maintains its influence in defining standards for "nano" through the work conducted by BSI and in association with CEN, ASTM and ISO. Emphasis should also be on developing and promoting measurement techniques in support of technology requirements for standards. This investment is required in the short to medium term given that there is not a critical mass of nanotechnology based industry to support this activity.

5. Continue to support knowledge transfer activities to deliver innovation in nanotechnology and pull through academic research into commercial applications.

Knowledge Transfer Networks must continue to collaborate with industry to deliver innovation in the cross disciplinary field of nanotechnology.

3.3. Skills

1. Develop world class professional education programmes at all levels covering all aspects of nanotechnology.

Given the multidisciplinary nature of nanotechnology it is appropriate that it is covered within existing science, technology, engineering and mathematics (STEM) courses.

2. Improve and promote vocational training in nanotechnology from technician level to develop individuals with the skills and expertise to support commercialisation of nanotechnology in the UK.

Training of the UK workforce through Professional Development (PD) is essential as an innovation led economy is going to require a highly skilled workforce. The need is for a range of courses including short courses on specific areas of nanotechnology which should be coordinated through the appropriate Sector Skills Councils.

3.4. Engagement

1. Ensure that the general public is informed of product developments based on nanotechnology.

Industry, trade associations and professional bodies should provide "technology champions" to engage with the public on the benefits of nanotechnology and ensure that any potential concerns are understood and that responses from Government, academia and companies are balanced and factual.

2. Industry and Government should engage in an evidence based dialogue with the Unions and Non-Governmental Organisations (NGOs).

Unions and NGOs need to be provided with scientific evidence and data as a sound basis for dialogue. There is also a need for NGOs to produce their own data in support of their arguments to understand potential issues that need to be addressed.

3. Provide support for two-way international collaboration to gather and share an information base on nanotechnology.

As nanotechnology is a global industry, international collaboration is essential for its exploitation. The provision of this could come through inter alia UK Trade and Investment (UKTI), the Science and Innovation Network, Technology Missions and the Technology Strategy Board.

4. Government and industry should assist banking and insurance companies in understanding nanotechnology to enable sound investments to be made.

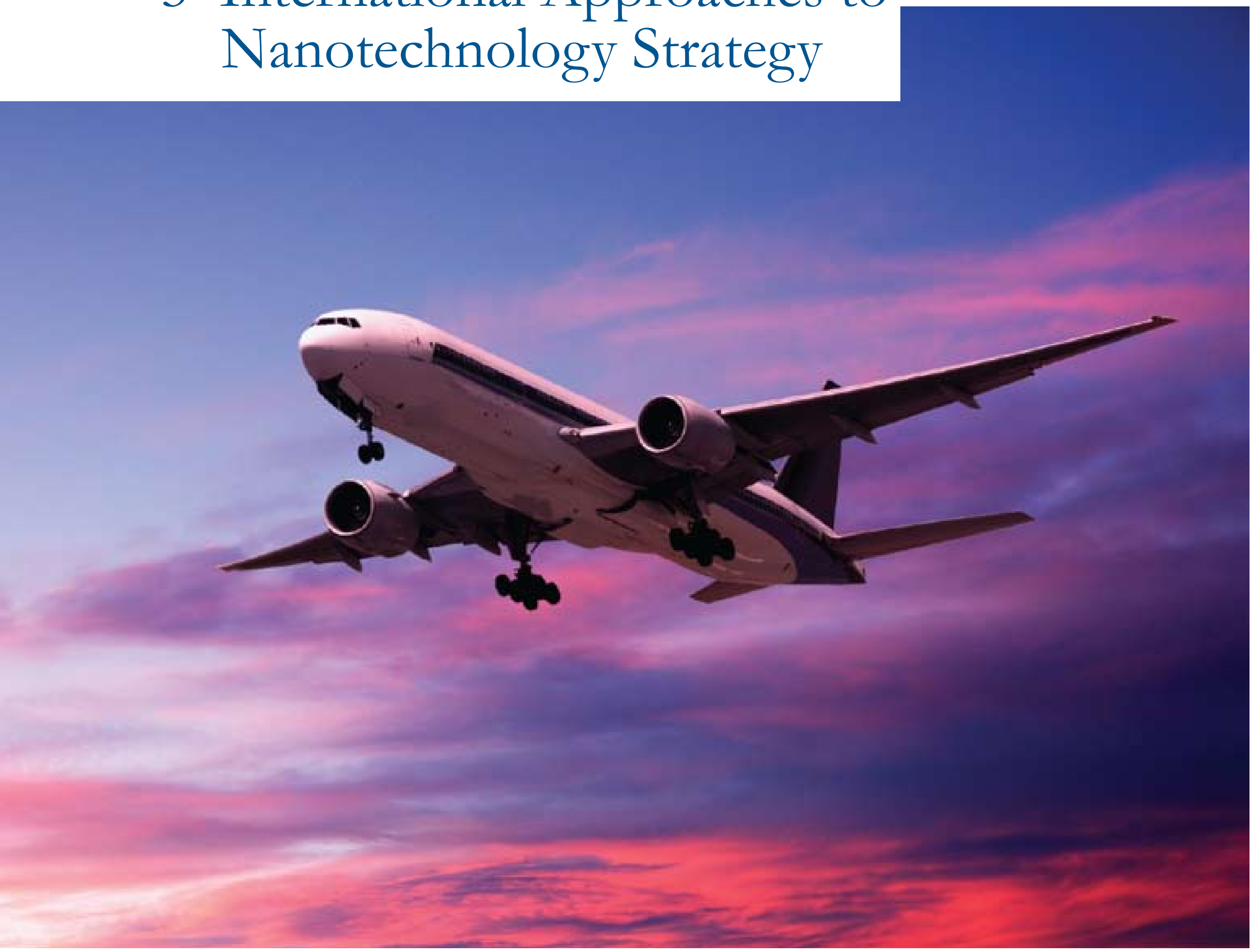
Banks and insurers need to be provided with evidence based commercial information including environmental, health and safety data on which to base investment and insurance decisions.

4 UK in 10 Years

There is a very strong technical base within the UK in the field of nanotechnology in 2009. Historically, the UK has been successful at research. It is crucial that this success follows through to commercialisation and the key to exploitation of this technical base is considered in this report with a series of recommendations provided in Chapter 3. It is believed that only if these recommendations are followed then the UK can become a successful player in the commercialisation of nanotechnology leading to significant societal and economic benefits. Below is a list of how the UK may be viewed in 2020:

- World class and integrated nanotechnology centres derived from the original set of MNT centres.
- Body of UK trained scientists, engineers and managers capable of ensuring significant growth in commercialisation of nanotechnology based products.
- Research Council and other Government funded programmes focussed on next generation nanotechnologies addressing Grand Challenge needs.
- Thriving nanotechnology SME community working with Government ensuring funding is directed in a timely fashion to grow value-adding nanotechnology based businesses.
- International regulation for nanotechnology agreed and understood by all with definitions and standards the basis for the regulation.
- The UK embedded in strong international nanotechnology business collaborations.
- Acceptance that processes for risk assessment and life cycle analysis for nanotechnology are no different in principle than for other technologies, and are conducted as a matter of standard practice by companies developing nanomaterials or nanotechnology based products.
- Family of nanotechnology based drugs and diagnostics products developed in the UK that ensure that the UK remains at the forefront of providing health benefits through its world class pharmaceutical businesses.
- Family of nanotechnology based products developed in the UK that contribute to the Low Carbon Economy.
- Public understanding that nanotechnology like any other technology has its benefits and risks and that these are considered and managed as part of the development of any nanotechnology based product.
- The UK recognised as a leader within The Organisation for Economic Co-ordination and Development (OECD) with respect to best practice in the development, manufacture and risk management of nanotechnology based products.
- UK led robust platforms for metrology and modelling in support of ongoing nanotechnology business needs.
- A comprehensive standards infrastructure to support industry and other stakeholders.
- UK developed nanotechnology based products manufactured in the Developing World for local use to address major health and welfare issues.
- The UK recognised as the leading centre for investment management and financial products related to nanotechnology.

5 International Approaches to Nanotechnology Strategy



Nanotechnology in the UK has to be viewed in the context of world wide activity in the field. Details of the approaches taken by different countries are in the Appendices.

The UK is not alone in determining a strategy for nanotechnology and has produced strategies by and for the Research Councils[2] and the Technology Strategy Board[3]. However, there is no overall strategy for nanosciences and nanotechnology and this report and subsequent work should form the basis of such a strategy that will lay out the UK approach and basis for future investment in this burgeoning area of technology. It is crucial that this is done promptly and clearly as the information in the Appendices summarises the efforts of other countries and confirms that the UK lags behind countries such as South Africa[4] in relation to 'nano' strategy.

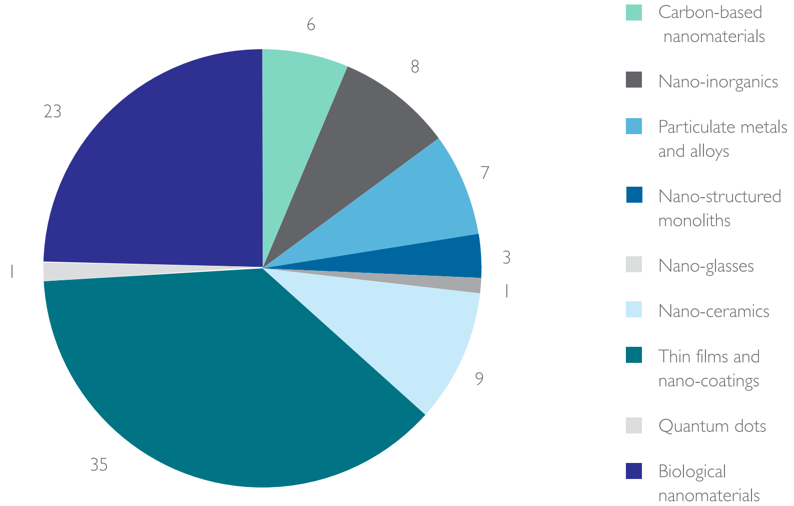
6 Size of UK Industry

The analysis of the UK's industrial and academic capability was based on data provided by the Nanotechnology KTN. This included the Nanotechnology KTN directory along with various contact databases provided by Nanotechnology KTN staff. These various databases were merged and further analysis carried out to present as comprehensive a picture as possible of the UK nanotechnology capability landscape.

There are a number of issues associated with this information that should be considered, namely:

- The limitations in the way that the Nanotechnology KTN database reflects the reality of the UK's nanotechnology industrial base – many companies that are known to have nanotechnology capability are missing and, in addition, there are companies on the database that could be suppliers but do not have any actual nanotechnology capability.
- Many of the companies listed in the database are suppliers or potential suppliers to nanotechnology companies rather than actually having capability in this area.
- The Directory is self-selecting so many companies that have nanotechnology capability or expertise have chosen not to be included.
- The focus is on SMEs so many of the larger UK companies active in this area are missing.

Figure 4
UK Nanomaterials Companies by Activity[5].



The final industrial database contained over 800 companies although, realistically only about one quarter of these are companies for which nanotechnology makes up a significant proportion of their business. Nonetheless, the following analysis gives a feel for the UK's nanotechnology capability and areas of expertise.

There is a core base of ca. 100 nanomaterials companies, consisting of mostly users and a small number of manufacturers, who are active in the UK. Figure 4 shows the distribution of these companies by activity.

This clearly shows that, by far, the largest number of companies are active in thin films and nanocoatings, with 35 companies indicating this as an area of expertise. This is followed by biological nanomaterials, with 23 companies, and then a cluster of companies with expertise in a range of nanomaterials specifically carbon based nanomaterials, nano-inorganics, nanoparticulate metals and alloys and nano-ceramics.

In addition, there are 23 companies indicating capability in nanoelectronics and a further 12 MEMS companies. It is our view that this final figure is low and this may be a reflection of the fact that the Nanotechnology KTN database is self selecting and some companies may have chosen not to include themselves on it.

Figure 5
UK Nanotechnology Support Infrastructure Companies by Activity[5]

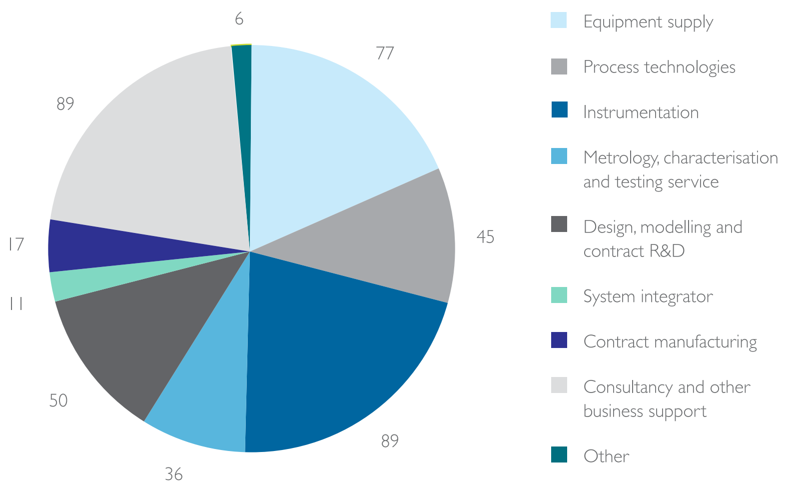
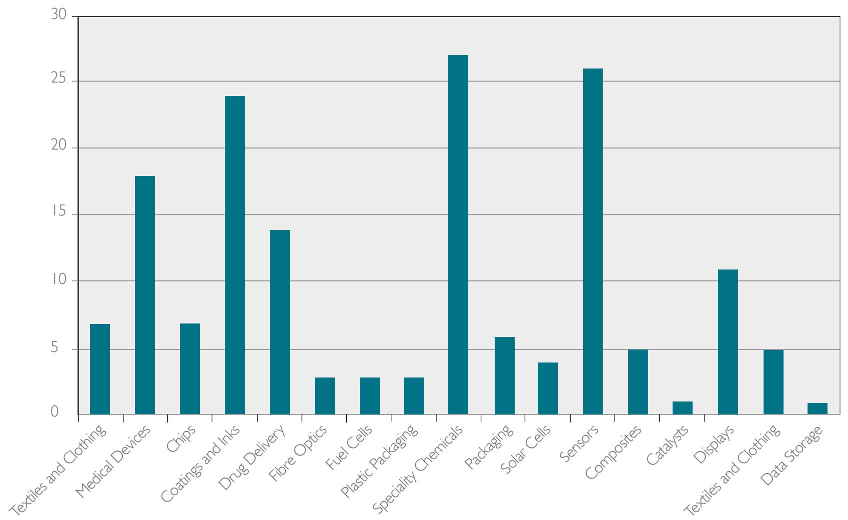


Figure 6
Market Application Focus of UK Nanotechnology Companies[6]



6.1. Nanotechnology Support Infrastructure

In addition to the nanomaterials and devices companies, there are a large number of companies that could be classified under support infrastructure. As has already been discussed, many of these companies have indicated that they are suppliers of products and services to nanotechnology producers and users. That is not to say that they have actual nanotechnology capability so Figure 5 should be viewed with that in mind.

6.2. Nanotechnology Applications

The final piece of analysis was to determine the market application focus of the companies on the database. This is shown in Figure 6.

Coatings and inks, speciality chemicals and sensors are clearly the key market sectors where companies are most active. This is not particularly surprising, especially in terms of coatings, inks and speciality chemicals. The UK has a strong chemicals sector, especially across the North of England and many of these companies are producers of nanoscale materials or are incorporating them into chemical formulations.

In addition, as was highlighted previously, the UK also has a strong emerging capability in large area electronics, the manufacture of which requires highly specialised inks and coatings. In the area of ICT hardware, an emerging UK strength is in printed, large area electronics, the advancement of which will rely strongly on nanoscale technologies. There could, therefore, be an excellent opportunity for the UK to gain a real competitive advantage in this area through a multi disciplinary approach to novel design, development and commercialisations, for example, low power lighting and displays. In addition, there has been significant public investment in the development of nanoelectro-mechanical systems (NEMS) and nanosensors, especially in academia. To date this has not however been exploited to any great extent. There is therefore a good opportunity to exploit these technologies and capabilities in the shorter term, for example in areas such as photonics and plastics electronics.

Similarly, in the sensors area, the UK has a competitive strength in sensor technologies for measurement, monitoring and control both in academia and industry so it is not surprising that a micro and nanotechnology capability in this area is apparent.

The UK life sciences industry is also a major success story – the pharmaceutical industry alone produced annual exports of £17.2 billion in 2008. When one then adds the major biotech activity, which is second only to the US, and the medical device sector, the UK is a leading powerhouse of innovation and commercialisation in this area. In order to ensure the UK remains a world leader in this sector, government, academia and industry must adopt, develop and support the next wave of technology, which can deliver the products of the future. Nanotechnology is one area that promises to provide that necessary innovation.

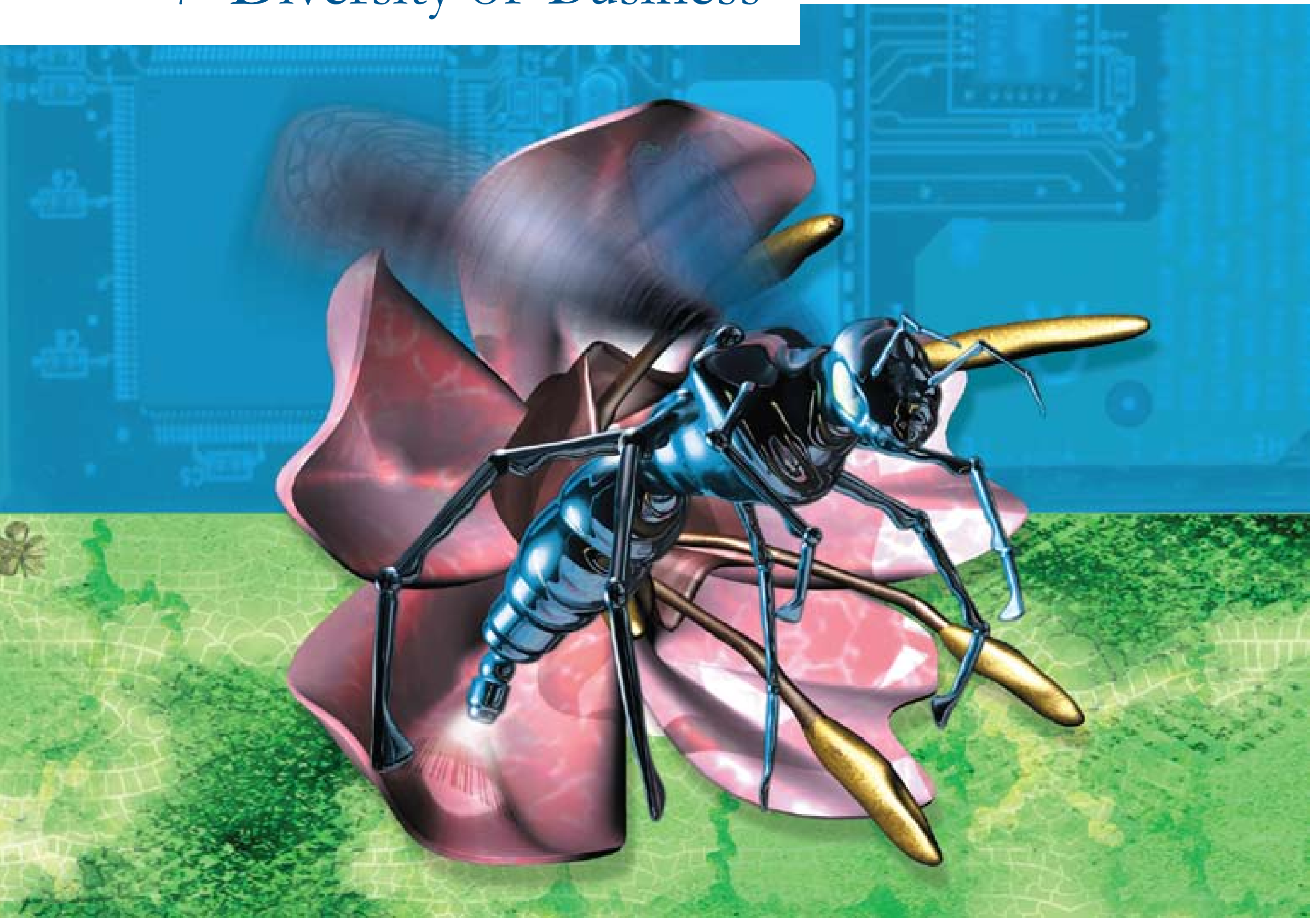
Accurately predicting future markets is a significant challenge within in the medical nanotech field and some of the figures placed in the public domain appear huge beyond imagination. However, as the regulatory pathway becomes clearer and companies start to gain approvals, nanotechnology will become more main-stream in healthcare and life sciences and its share of the market will increase significantly. A comparison with the biotech industry could be drawn here. Twenty years ago biotechnology had similar issues as nanotech faces now. It was seen as not having a clear regulatory pathway and not being able to be handled by the existing pharmaceutical company manufacturing capabilities and supply chain. Adoption of the technology therefore became an issue. Now (prior to Roche's recent purchase of Genentech) two of the top twenty pharmaceutical companies in the world are biotechnology companies and two of the top ten blockbuster drugs are biologics.

There are signs that this could be repeated with nanotechnology once the benefits are demonstrated and a route to market becomes clear. There are now around 30 nanoenabled drugs on the market, representing $30B in revenue. These are first-generation nanoenabled drugs, i.e. reformulations of generic products. As the regulatory and adoption pathway becomes clear, the second-generation products should appear, where the nano element provides targeting, or sensing functionality.

Healthcare and life sciences presents a major opportunity for nanotechnology and nanoenabled products. This is, however, a very wide ranging sector and within it, there are distinct sub-sectors with very different supply chains. Considering UK capability there are three areas that offer the greatest potential opportunities, namely drug delivery, drug discovery tools and medical devices (including diagnostics). In these sectors the UK has worldwide recognition. Significant progress has been achieved through strong cohesion between leading academic groups and industry, but there is intense international competition that threatens to draw talent, businesses and intellectual assets from the UK.

Nanotechnology can be used on the large scale in high throughput industries such as the steel industry. For example, new strong bainitic steel could be made from structures analogous to carbon nanotubes. Nano-injection during casting may also provide large scale potential benefits.

7 Diversity of Business



Nanotechnology is relevant to many branches of materials, electronics, chemistry, biology, medical science and engineering. This leads to some problems in regulatory approaches because the wide range of applications and approaches naturally lends itself to different sets of requirements according to the industry context.

It should be pointed out there are many industries which have been using nanotechnology for decades even before the term "nanotechnology" had been coined. For example, carbon black and silica are both produced and used in large volumes.

Many sectors involve products which are formulations, often including fine or colloidal particles. These include personal care, cosmetics, household products, food, coatings, inks, dyes, additives for fuels and lubricants and pharmaceuticals. The incorporation of nanoparticles into such products, compared with similar materials as larger "fine" particles, holds out the possibility of improved and distinctive properties based on the controlled size or increased surface area.

Nanomaterials can be considered in the following categories – the two large volume commercial nanomaterials, carbon black and silica; nanoparticles including metals and metal oxides; nanotubes and nanofibres; quantum dots; nanocapsules; nanowires; graphene; nanostructured materials and coatings and surfaces. Details of these are found in the Appendices.

8 Investment to Date

8.1. International Context

UK Government spending must be seen in the context of worldwide spending in the area. Lux Research state that Government spending in North America, Asia and Europe are significant (US$1.1B to US$1.7B each in 2005) on researching and developing nanotechnology.

Similar amounts are invested by industry in each region. In 2006 worldwide funding for nanotechnology reached US$11.8B, which is a 13% increase from 2005 according to the latest report by Lux Research. This is an indication that nanotechnology is viewed as a serious and important element to the world's future economy.

Newer players are also entering the field with some heavy commitments. For example, it has recently been announced that a nanotechnology funding programme in Russia has just been approved[8], making it the largest in the world, with $3.95B earmarked until 2015.

The German Government has supported nanotechnology since the 1980s, and Germany is now the leading player in nanotechnology in Europe in terms of funding, number of companies and dedicated research centres. Germany ranks among the top four nanotechnology locations worldwide. Its position is based on a well structured R&D infrastructure and high levels of research in the various subfields of nanotechnology. The industrial base for utilising the results of this research is also in place.

Public nanotechnology funding in Germany is mainly distributed through the country's network of research institutes – Fraunhofer, Max Planck, and Leibniz – and universities. German research institutions are global leaders in nanotechnology-related basic research. The institutes are an effective interface between basic research and industry, helping to transform basic research into applications. Funding bodies include the BMBF, the research foundation DFG, the Fraunhofer Gesellschaft and Max Planck Institutes, the Volkswagen Foundation, and the German States.

According to the German Government there are 1,000 plus companies active in the field, with an estimated €420M public-sector investment in 2008. Germany is also home to numerous global nanotechnology players such as BASF, Bayer, Siemens, Carl Zeiss and Evonik.

8.1.1. PUBLIC FUNDING RATIOS FOR NANOTECHNOLOGY R&D

Table 1 shows the estimated public sector funding for nanotechnology R&D in 2008, based on official Government websites and documents from each country[6]. This shows the actual level of funding in US $ as well

Table 1
Estimated public sector funding for nanotechnology R&D in 2008[6]

Country	Actual funding levels	Funding levels per capita
UK	$0.12B	$1.96
USA	$1.554B	$5.06
Germany	$0.5B	$6.07
Japan	$0.38B	£2.99
France	$0.21B	$3.28
Taiwan	$0.12B	$5.22

Table 2
Corporate funding for nanotechnology[6]

Country	Actual funding levels	Funding levels per capita
UK	$0.09B	$1.47
USA	$1.8B	$5.86
Germany	$0.3B	$3.64
Japan	$1.1B	$8.66
France	$0.1B	$1.56
Taiwan	$0.11B	$4.79

Table 3
Estimated Government support for nanotechnology[10]

Year	Estimated Amount
2009/2010	£83.20M
2008/2009	£77.60M
2007/2008	£73.50M
2006/2007	£66.27M
2005/2006	£66.00M
2004/2005	£65.76M
2003/2004	£60.80M
2002/2003	£40.58M
2001/2002	£50.00M
2000/2001	£35.50M
1999/2000	£11.00M
1998/1999	£12.39M
Total	**£642.60M**

as the funding levels per capita. The implications are clear – the UK public sector funding is lagging behind our global competitors both in terms of the absolute spend and in terms of its per capita spend.

8.1.2. CORPORATE FUNDING FOR NANOTECHNOLOGY R&D

Up to date, reliable data on corporate funding is not readily accessible. Lux Research[1] however, produced a report in 2005 which estimated corporate nanotechnology R&D spending in US$. Although now four years old, it does give an indication of the levels of relative spend in the UK and each of the international comparators. Again, this data is presented as actual funding levels and per capita funding levels and is shown in Table 2.

As can be seen, US and Japanese industry is significantly ahead in terms of actual corporate funding with Germany in third place but some way behind. Industry in the UK, France and Taiwan are all providing funding at a similar level.

However, when the funding is considered on a per capita basis, Japan clearly moves into a dominant position. Like many areas of technology, Japanese companies invest heavily in R&D. The World Economic Forum's (WEF) World Competitiveness Report 2008-2009 indicates that Japan is one of the world-leaders in the areas of "business sophistication and innovation" which the WEF suggests is as a result of *"a high availability of scientists and engineers, high company spending on R&D and an excellent capacity for innovation"*. This is reflected in the levels of spending on nanotechnology R&D.

Interestingly, once again, Taiwan moves into a more dominant position, ahead of Germany, France and the UK, when funding levels per capita are considered. Where Japan is a world leader in corporate R&D spend, the UK, in general, has a low industrial R&D spend. OECD highlights that in 2006, business enterprise expenditure on R&D was < 1.2% of GDP in the UK compared with ~ 1.6 % of GDP in the total OECD. It is therefore not surprising that corporate funding for nanotechnology R&D is low.

8.2. UK Government Spend on Nanotechnology over the last 12 years

In the UK, it is difficult to define accurately all Government spending in the area of nanotechnology as its reach is so broad and relevant to so many areas of science and technology. It should be noted that UK funding designation does frequently not distinguish between micro and nano technologies as in the case of MNT funding so that funding on nanotechnology according to accepted classification is likely to be less.

With this proviso, the estimated Government support for nanotechnology over the last 12 years has exceeded £640M, as detailed in Table 3.

As there is currently no UK strategy for nanotechnology and current support mechanisms, current spending reviews and the fact that future funding priorities will lie with the Technology Strategy Board, the Research Councils and relevant Government Departments and Agencies it is not yet possible to say how much the Government will spend on nanotechnology over the next ten years.

8.3. UK Government Spend on MNT Facilities

The last five years has seen a significant cash injection from the public sector into the UK micro and nanotechnology (MNT) community including a £90M investment on the development of a new network of MNT facilities and services, of which £40M was allocated to support and enhance collaborative research programmes and technology transfer initiatives, and £50M for capital projects and the development of the Nanotechnology KTN. Details of the MNT facilities are in the Appendices.

8.4. FP7 Funding

The EU's largest ever funding programme for research and technological development, the Seventh Framework Programme (FP7)[11], was launched on 1st January 2007. Under the old Sixth Framework Programme (FP6), between 2002 and 2006, more than €1.3B was spent on more than 550 projects related to nanotechnology R&D[12].

Under FP7, running from 2007 to 2013, funding for nanotechnology related projects is expected to reach €3.5B, out of a total budget of €50.5B with €300-400M spent in 2007.

Access to EU funding through FP7 programmes can support projects that otherwise may not have been funded by UK Government or industry alone or in combination. However, uptake of EU funding through FP7 programmes is weakened by the perception that the route to funding requires too much investment in proposal development against low expectations of approval.

8.5. Research Council Funding

EPSRC support for nanotechnology, classified by the Socio-economic Theme in Nanotechnology EPSRC[13], has amounted to £253M (since 2003) distributed over a portfolio of some 400 projects. According to the Nanoscale Technologies Strategy 2009-20123 report by the Technology Strategy Board, the main recipients of EPSRC nanoscale technology funding (2008 data) are shown in Table 4.

Notable recent initiatives include the Grand Challenge for Healthcare[14] £16.6M (19 projects) and the Grand Challenge for Energy[15] £6.78M (2 projects).

Table 4
Principal academic funding from EPSRC for nanotechnology (2008 data)[3]

Academic Institution	Research Funding
University of Oxford	£37M
University of Cambridge	£27M
University of Sheffield	£21M
Imperial College London	£19M
University of Surrey	£11M
University of Birmingham	£10M
University of Nottingham	£10M
University of Strathclyde	£9M
University of Glasgow	£8M
University of Manchester	£8M
University College London	£8M
University of Southampton	£7.5M

The Ministry of Defence (MoD), Biotechnology and Biological Sciences Research Council (BBSRC), Engineering and Physical Sciences Research Council (EPSRC) and Medical Research Council (MRC) contributed funds totalling £19.4M (£3.4M, £3M, £10M and £3M, respectively) towards running the Interdisciplinary Research Centres (IRCs) in nanotechnology including those at Oxford and Cambridge Universities[16].

8.6. Private Funding Ratios for Exploitation of Nanotechnology

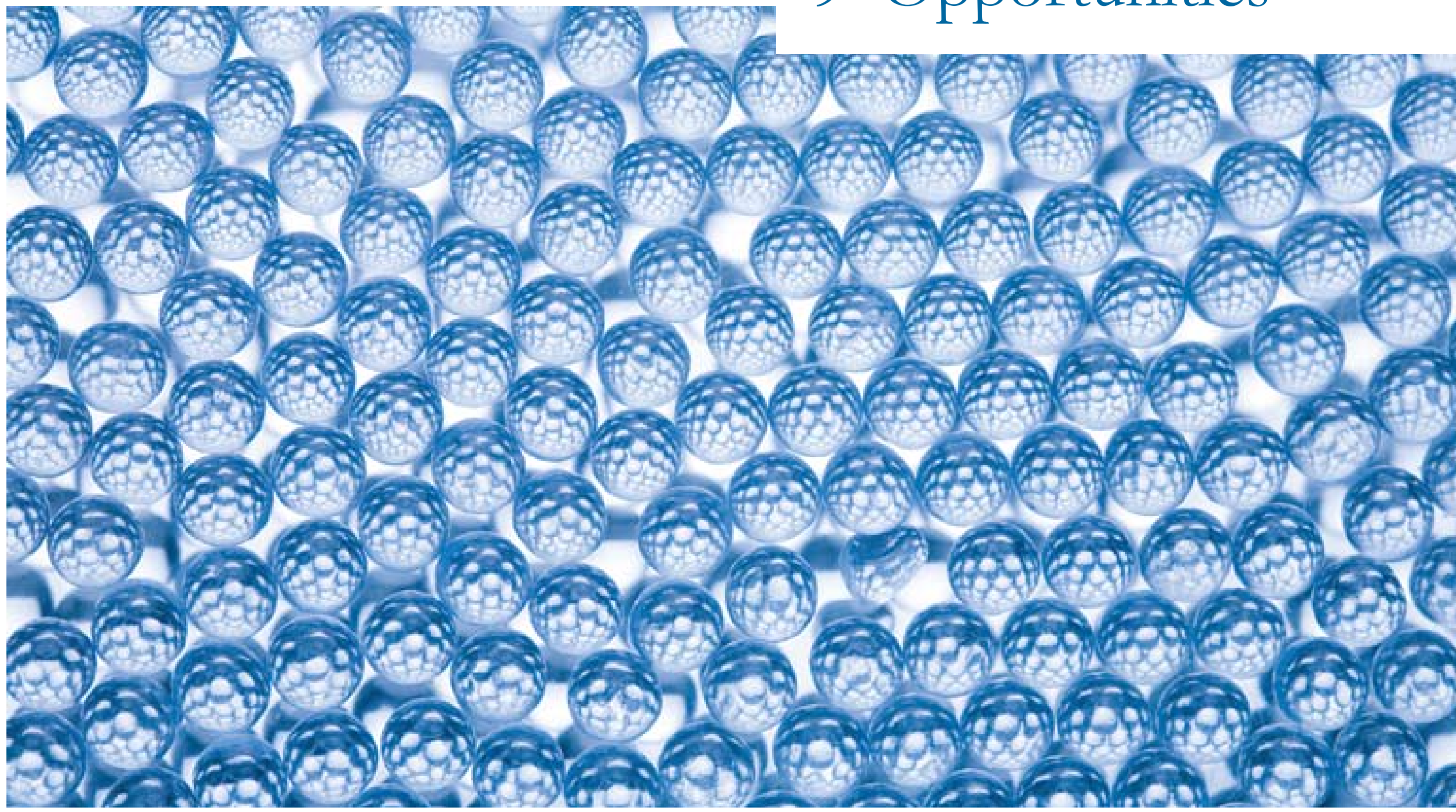
The published data for worldwide nanotechnology funding[1] in 2004 showed that total European and US funding levels have near parity at around $3000M each but the breakdown differs: private funding in the EU is of the order of $1300M comparing with $1700M in the US. The ratio of private funding in Japan is still higher, with $1400M identified compared with public investment of $900M.

Despite the public investment, in 2007 the total value of nanotechnology venture capital deals worldwide fell for the first time since 1999, with investment dropping from $738M across 73 deals in 2006 to $702M across 61 deals in 2007.

This 16% drop in the number of deals is evidence to the fact that new interest in investment needs to be created if start-up nanotechnology businesses are to continue emerging .

There are some difficulties in identifying UK private spend in Nanotechnology. UK investment in nanotechnology infrastructure and R&D has been significant in recent years. The Technology Strategy Board[3] points to the £150M joint investment with approximately 50% as industrial investment as part of the Government's initiative in the Micro and Nano Manufacturing Initiative which includes microfluidics, MEMs and nanotechnologies.

9 Opportunities



Nanomaterials and nanotechnologies can be applied to address most of today's societal challenges and this leads to significant opportunities. Nanoscale technology can be considered as a set of enabling technologies, leading to novel properties which can then be incorporated into products that can be marketed across a range of sectors.

Previous estimates of the size of the market are now held to be inflated according to current thinking. A more realistic view of the impact of nanoscale technologies within existing market sectors has been reported by Nanoposts[18]. Based on this report, the key sectors that are most likely to be impacted by nanoscale technologies and the associated market size estimates are summarised in Table 5.

The most significant global market impacts, as shown in Table 5, are seen to be within the ICT, automotive, shipbuilding, aerospace and defence, and food and drink sectors. The total revenue of $2.66B in 2007 is expected to grow to $85.7B by 2015.

Even in this more conservative forecast, the size of the market growth available is disruptive. The value of nanoenabled products produced in 2007 was estimated by Lux Research[1] as $147B. This is expected to reach $1.6T in 2013[19] and $3.1T in 2015. These figures should be taken with a note of caution, however, as the estimated market value varies significantly depending on the source of the data. This is clearly demonstrated in Figure 7.

It can be seen that, despite the significant range of values (ranging from $750B in 2015 quoted by Wintergreen[20] to $3,100B in 2015 quoted by Lux Research[1]) the market opportunity for nanoenabled products is significant with large scale commercialisation and, hence, market growth predicted to take place in 2010 and 2011. It must be clearly stated, however, that this predicted revenue is not all in addition to current revenues – many nanoenabled products will replace current conventional products to meet increasing demands for enhanced product performance, specifically:

- Product miniaturisation.
- Enhanced product functionality.
- Increased product efficiency.

Table 5
Summary of markets impacted by nanoscale technologies - $million[3]

	Nanoscale technology impact in 2007 ($M)	Predicted Nanoscale technology impact in 2015 ($M)
ICT	585	41402
Automotive	404	7134
Shipbuilding	357	4295
Aerospace and defence	323	3768
Food and drink	265	3210
Consumer goods	188	6225
Life sciences	145	5670
Textiles	122	2170
Energy	90	3615
Environment and water	86	3885
Construction	66	1672
Brand and product security	30	2650
Totals	2,661	85,696

Breaking down the market opportunities by Technology Readiness Level (TRL) is also informative. Technology Strategy Board data[3] which classifies the opportunity according to the current TRL is shown in Table 6.

The important observation here is the wide range of opportunities at different TRLs ranging from basic research through to near market readiness. The volume supply of commercial nanomaterials into mature markets such as carbon black and silica sols should also not be overlooked in this review.

This spread of opportunities at different TRLs emphasizes the need for managed private and state funding in order to maximize the UK position in IP generated, know how and the associated commercial position arising within a highly competitive market.

The Taylor Report[2] emphasised the multidisciplinary nature of the opportunities and there exists much scope for engaging the technology transfer, knowledge transfer and training instruments to make best use of the underlying science, technology and innovation capacities in the UK. In the end, it is the availability of people with necessary skills that allows translation of opportunity into exploitation. Skills and training are necessary but not sufficient conditions for this. Given the global context it is also clear that it is unrealistic to expect that the UK can achieve strong positions in all of these domains, and that prioritisation will be needed. This will be a key challenge.

Figure 7
Nanotechnology market opportunity[6]

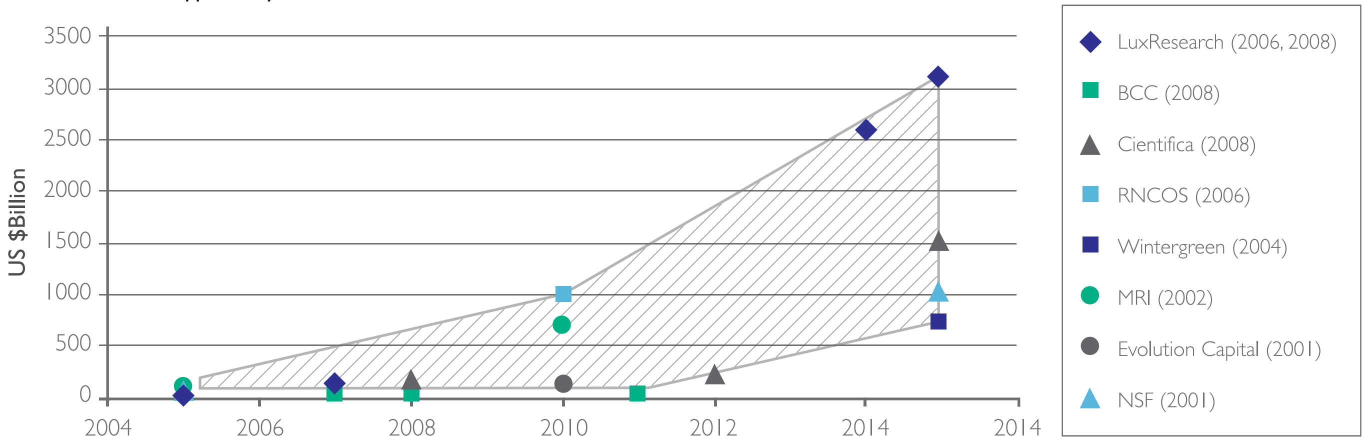


Table 6
Technology Readiness Levels (TRL)[3]

Challenge Area	Sector	TRL 8-9	TRL 6-8	TRL 2-6	TRL 0-2
Security	Aerospace and Defence	Composites for reinforcement.	Flame retardant materials for aircraft, protective coatings, lighter body armour (CNTs).	Self repairing structures, smart uniforms, sensors for biological and chemical threat detection, electronics in spacecraft.	Smart air/spacecraft.
Intelligent connected world	Electronics and ICT	Magnetic nanoparticles for data storage. Electronic nanoscale materials for dielectrics.	Flexible displays, nanocomposite heat management, nanowire electronic and photonic devices, nanosilver die attach.	Carbon nanotube single electron transistors, non volatile random access memory, molecular diodes, single hybrid molecular device, semiconductor single electron devices (quantum dots), graphene based circuits.	Molecular memory. Solid state quantum computing.
Security of supply/growing population	Energy	Nanocrystalline coated solar cells, nano porous aerogels, nanoparticle additives for energy efficiency.	Nanocatalysts for fuel cells. Nanomembranes for fuel cells.	Thermoelectric materials for heat conversion, carbon nanotube fuel cells and batteries, carbon nanotube hydrogen storage, polymer and hybrid photovoltaics.	Potential for wind power applications.
Ageing/growing population	Life Sciences and Healthcare	Nanotitania implants, nano-particle drug delivery, antibacterial coatings, healing wound dressings, lab-on-a-chip.	Dendrimers in bio-technology assay kits.	Biocompatible implants, magnetic nanoparticles as imaging agents, nanocoated stents for tissue engineering, non-invasive therapeutics using heat to treat cancer.	Smart materials for organ and limb replacements.
Low impact building	Construction	Strength increase/crack prevention, self healing additives to cement, exterior protection coatings, anti-graffiti coatings, self cleaning glass, nanoadditives to steel, heat blocking windows.	Aerogels for insulation, heat resistant materials.	Self repairing structural materials.	Smart sensors to monitor fracturing and flexibility, intelligent buildings.
Healthcare, modern world	Textiles	Self cleaning fabrics, wound dressings, healing textiles, antibacterial garments.	Fire retardant textiles.	Wearable computers, smart clothing, bioresponsive clothing.	Self healing textiles.
Security of water supply	Environment and Water	Air filtration, titania photocatalysts, nanoporous membranes for filtration	Nanoscale absorbents Desalination of sea water using nanomembranes; nanomaterial based products for water treatment (Nanofer)	Water purification using bio-nano, NEMS for sensing and acting on pollution,	
Growing population	Food and Drink	Nanoemulsions, nanocomposite barrier packaging, nanoporous membranes for processing.	Super hydrophobic surfaces, controlled release seed coatings, pathogen detection with nanoparticles.	Nanoencapsulated nutraceuticals, programmable barriers in coatings for atmospheric control, electronic tongue.	Smart paper for information display and packaging.
Quality of life	Consumer Goods and Household Care	Easy clean coatings for surfaces, self cleaning tiles, nanosilver cosmetics and oral care, nanoencapsulation for beauty care, nanocomposite sporting goods.	Nanocoated wipes for surfaces, self cleaning sprays (short lasting).	Nanoencapsulation for household hygiene and fragrancing.	Long term self cleaning wipes and sprays, nanoelectronics in leisure equipment.
Security	Brand and Product Security	Intelligent inks, nanoparticles for security printing.	Paper like electronic displays for condition information, magnetic nanoparticle tagging.	Decontaminating surfaces, nanoparticle chemical markers.	Smart dust for decontamination.
Transport, defence	Shipbuilding	Nanofillers for structural enhancement, anti bio-fouling and corrosion resistant coatings.	Thermal barrier materials for engines.	Fuel cells, embedded sensors.	Cloaking for warships.
Intelligent transport	Automotive	Nanofillers for structural enhancement, fuel additives, scratch proof & anti-glare fogging coatings.	Thermal barrier materials for engines.	Shape memory alloys, fuel cells.	Smart tyres.

10 UK Capability and Capacity to Exploit

The capability of the UK to exploit the emerging opportunities highlighted depends on a number of factors:

- That there exists a market opportunity for application of a nanotechnology or nanoenabled product to have impact.
- That market opportunity is not excessively constrained by competitor activity.
- That this opportunity is relevant to a working and responsive UK supply chain.
- That translation of the concept from low to high TRLs can be supported by robust academic and industrial research.
- That eventual exploitation is not constrained or blocked by any of the barriers (health, insurance, environmental etc) which are considered elsewhere.
- That there is adequate support in terms of facilities, funding, skills and direction.
- That innovation is protected by commensurate patent actions.

The combination of constraints applies some natural filters which lead to a prioritisation of the UK exploitation route. These factors are considered in more detail:

- There is good documentation of the market opportunity but forecasts need to be examined critically in terms of the constraints which might limit market uptake. The size of the market opportunity is one of the key determinants for prioritizing innovation activity so good market data and business awareness is essential. The other main determinant here is time to market, which likewise might be affected by potential exploitation barriers, such as insurance and regulation. Ranking by market size might be misleading because of segmentation.
- The competitive position is fast moving and time to market is more important than in many other industrial contexts.
- The health of the supply chain is probably the strongest determinant. The most important supply chains for the UK include Aerospace, Automotive, Chemicals, Consumer Products, Energy, Environmental, Healthcare and ICT. The published R&D scoreboards of companies provide an indication of the readiness of a supply chain to innovate either by itself or in concert with academic groups.
- The nanoscale technology industry includes a mix of university spin-outs, small to medium-sized enterprises (SMEs), and large, multinational companies that may focus a percentage (usually < 2%) of their research and development work on applications incorporating nanoscale technologies.
- The UK has strong academic groups working in the field. The Nanotechnology KTN database indicates that there are over 60 academic groups engaged in nanotechnology at some level. The UK science base in selected nanoscale technology areas is strong and initial activities to assist commercialization are in progress through the cross research council nanotechnology coordination group.
- In forthcoming years, the ability to maintain and strengthen the research base across disciplines, and to accelerate the translation of new discoveries into valuable products, will be two key factors for the UK to achieve a position as a world leader in selected areas of nanoscale technology.

The 23 MNT open access facilities in the UK, shown in Figure 8, are supported by combined Technology Strategy Board, RDA and industrial funding - £150M over 3 years. Together, with other relevant infrastructure including the DIAMOND light source, the National Measurement System and Health and Safety Laboratory, this represents a robust facilities platform for innovation.

UK funding is substantial but still lags behind several competing countries, both in terms of absolute and per capita spend.

Skills and training are key issues which may not be adequately supported in

Figure 8
Geographical representation of the 23 MNT Centres in the UK[3]

this context. There is scope for new initiatives, possibly involving Continuing Professional Development (CPD), to supply business with the necessary skill sets.

Clear Government direction with commensurate funding has not always been apparent. Recent initiatives by the Technology Strategy Board to assert a strategy for the UK may signal a shift in this. Ranking prioritisation across the UK is (or is likely to be) influenced by the new agenda through funding instruments such as the Research Council Grand Challenges.

Figure 9 shows a SWOT analysis for the UK capability in nanotechnology[6].

Figure 9
SWOT analysis of UK nanotechnology capability[6]

Strengths	Strong academic sector; Good track record of start-ups; Extensive business support network (KTN and MNT facilities, academic centres of excellence); Metrology and instrumentation expertise; Global leading role in metrology & standards; International recognized H&S capability.	Lack of direction/strategy from Government; No coherent public sector focus; Low public sector support; Relatively low investment in R&D; Sector highly fragmented – few large companies and many SMEs; Supply chain complexity; Poor track record of supply chain development; Technology (push) not business focus (pull); Few larger companies with high profile nanotechnology activity; Difficult to engage with end-users; Difficult to transfer IP from academia to industry.	Weaknesses
Opportunities	Significant global market growth; Wide range of market applications - Nano-medicine - Engineering applications - Chemical products; Engagement with global partners; R&D driven collaboration, e.g. participation in EC projects.	Long lead time to market; Poor fit with investor expectations; Limited large corporate investment; Limited private venture funding; Impact of strategic direction and investment elsewhere; Gaps in information on potential toxicity – a barrier to commercialisation; Public reaction to health scares in the media; Reduced support for standardisation reduces the UK's influence.	Threats

11 Barriers to Exploitation

Although nanotechnology offers great potential, a number of barriers inhibit its development and utilisation. The UK, with its earlier investments in this field, has built up a good research base. However, this is far from unique as other countries, notably the USA, Japan and Germany, have funded similar programmes.

Lord Sainsbury states in his 2007 review of Government Science and Innovation Policies that:

"In the future it will no longer be necessary to start every report of this kind with the dreary statement that, while the UK has an excellent record of research, we have a poor record of turning discoveries into new products and services.

While we believe that our record of innovation is better than is commonly supposed, we have not yet produced the best possible conditions to stimulate innovation in industry"

Although this perceived UK mind-set of invention prevailing over innovation is well embedded in our industry there are now companies that are taking the initiative and are implementing and relying upon nanotechnology as the bedrock for their businesses.

Nevertheless there are still barriers to the full and complete exploitation of nanotechnology in the UK, these include, amongst others:

- Environmental and health and safety issues.
- Knowledge transfer between the academic and industrial communities.
- Industry led research and development.
- Support for SMEs and start-up enterprises in the sector.
- The breaking down of communication barriers resulting from the broad range of scientific disciplines covered by nanotechnology[22].
- Training and skills development for the industry.
- Development and implementation of standards.

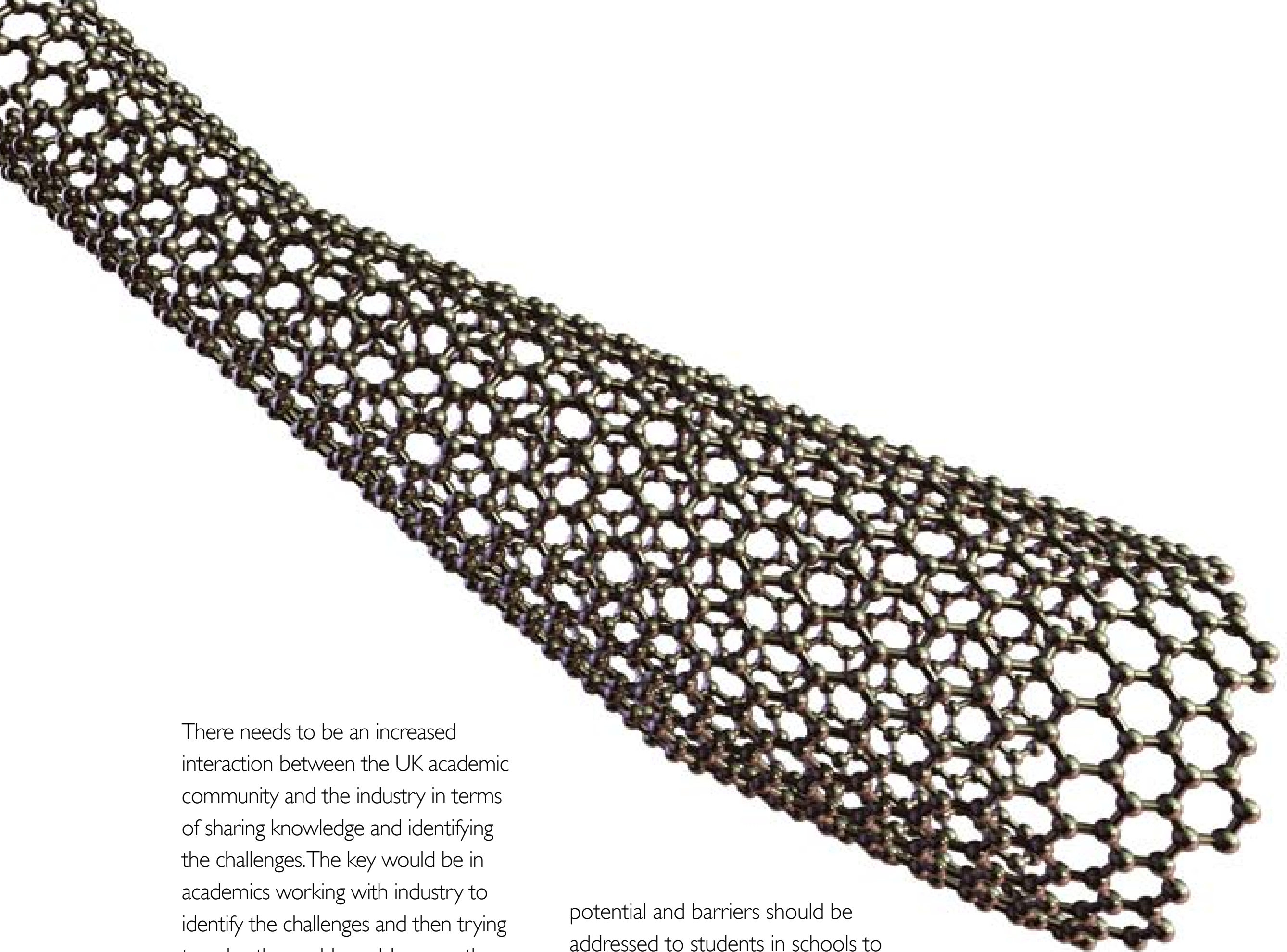
There is clearly a concern amongst the general public, fuelled by statements from NGOs and some public figures, that nanotechnology presents a serious health, safety and environmental threat. It is essential that objective information is gathered to provide a balanced view on this, and that the UK government develops a strategy for the communication and consultation with the public and the relevant NGOs. There are good and bad examples of how this has been done with similar issues (GM crops, stem cells) which should guide the strategy for nanotechnology.

Considering that many nanoenabled innovations are in the healthcare sector, companies will not be willing to take investment risks unless the safety issues are addressed. In addition, the existing regulatory requirements may not be adequate to address the new properties exhibited by nanotechnology.

Regarding business-led innovation, one of the main weaknesses to date has been the focus on technology development rather than addressing how consumer needs and societal issues can be addressed uniquely by nanotechnology. To ensure the rapid exploitation of technologies, there is a clear need for integrated system solutions; rather than focusing on nanotechnology alone, consideration should be given on how it can be a part of the solution.

Analysis of the UK market shows that the majority of solely nanotechnology based companies are comprised of either start-ups or SMEs. In addition to providing assistance to these companies, both financially and technically, there are other issues which are inhibiting development. An issue which has been highlighted by industry is the need for more patent information. This is both expensive and time consuming to locate and identify.

Amongst the larger companies there is a concern that public opinion and more stringent regulation will have a detrimental effect on their business. This is particularly relevant for current products which contain nanoparticles and have been successfully marketed and sold for several years (e.g. surface coatings). A balanced view needs to be taken on which categories of product should be subject to regulation.



There needs to be an increased interaction between the UK academic community and the industry in terms of sharing knowledge and identifying the challenges. The key would be in academics working with industry to identify the challenges and then trying to solve the problems. However, there are a number of constraints preventing the free flow of information. One of the major barriers in such circumstances is the fear of losing patentable ideas and the difficulty in negotiating IP agreements with universities.

It is also vital that everyone should be aware of the supply chain ranging from component manufacturers to system providers. This information should be promoted widely and the suppliers and customers should be able to access this information quite easily.

Contrary to FP7 funding mechanisms, the Research Councils' funding in the UK is less suited to cross-disciplinary research projects. Considering that nanotechnology is often of an interdisciplinary nature, it raises the issue of re-examining the funding strategy for this area.

Communication of technologies to a wider audience and stimulating a debate is vital for the success and acceptance of any technologies. In addition to that, the technology, its potential and barriers should be addressed to students in schools to stimulate their thinking and imagination.

In a high-value, high-skilled, knowledge based economy it is vital that people with sufficient skills are in place to drive innovations to sustain development of nanotechnology and its skill base. The lack of adequate training programmes and the high cost of training are two important factors affecting the technology growth.

Early standardisation is seen as vital for the successful commercialisation, market development and consumer acceptance of nanotechnologies. The UK has established itself at the forefront of standardisation of nanotechnology. In June 2004, the UK was the first country to set up a national committee for nanotechnology standardisation. It has published 11 standards and currently holds the chair and secretariat of both the ISO and CEN committees in the area – ISO/TC 229 and CEN/TC 352. It is currently leading 7 projects in the ISO committee and the three projects so far approved by the CEN committee.

Additionally the measurement techniques developed for conventional materials in many cases cannot be simply applied to nanostructures. Precise control of dimensions of objects key to nanotechnology is required to an accuracy of up to 0.1 nm. Special protocols for nanostructures and nanomaterials must be developed. Standards have to match technology advances and support the increasing applications of nanostructures[23].

Even with a plethora of potential barriers to exploitation, the UK is still relatively well equipped to gain full commercial advantage of the advances in nanotechnology.

12 Funding

Research into nanotechnology (and its related disciplines) has received UK Government funding in excess of £600M over the past 10 years. When this is coupled with industry supporting this on a 50:50 funding regime it is clear to see that investment in the UK from both Government and industry has been substantial and is easily in excess of £1B. It is now that this funding should be generating returns on investment for both companies and in turn the UK Government.

The total global nanoscale technology revenue in 2007 is estimated to be in region of $2,304M with a predicted rise to $81,404M in 2015[3]. This indicates that there is money to be earned from nanotechnology and it is therefore imperative that the UK is well placed to exploit the increased revenue available from the adoption of nanotechnology over the coming 5 years.

To do this, financial support will be required in both research and development to ensure that the UK remains at the forefront of the developments and advancements that will be taking place, and for industry, in particularly SMEs and start-ups, to better enable them to de-risk their business investments through better knowledge transfer and small scale R&D to prove concepts so that larger investments can be made with a higher degree of certainty for success.

The Technology Strategy Board[3] showed that growth in revenues for nanotechnology would occur in three main areas:

- ICT
- Automotive
- Consumer Goods

With all other sectors listed also showing significant growth, these include:

- Aerospace and Defence
- Agriculture, Food and Drink
- Life Sciences
- Textiles
- Energy
- Environment and Water
- Construction
- Brand and Product Security

Table 7 summarises market revenues for particular sector areas.

To manage this growth across a diverse range of industrial sectors the funding balance must be holistic in its approach and must focus on sectors that are deemed, by industrialists, to be key to the UK maintaining and growing a culture of economic growth through innovation. This will only happen if the funders can collaborate more effectively and efficiently between themselves in the UK and across funding bodies in the EU and further afield so thawt calls for funding are coordinated and managed across funding streams to deliver optimum benefit and impact for the UK nanotechnology industry.

Table 7
Summary of technologies within market sector areas[3]

Market area (market revenue in $millions 2007) potential revenue ($millions in 2015)	Sub areas (actual 2007 market revenue in $millions), (2015 predicted market revenue in $millions)			
Aerospace and defence (323.5), (3768)	1. Nanocomposites (27), (910)	2. Electronics & sensors (58.5), (182)	3. Nanocoatings (165), (1880)	4. Energy devices and fuel additives (45), (376)
	5. Smart materials (28), (420)			
ICT (585), (41402)	1. Carbon nanotubes (45). (800)	2. Nanowires (30), (900)	3. Nanoscale memory (250), (21000)	4. Printed electronics (150), (12000)
	5. NEMS (10), (520)	6. Spintronics (50), (6000)	7. Quantum dots (50), (650)	
Energy (90), (3615)	1. Photovoltaic film coatings (30), (760)	2. Fuel cells and batteries (30) (1650)	3. Thermoelectric materials (5), (445)	4. Aerogels (25), (760)
Life Sciences and Healthcare (145), (5670)	1. Nanoscale biosensors and imaging (20), (1220)	2. Nanocoatings on surfaces and implants (50), (1800)	3. Nanoparticulate drug delivery (75), (2650)	
Construction (66), (1672)	1. Nanoscale sensors and smart materials (1), (212)	2. Nanocomposites (5), (375)	3. Nanocoatings (50), (750)	4. Additives to concrete (10), (335)
Automotive (404), (7134)	1. Nanocoatings (181), (2451)	2. Composite fillers (150), (2106)	3. Additives in catalysts and lubricants (69), (1740)	4. Fuel cells (25), (450)
	5. Smart materials (15), (387)			
Textiles (122), (2170)	1. Coatings (120), (1850)	2. Smart materials and sensors (1), (125)	3. Nanofibres / nanotubes (2), (195)	
Environment and water (86), (3885)	1. Nanoporous membranes (41), (975)	2. Chemical and bio nanosensors (5), (490)	3. Nanoparticles (29), (2000)	4. Nanocoatings (11), (420)
Food and drink (265), (3210)	1. Nanosensors (2), (360)	2. Encapsulation (3), (320)	3. Nanocoatings (40), (495)	4. Nanocomposites (180), (1580)
	5. Nanoporous membranes (40), (455)			
Consumer goods and household (188), (6225)	1. Nanocomposites (67), (1248)	2. Nanocoatings (70), (1500)	3. Nanoparticles (51), (3477)	
Brand and product security (30), (2650)	1. Nanocoatings (10), (1000)	2. Nanoparticles (20), (1650)		
Shipbuilding (357), (4295)	1. Nanoscale electronics and sensors (25), (970)	2. Nanocoatings (180), (1850)	3. Nanocomposites (100), (1100)	4. Additives in catalysts, lubricants and fuels (52), (375)

Note: the coloured boxes indicate technologies that have significant cross over into a number of market areas. For example, both coatings and composites apply to all transport sectors and also in the defence and construction sectors.

13 Issues

13.1. International Regulation

Different countries and legislations have addressed the issue of nanotechnology regulation in different ways, but no country to date has any specific regulation relating to nanotechnology, although there are different approaches to reporting the use of nanotechnology based products for use within a given country or area. For example, Canada has recently introduced a mandatory safety reporting scheme[24] for companies producing or supplying nanomaterials, becoming the first country in the world to do so. It is still too early to draw conclusions as to its effectiveness.

The European Commission (EC), the US Environmental Protection Agency (EPA) and the UK Department for Environment, Farming and Rural Affairs (Defra) have all previously launched their own schemes to gather information on nanomaterials. However, all three have shied away from making Canadian-style demands for information from industry, and opted instead for voluntary schemes, asking manufacturers and users to take part and provide them with information about what materials they make, in what quantities, and how they are used.

In Europe, the recently introduced REACH regulations already apply to nanoparticles. However, as REACH currently stands, the quantities produced are often too small to be considered with the regulatory trigger for REACH being one tonne per year.

The fact that the Canadian Government has opted to set the lower limit for its safety reporting scheme at only 1 kg is a clear discrepancy with the EC. There are no current plans to change the regulatory threshold within the EC, but REACH is up for a full review in 2012, at which time all recommendations will be considered.

In the US, the EPA's nanomaterials stewardship program (NMSP)[25], launched in 2008 and due to be concluded in 2010, was split into two: the basic program, whereby companies were simply required to submit information about the materials they produce; and the in-depth program, which offered companies the opportunity to work with the EPA to identify what additional information might be useful in regulatory decision-making, and to devise methods to generate this information.

An EPA interim report[26], released in January 2009, claimed the NMSP had been successful - despite a notable lack of participation from industry. According to the EPA, approximately 90% of the different nanoscale materials likely to be commercially available were not reported under the basic programme, and there were 'important gaps' in the information that was reported. For example, some submissions did not contain exposure or hazard-related data.

The EPA defends its current stance having received over 50 new chemicals notices for nanoscale materials since 2005, and have taken steps to control or limit exposures to all of these chemicals, including limiting the uses of the nanoscale materials, requiring the use of personal protective equipment. However, they will consider issuing regulations at any time to protect human health and the environment. The very low rate of engagement in the in-depth programme (only four companies have so far agreed to participate) "suggests that most companies are not inclined to voluntarily test their nanoscale materials," the report concluded.

Defra reported that its own voluntary reporting scheme was a quick and efficient way to gather information since to have gone down the mandatory route would have taken much longer. Currently, the UK regulators say that they can work with existing regulations to protect consumers and the environment, while supporting the growth of the industry.

The Royal Commission on Environmental Pollution (RCEP)[27] report on Novel Materials in the Environment: The Case of Nanotechnology was published in

November 2008 and made the following recommendations regarding revisions to existing legislation in the UK:

- In any revision to existing regulations, the relevant authorities should focus specifically on the properties and functionalities of nanomaterials, rather than size.
- As REACH is adapted to meet the challenges presented by nanomaterials, particular attention should be given to the issue of weight thresholds. In view of the persistent uncertainties involved, a precautionary approach should be adopted when determining new, lower thresholds for nanomaterials.
- The UK Government should press the European Commission to proceed with urgency, in consultation with Member States, the European Chemicals Agency and SCENIHR (Scientific Committee on Emerging and Newly Identified Health Risks), to review REACH and product or sector specific regulations. The object of the review should be to amend the regulations to facilitate their effective application to nanomaterials and then provision of adequate testing arrangements.

In its response[28] the UK Government agreed with the Royal Commission that the REACH regulation provides the most sensible legislative framework for the regulation of nanomaterials. Likewise, the Government recognised that functionality rather than size should be the focus of any revisions to REACH and that weight thresholds must be given particular attention. However, there has been no indication regarding a process or methodology that would recognise properties as a basis for regulation.

However, fundamental issues remain. According to a report published this year by SCENIHR[29], there is as yet no generally applicable paradigm to test the safety of nanomaterials, and so the committee recommended 'a case by case approach' for risk assessment. Given that legislation would at least in part be addressing potential safety issues, such a recommendation makes defining legislation to cover nanomaterials and nanotechnology extremely challenging if not impossible.

13.2. Codes of Conduct for Responsible Research and Commercialisation

In November 2006, the Royal Society, Insight Investment and the Nanotechnology Industries Association (NIA) came together to explore the societal and economic impact of the technical, social and commercial uncertainties related to nanotechnologies. Following a successful Workshop, the three organisations together with the Nanotechnology KTN decided to facilitate the development of a voluntary Code of Conduct for Responsible Nanotechnology.

This became the Responsible NanoCode and was developed by a Working Group comprising the founding members together with representatives from industry, both multinational and SME, trade unions, consumer groups and academia. Seven Principles formed the basis of the Code and these are in the Appendices. The Code was designed for adoption by organizations involved in the research, development, manufacturing, retailing, disposal and recycling of products using nanotechnologies.

Alongside this work on the development of the Responsible NanoCode[30], the Commission of the European Communities developed and published a Code of Conduct for Responsible Nanosciences and Nanotechnologies Research.

13.3. Public Perception

Attempts have been made to gauge public perceptions of the issues surrounding nanotechnology. Given the breadth of the field and the technical complexity surrounding some the technologies this is not an easy task.

Nanojury[31] is an example of participatory action research which was set up to probe public perceptions of the field. The picture that emerges is recognition that nanotechnology offers potential for both great benefit and harm. One of the jurors commented:

"My immediate reaction to when I began to see what nanotechnology was, like all new tech it was going to be a mixture of good, bad and indifferent. Like all tech it is about who controls it and how. I analyse through a model of conspiracy of goodwill. People clubbing together trying to do the right thing but doing the wrong thing"

There are some negative observations on corporate ambitions, but these are in line with generic attitudes across wider technology areas and are not specific to nanotechnology.

Some of the main general recommendations tabled as a result of Nanojury include:

- More openness on how public money is spent on nanotechnology research.
- Government should support those technologies that bring jobs to the UK by investment in education, training and research.
- If public money is to be spent, then it should go on technologies which contribute towards the solving of longer term issues, such as health and environmental. This should be combined with the use of incentives and strings attached for the private sector.

On health:

- All manufactured nano-particles should be labelled in plain English, classified and tested as if they were a new substance.

There seems to be a general expression that benefits available from nanotechnology need to be available with minimum discrimination arising from corporate interest.

DEMOS[32] pointed out that:

"the emergence of nanotechnology has coincided with a greater openness in science and innovation policy. For government, public engagement has become a way of avoiding a repeat of past mistakes. Depending who you ask, nanotechnology might be the Next Big Thing, the Next Asbestos or the Next GM. But before its impacts have been felt, nanotechnology has become a test case for a new sort of governance. It is an opportunity to re-imagine the relationship between science and democracy".

Based on the results of members of the public joining scientists in discussions on regulation, research funding, development and corporate innovation, DEMOS say that there is a reciprocal problem in public dialogue:

"Our experiments have taken us behind the scenes of science policy. From backstage, we can see that policymakers tend to see the public as a problem rather than an opportunity. For public engagement to matter, it must go beyond risk management. New conversations with the public do not provide easy answers. They ask difficult but important questions, opening up new possibilities for science. The value of public engagement is that it takes us into a vital discussion of the politics of science".

Which? produced a Nano Briefing[33] which is attuned to consumer interest and perception. This presents the anxiety about potential risks:

"Nanotechnologies could offer consumers many exciting new benefits. Some of the products already on the market are already doing so. But unless the lack of scientific understanding about the risks presented by some manufactured free nanoparticles are addressed as a priority, consumers won't be able to appreciate these benefits, and neither will the researchers and companies developing them."

Their assessment resulted in a ten point action plan based on its view that "The Government has to take a more responsible approach and act on the advice it has received". The ten point action plan was:

CO-ORDINATION
Establishing a strategic stakeholder group to ensure there is effective input from all sectors of society and that the necessary measures are implemented and progress monitored.

DEFINITIONS
Ensuring there are agreed definitions for nanotechnologies.

PRODUCTS
Understanding what products are already on the market, in the pipeline or at the research stage and identifying those likely to raise most concerns based on current understanding.

RESEARCH
Increasing funding and ensuring the uncertainties around the environmental and health risks presented by some manufactured nanomaterials are urgently addressed.

ASSESSMENT
Providing clarity over how the safety of nanomaterials should be assessed given the current knowledge gaps.

PRECAUTION
Applying the precautionary principle to products where there are potential risks, but where it is not currently possible to assess their safety, so that consumers are not put at risk.

TRANSPARENCY
Ensuring there is openness about the uncertainties that some nanomaterials may raise and the research underpinning safety assessments as well as claims about potential benefits.

REGULATION
Addressing the loopholes in regulations so that nanomaterials are included and there is clear guidance on how the regulations apply.

INFORMATION
Ensuring consumers, industry and regulators have clear information about where nanomaterials are being used and that any claims they make are true.

ENGAGEMENT
Involving the public in meaningful discussions about the development of the technology, priority applications and any no-go areas.

However, it should be noted that this report is centred on consumer interest and may not engage the wider interest of an industrial society.

13.4. Measurements and Standards

The UK is particularly well placed with regards to Measurements and Standards. The National Physical Laboratory (NPL), the UK's National Measurement Institute, has long been regarded as outstanding in the field of metrology. Recent advances in precision engineering, optics, electronics, materials technology and molecular biology have placed increasing demands on nanometrology – the measurement of dimensions or tolerances below 1 micron. To cater for this NPL is currently engaged in research to improve metrology at the nano level which builds on a number of instruments previously developed at NPL. Work is split into nanodimensional research and nanodimensional products and services, the latter focussing on materials testing at the nanoscale as well as development of novel instruments and measurement techniques.

Within the UK MNT Capital Facilities set up in 2005, there are two NanoMetrology Facilities. These are CEMMNT, based in Loughborough and BegbrokeNano, based at the University of Oxford. CEMMNT offers measurement, characterisation, analysis and systems engineering services from single analysis to bespoke R&D solutions by acting as a broker or interface between a customer company requiring such services and suitable service provider(s). BegbrokeNano, on the other hand provides an onsite comprehensive range of materials characterisation services and materials consultancy and has at its disposal state of the art equipment capable of providing bulk analysis, surface analysis and particle analysis.

British Standards Institution (BSI) in the UK is playing a key role in leading the development of nanotechnology standards through its national committee NTI/1 "Nanotechnologies" and the UK holds both the chair and secretariat of ISO TC/229 "Nanotechnologies" and CEN/TC352 "Nanotechnologies". Through these committees and through participation in IEC/TC113 "Nanotechnology standardisation for electrical and electronic products and systems", the UK will be able to support this emerging discipline and use standardisation to help ensure its safe global development and growth.

As part of BSI's work on nanotechnology, a series of Publicly Available Specifications (PAS) has been prepared on nanotechnology terminologies and these are available free from the BSI website. There are seven in total as follows:

- PAS 71 Vocabulary. Nanoparticles
- PAS 131 Terminology for medical, health and personal care applications of nanotechnologies
- PAS 132 Terminology for the bio-nano interface
- PAS 133 Terminology for nanoscale measurement and instrumentation
- PAS 134 Terminology for carbon nanostructures
- PAS 135 Terminology for nanofabrication
- PAS 136 Terminology for nanomaterials

Additionally, one further Publicly Available Specification and two other BSI documents support the commercialisation of nanotechnology. These are:

- PAS 130 Guidance on labelling of manufactured nanoparticles and products containing manufactured nanoparticles
- PD 6699-1 Guide to specifying nanomaterials
- PD 6699-2 Guide to safe handling and disposal of manufactured nanomaterials

Ensuring the language of Measurements and Standards is appropriate for industry and academia alike provides the basis for full and proper studies to be undertaken in fields as diverse as engineering and toxicology. Having the UK at the heart of the development of standards for nanotechnology is extremely important for the UK to be seen as a major force in nanotechnology as well as providing the common basis for development and testing of nanotechnology based products. Ensuring ongoing funding is available to maintain and reinforce this role is therefore fundamental to ensuring the UK's strengths in Standards and Measurements are sustained.

Continued support for the UK's leadership of standardisation for nanotechnologies will mean the UK will maintain its position at the cutting edge of technical and commercial developments in the area, despite a significantly lower national spend on nanotechnologies than its principal competitors. This leadership role will help secure critical opportunities to compete effectively in an increasingly aggressive global market.

13.5. Health and Safety

13.5.1. OVERVIEW

Humans have been exposed to nanoparticles for millennia, including natural and anthropogenic nanoparticles, and have been able to respond to these nanoparticles by developing mechanisms to ensure no significant damage to health results from exposure to them, but some humans are more sensitive to these nanoparticles than others.

Engineered nanoparticles are now available and humans can be exposed to them under specific circumstances. Existing response mechanisms can be considered to be similarly effective against them, but there is a need to consider the chemistry and physical form of these engineered nanomaterials and conduct risk assessments for them considering both hazard and exposure, the latter being a function of manufacture, use and disposal of both the nanomaterials and the product comprising the nanomaterials.

Focus can then be on managing the risk based on real data and decisions can be taken on the basis of a full risk-benefit analysis as to whether a given nanomaterial should be manufactured and used for a particular application. Exposure limits can also be imposed based on the data generated.

Three routes of potential access to the body should be considered as part of this risk assessment i.e. inhalation, ingestion and skin penetration. There has been little work done on ingestion. The bulk of the work on skin penetration concludes that nanoparticles do not penetrate intact skin[34].

Inhalation studies dominate the literature where it is clear that where there are effects, they are not generic to nanomaterials - both chemical and physical characteristics of the nanomaterials have to be considered. This applies to both nanoparticles and nanofibres, the aspect ratio of the latter recently being shown to be a significant issue[35].

A similar approach should be taken regarding potential environmental effects of nanomaterials i.e. a full risk assessment should be considered taking account of both hazard and exposure for nanoparticles and the products that might contain nanoparticles.

The use of nanomaterials to access specific sites in the body either for them to be activated in their own right or to act as carriers for active species generally requires a coating or other attached molecule to facilitate penetration through cell walls or across membrane barriers. Thus, direct comparison between 'naked' nanoparticles and 'nanomedicinal particles' may not be relevant.

The UK has a number of experts who have studied the human and environmental effects of nanomaterials and have published extensively. However, there is still a lack of interaction between academic research and test programmes and industrial development of nanomaterials based products. To produce conclusive and valued risk assessments, more effective and focused collaboration is required in the future.

13.5.2 FUNDING FOR SAFE IMPLEMENTATION

There remains more work to be done to ensure safe practices in the use, manufacture and disposal of nanomaterials and nanomaterial products as is the case with all materials. The most important gaps have been identified in recent Defra reports[36].

Government has stated that the *"the identification of applied research on the more immediate issues of the exposure of people and the environment to nanomaterials is the responsibility of Government Departments and the regulatory authorities that have an understanding of the sectors of industry with which they deal"*[37].

Total funding for toxicology, health and safety and environmental by the Department for Trade and Industry (DTI) over the period 2002-2007 was £3M – contrasting with around £40M per annum of EPSRC funding as responsive mode research grants in nanotechnologies, £19.8M interdisciplinary research by EPSRC, BBSRC, and the MRC, and the £90M DTI investment over six years on research and infrastructure to promote commercialisation.

Part of the picture that emerges is insufficient coordination of work across Government departments although there is piecemeal collaboration (e.g. the Environmental Nanoscience Initiative (ENI) funded by Defra, NERC and the Environment Agency).

Connecting the work of NRCG more directly to research funding is one possible mechanism for appropriate direction of available research funding but this is only possible if NRCG is adequately resourced.

13.5.3 INTERNATIONAL EFFORTS

The UK is very proactive at an international level, having set up and chaired ISO/TC 229, the ISO standards committee on nanotechnologies, as well as participating in NSF international meetings and setting up European level meetings.

A high level of activity is now underway through the OECD, with eight projects underway to address EHS themes. These are:

1. OECD Database on Safety Research.
2. Research Strategies on Manufactured Nanomaterials.
3. Safety Testing of a Representative Set of Manufactured Nanomaterials.
4. Manufactured Nanomaterials and Test Guidelines.
5. Cooperation on Voluntary Schemes and Regulatory Programmes.
6. Cooperation on Risk Assessment.
7. Alternative Methods in Nanotoxicology.
8. Exposure Measurement and Exposure Mitigation.

Some 14 nanomaterials have been selected for study at present.

The UK is on the steering group for five of the eight topic themes including safety testing, also leading the project for cooperation on risk assessments and exposure measurements. A good example of the UK leading and benefiting from international collaboration is the LINK project on cerium and zinc oxide nanomaterials.

Examples of European collaborative projects supporting the theme include:

- Nanosafe2 (£8.3M), which sought to develop risk assessment and management for secure industrial production.
- Nanosh (total budget £27M), as a multi-centre European research initiative focused on occupational exposure to nanoparticles and the impact on health.

The UK contribution to these two projects totals £643K, illustrating the benefit of participating in collaborations of this type.

13.5.4 GOVERNMENT POSITION

The HSE guidance is specific. It states that anybody undertaking a risk assessment related to nanotechnology should, in the absence of any other evidence, assume that the nanoparticle or fibre is at least as harmful as larger particles and may be more harmful.

HSE concluded that the current work undertaken and the resource provided for policy development and health and safety interventions are adequate to ensure the continuing engagement of the issues raised by the various monitoring organisation, and that the Government is working to maintain and improve health and safety standards associated with nanotechnologies.

The UK Government, in its written response[38] of February 2005 to the Royal Society's recommendation, states in paragraph 44 thus:

"We are supportive of the precautionary stance taken by the Royal Society and Royal Academy of Engineering in their Report. Given the uncertainty associated with risks to the environment from release of free manufactured nanoparticles and nanotubes, the report asks industry to reduce or remove these from waste streams. We support this recommendation and will, with other stakeholders (including Local Authorities), work in partnership with industry, to help implement it".

Given that the UK, through its Government agencies, is at the forefront of occupational health management and environmental responsibility, nanomaterials production, use and disposal are managed in accordance with legal constraints imposed by these agencies.

13.5.5 IMPLICATIONS FOR INSURANCE

The trade off of benefits against risks is reflected in increasing facilities investment and research funding in order to understand the risk.

The Swiss Re report[39] distinguished between traditional insurance risks – which are evolutionary - and disruptive or revolutionary risks, as seems to be the case with nanotechnologies because of the lack of long term data to support insurance provisions.

A comparison was offered with hazards from the asbestos industry, given the many similarities. Asbestos has been widely used for over a hundred years, and although isolated studies had shown that there was a potential risk and that the form and size of the fibres could cause mesothelioma, regulations and protective measures were only introduced after patients all over the world had fallen incurably ill. The true extent of the damage could not be foreseen even approximately in the absence of long term experience. Despite the early evidence of the danger of asbestos exposure, it took approximately one hundred years to introduce internationally accepted standards.

The danger for the insurance industry is that exposure to nanoparticles represents a potential chronic, rather than an acute health hazard and that it might be some time before it manifests itself. This is the real risk for insurers, and the comparison with asbestos should be seen in this light.

The strategy for establishing occupation exposure limits is already well established. The proposed risk assessment procedures will help allay the fears expressed by the insurance industry as this will bridge the gap between unknown (and hence uninsurable) risk and known risk, which can be managed by the insurance industry.

Acknowledgments

The secretariat would like to thank all the contributors to the questionnaire and colleagues in the Nanotechnology KTN, the Materials KTN, the Chemistry Innovation KTN and the Sensors and Instrumentation KTN for their extremely valuable input to this report. Thanks also go to the members of the Steering and Review Group whose contributions to the final document have been very helpful. Finally, thanks go to members of the Department for Business, Innovation and Skills for their help and advice throughout this process.

List of Tables and Figures

Table 1
Estimated public sector funding for nanotechnology R&D in 2008.

Table 2
Corporate funding for nanotechnology.

Table 3
Estimated Government support for nanotechnology.

Table 4
Principal academic funding from EPSRC for nanotechnology (2008 data).

Table 5
Summary of markets impacted by nanoscale technologies - $million.

Table 6
TRL Levels for technology themes.

Table 7
Summary of technologies within market sector areas[3].

Figure 1
Classification of respondents to questionnaire.

Figure 2
Breakdown of the sales based on nanotechnology enabled products.

Figure 3
Breakdown of the time companies had been involved with nanotechnology.

Figure 4
UK Nanomaterials Companies by Activity.

Figure 5
UK Nanotechnology Support Infrastructure Companies by Activity.

Figure 6
Market Application Focus of UK Nanotechnology Companies.

Figure 7
Nanotechnology market opportunity.

Figure 8
Geographical representation of the 23 MNT Centres in the UK.

Figure 9
SWOT analysis of UK nanotechnology capability.

Glossary

ASTM	American Standards and Test Methods
BBSRC	Biotechnology and Biological Sciences Research Council
BIS	Department for Business, Innovation and Skills
BSI	The British Standards Institution
CEN	European Committee for Standardization
DA	Devolved Administrations
Defra	Department for Environment, Food and Rural Affairs
DIUS	The former Department for Innovation, Universities and Skills
DTI	The former Department for Trade and Industry
EA	Environment Agency
EC	European Commission
EHS	Environmental Health & Safety
ENI	Environmental Nanoscience Initiative
EPA	Environmental Protection Agency
EPES	Electronics, Photonics and Electrical Systems
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
FP	Framework Programme
HSE	Health and Safety Executive
ICT	Information and Communication Technology
IRC	Interdisciplinary Research Centre
ISO	International Standards Organisation
KTN	Knowledge Transfer Network
KTP	Knowledge Transfer Partnership
MEMS	Micro-electro Mechanical Systems
MNT	Micro and Nano Technologies
MoD	Ministry of Defence
MRC	Medical Research Council
MRI	Medical Research Institute
NEMS	Nano-electro Mechanical Systems
NERC	Natural Environment Research Council
NGO	Non-Governmental Organisation
NPL	National Physical Laboratory
NRCG	Nanotechnology Research Coordination Group
NSF	National Science Foundation
OECD	Organisation for Economic Cooperation and Development
PD	Professional Development
RCEP	Royal Commission on Environmental Pollution
RDA	Regional Development Agency
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SME	Small or Medium sized Enterprise
STEM	Science, Technology, Engineering and Mathematics
SWOT	Strengths, Weaknesses, Opportunities, Threats
TRL	Technology Readiness Level
TSB	Technology Strategy Board
UKTI	UK Trade and Investment
VRS	Voluntary Reporting Scheme

Appendices

APPENDIX 1
BACKGROUND

Nanotechnology became an area of technology of note in the 1990s and grew in importance with developments within university departments spun out as the basis for new companies. Prior to this explosion in the commercialisation of nanotechnology, nanomaterials had been manufactured and used over a number of years. They had been called ultrafine and superfine particles and materials such as carbon black and fumed silica had found their way into many products to provide reinforcement with producers of rubber vehicle tyres and plastics goods the major users of these materials.

Following this period, Lord Sainsbury, Minister for Science and Innovation commissioned a report on Nanotechnology from Dr John Taylor, Chairman of the Advisory Group on Nanotechnology Applications. Dr Taylor was Director General of the Research Councils, Office of Science and Technology.

It was concluded in this report2, later referred to as the "Taylor Report" that the major obstacles to achieving the success believed to be possible over the next few years for nanotechnology applications in the UK were:

- The lack of a stable, visible and coordinated strategy for public support for nanotechnology applications in industry.
- Fragmentation and lack of critical mass in UK R&D activities, and a mismatch between our research and industrial capabilities.
- Absence of a level playing field for Government support in international competition.
- Lack of appropriate technology access and business incubation facilities
- Access to skilled people – training and recruitment.
- Recommendations for Government action to address these issues focussed on:
- National nanotechnology application strategy.
- National nanotechnology fabrication centres.
- Nanotechnology roadmaps.
- Awareness and networking.
- Training and education.
- International – promotion and inwards transfer.

It was also recommended that the UK should develop and articulate a coherent and coordinated strategy for accelerating the application of nanotechnology as widely as possible across the economy, beginning with those areas highlighted in the report. It was further recommended that the strategy should be overseen by an independent steering group from industry, Research Councils UK and Government, referred to here as the UK Nanotechnology Applications Strategy Board or NASB and should be set up by the autumn of 2002.

Taylor concluded:

"We believe that the field of nanotechnology and its applications is crucial to the future competitiveness and productivity of the UK economy, and to the well being and prosperity of its people. We hope that the Government will take forward these recommendations with urgency and we are confident the research community will be ready to play a full part in their implementation."

A major part of the UK's micro and nano-technology infrastructure is the 23 Micro and Nanotechnology (MNT) Capital Facilities that were set up by the Government during the period 2003-2007.

The Science and Technology Committee of the House of Commons produced a report[40] in 2004 focussed on nanotechnology which included the following observations:

"The commercialisation of nanotechnology research in the UK in many ways presents a depressingly familiar picture of excellent research that is not being translated to the country's commercial benefit to the same extent as it is in other competitor countries. The story is all the more dispiriting because the UK was recognised to be ahead of the game when a nanotechnology research programme was started in the mid-1980s. The DTI and the scientific community lacked the foresight and leadership to drive forward this advantage. A commercially valuable trick was missed. The benefits of nanotechnology were too uncertain and far off for industry to get involved without Government stimulation of interest and help with the provision of expensive facilities. The DTI belatedly commissioned an advisory group to develop a commercialisation strategy, but cast aside the main tenets of the subsequent recommendations in the Taylor Report."

"Instead of taking a lead on nanotechnology, the DTI has followed on microtechnology. We believe that the £90M could have been better spent. The DTI has chosen to develop, not a focussed strategy for nanotechnology commercialisation and applied research, but funding streams that are likely to be based upon existing microtechnology research and facilities that are dispersed around the country. This strategy has evolved in order to meet the short term interests of the RDAs which are providing a large proportion of the financial muscle. It is a muddled strategy that seeks to reconcile the conflicting long term interests of the DTI's science and innovation policy with the development of regional policy. In respect of the commercialisation of nanotechnology, the conflation of the two policies has served to undermine the UK's position. If the involvement of the RDAs is envisaged as a template for innovation in other sectors, a better way of resolving this fundamental conflict needs to be found."

"It is not too late for the DTI to take steps to avoid the UK falling further behind our major competitors. The MNT Manufacturing Initiative needs to be given strong leadership and a sense of direction, with the right facilities to support nanotechnology research and development in areas in which the UK can make an impact. A skills strategy to provide the people required to support these facilities and industry will need to be co-ordinated between the Research Councils, the DTI and the universities. Even with the availability of the right facilities and people, companies using and exploiting nanotechnology need, like any others, the right incentives to persuade them to operate in the UK. Recent measures taken by both the DTI and the Treasury should improve the prospects for innovation, but a slow warming of the innovation climate will not be sufficient to make the UK the recognised stronghold for nanotechnology that it should now be."

Lord Sainsbury also requested in 2003 that the Royal Society and the Royal Academy of Engineering review the position on nanotechnology and a report was duly commissioned. This report[41], which became a seminal document quoted by many authorities across the world, was published in July 2004.

A total of 21 recommendations were made under the following headings:

- The industrial application of nanotechnologies.
- Possible adverse health, safety and environmental impacts.
- Regulatory issues.
- Social and ethical issues.
- Stakeholder and public dialogue.
- Ensuring the responsible development of nanotechnologies.

The Government published a Response to this report in February 2005 with individual responses to the specific recommendations in the original report together with an Overall Response. Further reviews by Government bodies including the Council for Science and Technology[42] have considered the actions by the Government following the publication of this Response.

In November 2005 Defra published a report [36] called "Characterising the Potential Risks posed by Engineered Nanoparticles". This report set out a programme of research objectives to characterise the potential risks posed by nanoparticles and to describe ongoing activities and funding mechanisms to address these priorities. It proposed that it would lead to the development of an appropriate framework and measures for controlling any unacceptable risks.

Three key areas were identified where further research was needed to develop a risk management framework for nanoparticles:

- Properties, characterisation and metrology, including standardisation.
- Human and environmental exposure.
- Hazard to human health and the environment.

Understanding the societal and ethical dimensions of nanotechnologies as they arise was also considered important. Overarching this was a need for the development of an international agreement on nomenclature and definitions.

Since the publication of the Royal Society and Royal Academy of Engineering report, the Nanotechnology Research Co-ordination Group (NRCG), the Government's dedicated vehicle for co-ordinating work in this area was set up and has made significant progress in developing a fit for purpose programme of research to enable Government to understand and manage the potential risks posed by nanoparticles. In this first report, an initial set of research objectives and funding opportunities were outlined.

In the wake of this, Defra, following consultation with, inter alia members of the Nanotechnologies Stakeholder Forum, developed and defined a Voluntary Reporting Scheme for engineered nanoscale materials[43].

The option recommended was to pursue a voluntary approach with a longer term goal of appropriate controls. Given the uncertainty over risk Defra believed that this low cost approach was appropriately precautionary, but did allow Government to develop the evidence base on the uses, producers, importers and users. It would also allow for a profile of nanomaterials to be developed that could later be applied to data as it was generated. Should it become clear that a certain feature of a nanomaterial was of concern it would allow Government to rapidly locate sources, understand exposure, environmental fate and measurement techniques and consider what action may be appropriate.

While the Voluntary Reporting Scheme (VRS) was becoming established, a report was produced for the DTI by the ESRC Centre for Business Relationships Accountability Sustainability and Society (BRASS)[44].

This report represented an analysis of the potential gaps in the regulation of the development, manufacture, supply, use and end of life of free engineered nanoparticles. In the report current and future foreseeable applications of nanomaterials were mapped against regulatory frameworks that might govern the lifecycle of these materials. These regulations served a number of purposes including controls on marketing, health and safety, consumer and environmental protection and waste regulation.

Reviewing these types of legislation, the report found potential gaps where thresholds were set to govern whether materials or products fell within regulation. Many of the gaps identified in this report arose due to a lack of existing data on the potential effects of nanomaterials on human health and the environment. If nothing else, this report demonstrated how effective regulation would depend on moving to a position of greater certainty on such questions. Even where risk assessment procedures established under existing regulatory frameworks appeared robust, it was noted that their ability to accurately characterise and assess potential risks associated with nanotechnologies was limited by fundamental uncertainties about the impact of exposure to free, engineered nanomaterials. It was said that better research and better regulation ought to move hand in hand.

The Royal Society and Royal Academy of Engineering report was highly influential internationally and led to the UK being seen as a world leader in its engagement with nanotechnologies. However, the clear message in 2006 was that the UK was losing that leading position and falling behind in its engagement with this fast developing field, primarily due to a distinct lack of Government activity or funding research into toxicology, health and environmental effects of nanomaterials.

The Council for Science and Technology (CST) was commissioned to review Government's progress against its policy commitments based on the recommendations outlined in the Royal Society (RS) and Royal Academy of Engineering (RAEng) report.

Recommendations were made on areas including the following:

- Coordination and Review.
- Research Funding Methods.
- Nanotechnology Research Coordination Group (NRCG).

- Research Priorities.
- International Engagement.
- The Interface with Industry.
- Regulation.
- Voluntary Reporting Scheme (VRS).
- Public Engagement.

The CST report[42] concluded that although there had been good progress on many commitments the lack of research and the uncertainties that still surrounded many issues to do with nanotechnologies – particularly long term environmental fate, health and environmental impacts and metrology, standards and detection – threatened to undermine the UK's good work in other areas. The Government was widely commended for its foresight in commissioning the landmark RS/RAEng report and at that time it was felt that the UK enjoyed a leading position in its engagement with nanotechnologies. It was now widely believed – by stakeholders from industry, academia, learned societies and NGOs – that the UK had lost that leading position, though it had not slipped so far that swift and determined action could not regain it.

In contrast to these reports a report was commissioned by Defra with the title Environmentally Beneficial Nanotechnologies: Barriers and Opportunities . The purpose of this Defra commissioned study was to provide an overview of the areas where nanotechnology could have a beneficial environmental impact above current technology and the barriers preventing its adoption. Green house gas reduction was taken as the major factor in targeting environmentally beneficial nanotechnologies. Five nanotechnological applications were subject to detailed investigation; fuel additives, solar cells, the hydrogen economy, batteries and insulation.

Recommendations were made for each of these areas although it is not clear whether Government funding has been specifically provided following the publication of this report to invest in the areas identified.

The second UK Government Research Report [36] on Characterising the Risks posed by Engineered Nanoparticles was published in December 2007 and built on the 2006 publication, providing an update on the NRCG's objectives and associated programme of work. It set out an updated approach for funding additional research and placed UK activities in an international context. It also responded to recommendations made by the Council for Science and Technology Review published in March 2007 of the UK research programme which was instigated following publication of the Royal Society and Royal Academy of Engineering Report "*Nanoscience and Nanotechnologies: Opportunities and Uncertainties*".

The five task forces, set up to take forward the work of the NRCG, had benefited from a broader range of membership, and they now included representatives from industry and additional members from the academic community. Unfortunately the task forces were not financially resourced. This report covered the activities of the five task forces and progress on their action plans set out in the 2006 report to meet the 19 objectives from the Royal Society and Royal Academy of Engineering report.

The second research report provided an update on the activities carried out to date and highlighted key priorities to be taken forward in the future. Significant progress had already been made, both within the UK and internationally, but research programmes were generally still in their infancy and it would be a while before concrete data would be available upon which to base an appropriate appraisal of the potential risks posed by manufactured nanoparticles.

A further report[46] was prepared by the Royal Commission on Environmental Pollution and the aim of this report was to provide a framework for thinking about and addressing concerns about the impact of novel materials. Consideration was given to what arrangements would be most appropriate for the governance of emerging technologies under two conditions that pose serious constraints on the regulator. First was the condition of ignorance about the possible environmental impacts in the absence of any kind of track record for the technologies. Second was the condition of ubiquity – the fact that new technologies no longer develop in a context of local experimentation but emerge as globally pervasive systems – which challenges both trial and error learning and attempts at national regulation.

Both new governance approaches and modifications to existing ones are likely to be called for. They will need to be rooted in ideas of adaptive management that require multiple perspectives on the issues. In the meantime, it was emphasised that it makes little sense to frame the governance challenges in terms of whether industry, Government or citizens should be "for" or "against" nanomaterials or any other kinds of novel materials. It is the functionality of the material, not particle size or mode of production, which is critical for evaluating its potential impact on the environment or human health.

Their recommendations reflected three main priorities, namely:

- Functionality.
- Information.
- Adaptive management.

These issues underlie specific recommendations under two main headings, i.e. Environmental and Health Impacts and Governance.

The Government also responded to this Report and its conclusions [28] were as follows:

a) The Government's over-arching aim for nanotechnologies is to realise the potentially significant benefits to human and environmental health as well as the wider economy, but in a way that appropriately controls potential risks.

b) The Government will develop an approach that has the protection of human and environmental health at the heart of its agenda

c) The Government will continue to ensure an integrated and co-ordinated approach to nanotechnology.

d) The Ministerial Group on Nanotechnologies will continue to provide the strategic lead in this area, with input from relevant groups.

e) The continued development of the evidence base is important.

f) The Government will continue to support the research programme at both the domestic and international level.

g) The Government will continue to work collaboratively with international partners to deliver more effective management.

h) The Government intends to widen public engagement and capture the benefits.

i) In order to realise these commitments, the Government intends to launch an evidence gathering exercise with stakeholders in the summer of 2009 to inform the development of a UK strategy for nanotechnologies.

A chronological summary of these reports is below:

Report title	Authored by	Date
New Dimensions for Manufacturing, A UK Strategy for Nanotechnology Report of the UK Advisory Group on Nanotechnology Applications	Submitted to Lord Sainsbury, Minister for Science and Innovation by Dr John M Taylor, Chairman	June 2002
Proceedings of the Science and Technology Committee- Fifth Report	House of Commons Science and Technology Committee	March 2004
Nanoscience and nanotechnologies: opportunities and uncertainties.	Report by Royal Society and the Royal Academy of Engineering	July 2004
Response to the Royal Society and Royal Academy of Engineering Report: Nanoscience and nanotechnologies: opportunities and uncertainties	UK Government	February 2005
Characterising the Potential Risks posed by Engineered Nanoparticles	A First UK Government Research Report from Defra	November 2005
Consultation on a proposed Voluntary Reporting Scheme for engineered nanoscale materials	Defra	March 2006
An Overview of the Framework of Current Regulation affecting the Development and Marketing of Nanomaterials. A Report for the DTI	ESRC Centre for Business Relationships, Accountability, Sustainability and Society	December 2006
Nanosciences and Nanotechnologies: A Review of Government's Progress on its Policy Commitments	Council for Science and Technology	March 2007
Environmentally Beneficial Nanotechnologies: Barriers and Opportunities A report for Defra	Oakdene Hollins	May 2007
Characterising the potential Risks posed by Engineered Nanoparticles.	A Second UK Government Research Report from Defra	December 2007
Novel Materials in the Environment: The case of nanotechnology	Royal Commission on Environmental Pollution	November 2008
Response to The Royal Commission on Environmental Pollution (RCEP) Report "Novel Materials in the Environment: The Case for Nanotechnology",	UK Government	June 2009

APPENDIX 2
NATIONAL STRATEGIES

USA

In 2001 the Clinton Administration raised nanoscale science and technology to the level of a federal initiative, officially referring to it as a National Nanotechnology Initiative (NNI). The goals of this Initiative were to:

- Advance a world class nanotechnology research and development program.
- 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.
- Support responsible development of nanotechnology.

The NNI is ultimately the responsibility of the Executive Office of the President of the United States of America, National Science and Technology Council. The National Nanotechnology Coordination Office (NNCO) provides technical and administrative support for the NNI.

There are 25 participating agencies in the NNI ranging from the Department of Defense and NASA to the Department of Education. The first Strategic Plan[47] was published in December 2004 with an update[48] published in December 2007.

JAPAN

The Japanese Government set the goal of *"becoming an advanced science and technology oriented nation"* as a national strategy and as a result, the Science and Technology Basic Law was enacted. Under this law, a comprehensive range of measures has been developed and set out in the Science and Technology Basic Plan. The 3rd Basic Plan[49] covers the period FY2006 to FY2010. The bureau of Science and Technology in the Cabinet Office of the Government of Japan is responsible for the development of these plans.

The 3rd Basic Plan has identified "four priority fields to be promoted", these are:

- Life sciences.
- Information and telecommunications.
- Environmental sciences.
- Nanotechnology/materials.

and funds are preferentially allocated to these four areas. There is not however a strategy that is focussed particularly on nanotechnology.

GERMANY

The German Government launched its High Tech Strategy[50] in 2006. It deemed nanotechnology to be cross-sectoral and underpinning and, as a result, was granted "special status". The outcome of this was the nano-initiative supported by the Action Plan 2010 document[51].

Nano-initiative is the responsibility of the Federal Ministry of Education and Research, but also has the involvement of:

- Federal Ministry of Labour and Social Affairs.
- Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.
- Federal Ministry of Food, Agriculture and Consumer Protection.
- Federal Ministry of Defence.
- Federal Ministry of Health.
- Federal Ministry of Economics and Technology.

The Government's Action Plan 2010 constitutes a list of measures for meeting the challenges that arise when attempting to successfully exploit the benefits of nanotechnology. These are categorised under 5 key themes:

- Opening up future markets – introducing new sectors.
- Improving general conditions.
- Behaving in a responsible manner.
- Informing the public.
- Identifying the future demand for research.

FRANCE

The National Nanosciences Programme[52] was launched in 2001 by the Ministere de la Recherche with the Centre National de la Recherche Scientifique (CNRS), the Commissariat a L'Energie Atomique (CEA) and the Delegation Generale a L'Armament (DGA).

Since 2005, this programme called PNANO – Programme en Nanosciences et Nanotechnologies – is managed by the Agence Nationale de la Recherche (ANR) and aims to coordinate and develop fundamental research in nanosciences. There are six main themes under which projects are undertaken:

- Effects and phenomena at nanoscale dimensions.
- New materials and fabrication techniques.
- Micro-nano devices and micro-nano systems.
- Instrumentation, modelling and simulation.
- Converging nanotechnologies – medicine and nanotechnology, environmental sciences and nanotechnology.
- Societal and regulatory impacts.

EUROPEAN UNION

While individual countries may have national strategies for nanotechnology, the CEC published a document in 2004 called Towards a European Strategy for Nanotechnology[53].

This document proposed actions as part of an integrated approach to maintain and strengthen European R&D in nanosciences and nanotechnologies. It considered the issues that were important to ensure the creation and exploitation of the knowledge generated via R&D for the benefit of society.

The debate was launched to consider how to:

- Increase investment and coordination of R&D to reinforce the industrial application of nanotechnologies.
- Develop a world-class competitive R&D infrastructure.
- Promote the interdisciplinary education and training of research personnel.
- Ensure favourable conditions for technology transfer.
- Integrate societal considerations into the R&D process at an early stage.
- Address any potential public health, safety, environmental and consumer risks upfront.
- Complement the above actions with appropriate cooperation and initiatives at international level.

TAIWAN

The National Science and Technology Programme for Nanoscience and Nanotechnology is a six year national programme which started in 2003 to develop nanotechnology in Taiwan. This US$700M programme is aimed at industrialisation of nanotechnology with over 60% of the funding for industry with the remaining funds for academic research, R&D facilities and human resource development.

The programme consists of eight working groups including four execution groups and four R&D programmes namely:

- Academic Excellence Research Programme.
- Nanotechnology Industrialisation Programme.
- Core Facilities Programme.
- Education Programme.

The Taiwanese Government encourages a high degree of interaction between Government, industry and academia. The National Programme is overseen by a steering committee, consisting of representatives from the National Science Council, other Government officials and industry leaders.

SWITZERLAND

Switzerland is acknowledged to be one of the European leaders of innovation and scientific advancement in nanotechnology ahead of the US and other European countries on both nanotechnology publications and patents. Nanotechnology research is pursued as a result of the long Swiss academic and industrial tradition of miniaturisation in micro technology. Nanotechnology in Switzerland is now finding applications in the life sciences, material science, chemical engineering and manufacturing.

RUSSIA

At the recent Rusnano meeting in Moscow, President Medvedev announced a nanotechnology funding programme amounting to $3.95B earmarked until 2015[8]. This was noted as being the largest funding programme in the world and that new innovations were expected to be created by small and mid-sized businesses. Changes to the tax system and to training were highlighted as being important to ensure effective use of the investment.

SOUTH AFRICA

A document entitled The National Nanotechnology Strategy[4] has been published by the Department of Science and Technology of the Republic of South Africa. The main objectives of the strategy are to:

- Support long-term nanoscience research that will lead to the fundamental understanding of the design, synthesis, characterisation, modelling and fabrication for nanomaterials.
- Support the creation of new and novel devices for application in various areas.
- Develop the required resources, both human and supporting infrastructure, to allow development.
- Stimulate new developments in technology missions, such as advanced materials for advanced manufacturing, nano-bio materials for biotechnology, precious metal bases nanoparticles for resource based industries and advanced materials for information and communication technologies.

The strategy proposes the establishment of nanotechnology characterisation centres, research and innovation networks, a capacity building programme and a flagship project programme.

CHINA

China is one of the most productive countries in terms of publications citing nanotechnology. China has focused on fast adoption of nanotechnologies. This is in line with their approach to *"take the lead in nanotechnology and nanoscience, just by getting on with it while Europe hesitates due to safety legislation and the US holds back in being unsure where to direct the funds"* [55].

APPENDIX 3
NANOMATERIALS

CARBON BLACK

The use of carbon black as a reinforcement for wear improvement in rubber and plastics is well known. At a market size of 9.6 million tonnes in 2008, with some two thirds going into rubber for tyres, it is the largest market for nanomaterials by tonnage and value. Plastics, inks, paint and conductive filler are also large application areas and there is much R&D ongoing to increase market uptake here because of higher margins available compared with the car tyre market.

SILICA

World production of colloidal and fumed silicas is of the order of 500 and 170 kilo tonnes per year respectively. These materials go mostly into coated gloss finished papers and boards. Colloidal silicas are used in a wide range of papers – even newsprint and brown paper grades because of improved processibility and productivity that follows from this. New generation anionic sols lead to new applications in lightweight coated, super-calendered and recycled media.

Another mainstream application of colloidal silica driven by its behaviour as a nanomaterial is a high temperature binder for precision investment casting[56].

The drive to reduce solvents in paints leads to opportunities for fumed and colloidal silicas, especially in UV curing systems and powder coating systems.

Significant tonnages also go into chemical mechanical planarisation for polishing silicon for the semiconductor industry, and also optical surfaces. Colloidal silicas are also used as flocculation agents used in manufacturing, industrial and food manufacture, and water purification processes.

Further applications include coatings for metallurgical processing, fractionising of paper and card for improved handling, coating of plastic film for reducing blocking (self adhesion), improved printability, and increased strength of seam welds, anti-soil surfaces used in applications ranging from carpet cleaners to anti-soil treatments on fighter aircraft.

A further mainstream application is the use of colloidal silicas in reducing rock permeability to effect higher extraction levels in oil wells. Similar technologies are useful for isolating underground pollution and preventing spread into water supply.

Other materials and applications include the following[3]:

NANOPARTICLES

Nanoparticles are a predominant form of nanomaterial. Many of the applications are based on an extrapolation of functional benefits available with continuing reduction in particle dimensions.

Inorganic nanoparticles include metals such as aluminium, copper, nickel, cobalt, iron, silver and gold, and metal oxides such as titanium dioxide, zinc oxide, copper oxide, cerium oxide, zirconium oxide, aluminium oxide and nickel oxide, and clays and a specific subset of compounds known as quantum dots[57].

The applications arising include drug delivery, stain resistance in fabrics, antimicrobial silver, high density data storage, clear protective sunscreens, lubricants, hydraulic additives and catalysts (predating the "nano" culture).

Other niche applications include thermal fluids which can lead to enhanced heat transfer in critical cooling applications, and additions to boiler feedstock to improve nucleate boiling behaviours.

Nanosilver pastes, which are engineered to sinter at low temperatures, are being used in power electronics applications for die attach and also for some high temperature electronics applications.

NANOFIBRES

Applications for nanofibres include filtration and separation media. Electrospinning is gaining more attention as a process, and applications in energy storage and generation are envisaged.

QUANTUM DOTS

Control of particle dimensions in quantum dots leads to tuneable band gaps and thereby control of optical and electronic properties. This lends itself to emerging applications in electroluminescent displays, solid-state lighting, anti-counterfeiting and other security applications and some applications in healthcare diagnostics.

NANOCAPSULES

Nanocapsules can be used to deliver a functional payload in various ways. The payload can be fragrances, enzymes, catalysts, oils, adhesives, cells or drugs and this leads to applications in cosmetics, antifouling, and drug delivery in healthcare.

NANOWIRES

Nanowires of silicon, gallium nitride, germanium and indium phosphide are being developed to exploit their combination of electronic and magnetic characteristics which can be substantially different at the nano scale. These are being introduced into markets for high density data storage and electronics.

CARBON NANOTUBES

Carbon nanotubes (CNTs) have excited enormous interest for a range of applications. CNTs are hugely diverse in terms of structure and purity with applications segmenting according to quality, cost and composition.

When compounded in a matrix they can impart both mechanical and functional enhancement. The property enhancement available from single and multiwalled nanotubes drives various applications in aerospace and defence, many based on high strength polymers.

They are beginning to find market penetration in high-end sports goods. For example, Wilson produce a tennis racket reinforced with CNTs, Adidas now produce a running shoe incorporating a carbon nanotube reinforced plate. Apart from technical edge that such projects may deliver, the marketing appeal is itself of high commercial significance.

Nanotubes are also finding applications in electronics in interconnect and thermal management applications. CNT filled resins are being developed and tested for carbon fibre reinforced plastic (CFRP) composite wing structures to improve conductivity and hence reduce vulnerability to lightning strike damage. A related application is addition of CNTs to thermoplastic fuel lines to improve static charge dissipation behaviour.

If dispersion processes in manufacture are optimized, useful functional improvements can follow from low addition levels.

GRAPHENE

Graphene is a hexagonal array of SP2 bonded carbon with extremely high thermal and electrical conductivity. This is being intensively researched for high speed electronics switching with improved power efficiency compared to silicon, gas sensors, and also in atomically thin protective coatings.

CARBON FULLERENES

It should be noted that, although often included in lists of nanoparticles carbon fullerenes are actually molecules. There are however many applications for fullerenes (C_{60}) in energy storage systems including fuel cells, solar cells, batteries, flywheels and supercapacitors. Market values (2007) are quoted at $58.5M with growth in the $1-2B range by 2015[3].

NANOSTRUCTURED MATERIALS

Highly dispersed distributions of clays, e.g. bentonite and montmorillonite, in polymers deliver functional benefits based on improved stiffness, increased softening temperature, and improved fire resistance and enhanced oxygen barrier properties.

There is growing interest in metal organic frameworks, often referred to as *"molecular sponges"*; these are materials with controlled and functionalised pores with applications in gas storage, separation and catalysis.

COATINGS AND SURFACES

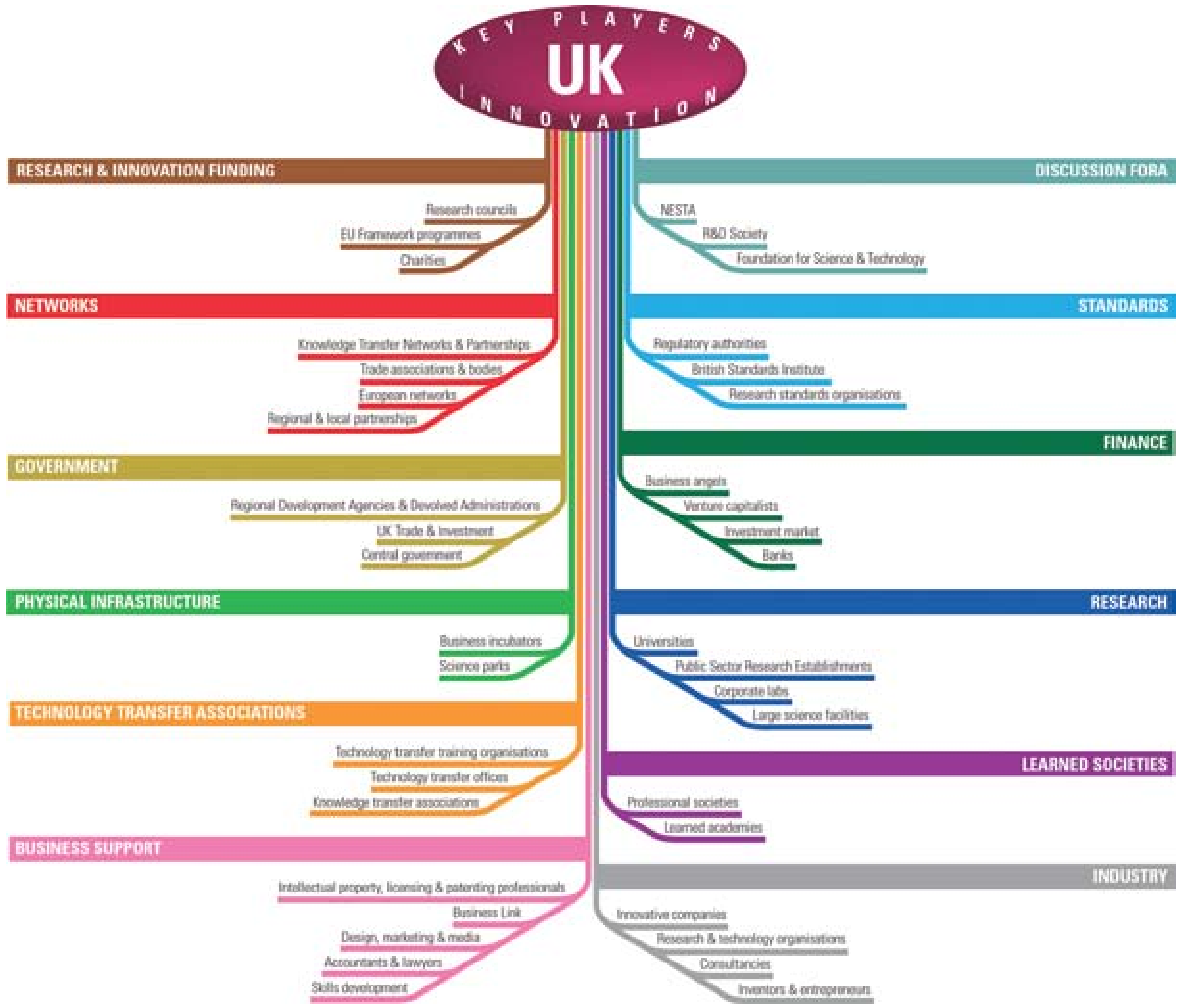
Many different types of coatings are based on nano-processes. Physical vapour deposition (PVD) processes for producing a hydrophobic surface for waterproofing are a good example. Sol gel process deliver scratch resistance, self healing surfaces, wear reduction, anticorrosion, and anti-microbial systems.

APPENDIX 4
CASE STUDIES

A number of relevant and interesting case studies have been reviewed and compiled and may be found on both the Nanotechnology KTN and the Materials KTN websites at:

www.nanoktn.com or www.materialsktn.net

APPENDIX 5
ORGANOGRAM OF GOVERNMENT PLAYERS



APPENDIX 6
RESPONSIBLE NANOCODE - SEVEN PRINCIPLES

PRINCIPLE ONE
BOARD ACCOUNTABILITY
Each organisation shall ensure that accountability for guiding and managing its involvement with nanotechnologies resides with the Board or is delegated to an appropriate senior executive or committee

PRINCIPLE TWO
TAKEHOLDER INVOLVEMENT
Each organisation shall identify its nanotechnology stakeholders, proactively engage with them and be responsive to their views

PRINCIPLE THREE
WORKER HEALTH AND SAFETY
Each organisation shall ensure high standards of occupational health and safety for its workers handling nanomaterials and nanoenabled products. It shall also consider occupational health and safety issues for workers at other stages of the product lifecycle

PRINCIPLE FOUR
PUBLIC HEALTH, SAFETY AND ENVIRONMENTAL RISKS
Each organisation shall carry out thorough risk assessments and minimise any potential public health, safety or environmental risks relating to its products using nanotechnologies. It shall also consider the public health, safety and environmental risks throughout the product lifecycle

PRINCIPLE FIVE
WIDER SOCIAL, ENVIRONMENTAL, HEALTH AND ETHICAL IMPLICATIONS AND IMPACTS
Each organisation shall consider and contribute to addressing the wider social, environmental, health and ethical implications and impacts of their involvement with nanotechnologies

PRINCIPLE SIX
ENGAGING WITH BUSINESS PARTNERS
Each organisation shall engage proactively, openly and co-operatively with partners to encourage and stimulate their adoption of the Code

PRINCIPLE SEVEN – TRANSPARENCY AND DISCLOSURE

Each organisation shall be open and transparent about its involvement with and management of nanotechnologies and report regularly and clearly on how it implements the Responsible NanoCode

APPENDIX 7
MICRO AND NANOTECHNOLOGY FACILITIES

Government investment in the MNT facilities equates to some £60M including additional significant investment from the UK Regional Development Agencies (RDAs) and industry. The aim of these facilities is to fill gaps identified within the UK MNT supply chain. Their remits are summarised below:

- Kelvin Nanotechnology Ltd (KNT) – Photonix - provides nanofabrication solutions, specialising in electron beam lithography.
- INEX - Contract development, manufacturing and commercialisation centre for specialist electronic devices, microsystems and nanotechnology.
- Laser Micromachining Centre - High quality laser micromachining services for prototyping and production of micro-nano products.
- MicroBridge Services Ltd - Offers micro and nano engineering and fabrication - engineers making things smaller.
- AML Bondcentre - Wafer bonding services: process development, bonding, WLP, 3D integration, MEMS and substrates.
- BegbrokeNano - A comprehensive range of materials characterisation services and materials consultancy.
- The Bio Nano Centre - Product development consultancy focusing on nanofabrication and characterisation using specialist instrumentation.
- EMINATE - Offers nanotechnology solutions in the healthcare sector for product development.
- SEME-MEMS - Open access facility for MEMS process / product development.
- NanoForce Technology Ltd - To exploit and disseminate nanotechnology to the creative industries and beyond.
- The Dolomite Centre - Advanced microfluidic systems and device design and fabrication solutions.
- Fluence - Support from idea to manufacture enabling products and processes using multifunctional microfluidics.
- CEMMNT - Measurement, characterisation, analytical and systems engineering services from single analyses to bespoke R&D solutions.
- MetaFAB - Product differentiation through micro nano technology convergence: specialism's in engineering microfluidics, laser micromachining, microseparations, fashionware.
- The Nanoscience Centre, University of Cambridge - State of the art clean-rooms and laboratories providing nanofabrication and characterisation facilities.
- BAE Systems ATC - provides open access to MEMS design and prototyping expertise.
- National Prototype Facility - Prototyping and processing services for novel devices in leading edge technologies.
- Centre for Micro & Nano Moulding - Volume manufacture of micro / nano scale components in polymers, metals and ceramics.
- Comina - Plasma manufacture (ca. 50g samples) of bespoke inorganic nanomaterials.
- SafeNano - The UK's premier site for information on nanotechnology health and safety.
- Materials Solutions - Laser sintering of metal powders.
- NanoCentral - Alliance of leading organisations created to unlock the commercial potential of nanomaterials.

In addition, there are 15 research centres and centres of excellence that focus on a wide range of nanotechnologies and applications.

APPENDIX 8
STEERING AND REVIEW GROUP

List of the members of the Steering and Review Group

Dr Andrew Burgess	AkzoNobel
Dr John Saffell	Alphasense Ltd & Chairman of CoGDEM
Dr Victor Higgs	Applied Nanodetectors Ltd
Dr Alan Smith	AZ-TECH
Dr Matthew O'Donnell	BioCeramic Therapeutics Ltd
Dr Julie Deacon	BioNano
Dr Ian Pallett	British Water
Prof Kai Cheng	Brunel University
Andrew Matthews	Cambridge Enterprise Ltd
Dr Bojan Boskovic	Cambridge Nanomaterials Technology Ltd
Dr Roger Pullin	Chemical Industries Association
Bob Mackison	Chemical Solutions
Dr Steve Fletcher	Chemistry Innovation KTN
Darren Ragheb	Chemistry Innovation KTN
Angela Vessey	Copper Development Association
Dr Didier Farrugia	Corus
Prof Derek Sheldon	Derek Sheldon Consultants Ltd
Prof Don Pedder	Donald Pedder Associates
Dr Tim Ryan	Epigem and Fluence MNT Centre
Dr Brian More	Exilica Ltd
Pat Selwood	Foresight Vehicle
Dr Katy Berry	Government Office for Science
Isobel Pastor	Government Office for Science
Prof Julian Jones	Heriot-Watt University
Dr Paul Findlay	Hydra Polymers Ltd
Dr Martin Dare-Edwards	Infineum UK Ltd
Dr Ian McRobbie	Innospec
Dr Mark Morrison	Institute of Nanotechnology
Del Stark	Institute of Nanotechnology
Dr Paul Reip	Intrinsiq Materials Ltd
Dr Peter Hatto	IonBond Ltd
Dr Wynn Jones	Ionotec Ltd
John Blackburn	Ionotec Ltd
Andrew Elphick	Iota NanoSolutions Limited
Dr Kevin Matthews	Isogenica Ltd
Dr Sam French	Johnson Matthey
Dr Peter Bishop	Johnson Matthey
Graham Hards	Johnson Matthey
Dr Brendan Casey	Kelvin Nanotechnology Ltd
Simon Allison	Marks & Spencer
Dr Robert Quarshie	Materials KTN
Dr Colin Johnston	Materials KTN
Stuart MacLachlan	Materials KTN
Dr Neil Ebenezer	Medicines & Healthcare Products Regulatory Agency
Prof Ben Beake	Micro Materials Ltd
Ottilia Saxl	Nano Magazine
Tom Warwick	NanoInk Inc.
Prof Terence A Wilkins	Nanomanufacturing Institute, University of Leeds
Dr Mike Fisher	Nanotechnology KTN
Dr Alec Reader	Nanotechnology KTN
Dr Neil Harrison	National Physical Laboratory
Dr Marc Bailey	Nokia
Dr Piers Andrew	Nokia Research Centre
Dr Gareth Wakefield	Oxford Advanced Surfaces Group plc
Prof Hagan Bayley	Oxford Nanopore Technologies
Dr Peter Luke	Pfizer
Robert Hemingway	PPG Architectural Coatings EMEA
Peter Waites	PPG Architectural Coatings EMEA
Dr Andrew Auty	Re: Liability (Oxford) Ltd
Dr Al Lambourne	Rolls Royce Plc
Dr David Rickerby	Rolls Royce Plc
Neil Gray	Scott Bader Co Ltd
Phil Cooper	Sensors and Instrumentation KTN
Tiju Joseph	Sensors and Instrumentation KTN
Jonathan Foulkes	Smith & Nephew Extruded Films Ltd
Christian Inglis	Technology Strategy Board
Dr Kevin Cooke	Teer Coatings Ltd
Stuart Challenor	Tesco Stores Ltd
Mike Brown	The Boots Company Plc
David Kent	The Institute of Measurement and Control
Richard Bahu	The Oxis Partnership
Prof Steven Rannard	Unilever
Dr Michael Butler	Unilever Research Colworth
Prof Gerard Fernando	University of Birmingham
Prof Richard Palmer	University of Birmingham / Inanovate / Interface Spectra / Birmingham Instruments / Irresistible Materials
Prof Sergey Mikhalovsky	University of Brighton
Dr Neil Bowering	University of Glasgow
Prof David Cumming	University of Glasgow
Prof Andrew Abbott	University of Leicester
Prof Ping Xiao	University of Manchester
Prof John Gray	University of Manchester
Dr Paul Christian	University of Manchester & Chairman of the IOM3 Nanomaterials and Nanotechnology Committee
Prof Peter Dobson	University of Oxford
Prof Julian Gardner	University of Warwick

References

[1] The Nanotechnology Report 4th Edition, 2006 (Lux Research)

[2] New Dimensions for Manufacturing - A UK Strategy for Nanotechnology Report of the UK Advisory Group on Nanotechnology Applications submitted to Lord Sainsbury, Minister for Science and Innovation by Dr John M Taylor, Chairman, June 2002

[3] Nanoscale Technologies Strategy 2009-12, Technology Strategy Board, 2009

[4] The National Nanotechnology Strategy published by The Department of Science and Technology, Republic of South Africa, 2006

[5] MNT Database (courtesy of The Nanotechnology KTN)

[6] Formulation Of A Strategy For The Nanotechnology KTN To Support Development Of The UK Nanotechnology Sector (2009 -2019), Centre For Process Innovation Optimat, 2009

[7] The Nanotechnology Report, 4th Edition, Investment Overview and Market Research for Nanotechnology, Lux Research

[8] www.themoscowtimes.com/print/article/386882.html

[9] The Organisation for Economic Co-ordination and Development (OECD)

[10] BIS data

[11] http://ec.europa.eu/research/fp7

[12] www.ec.europa.eu/research/reports/.../fp6_evaluation_final_report_en.pdf

[13] EPSRC: Grants on the Web

[14] Grand Challenge for Healthcare http://epsrc.ac.uk/ResearchFunding/Programmes/Nano/RC/ConsultNanoHealthcare.htm

[15] Grand Challenge for Energy http://epsrc.ac.uk/ResearchFunding/CMSWeb/Downloads/Calls/

[16] Characterising the potential Risks posed by Engineered Nanoparticles. A Second UK Government Research Report, December 2007

[17] http://www.innovationuk.org/news/innovation-uk-vol4-1/0124-nanotechnology-in-the-uk.html

[18] Nanomaterials and Markets 2008-2015, Nanoposts, 2008

[19] Nanotechnology market forecast to 2013, RNCOS, May 2009

[20] www.wintergreenresearch.com/reports/Nanotechnology_Final.htm

[21] The Race to the Top - A Review of Government's Science and Innovation Policies, Lord Sainsbury of Turville, October 2007

[22] Recommendations for Business Incubators, Networks and Technology Transfer from Nanoscience to Business, Lojkowski, W and Werner, M, May 2007

[23] Nanometrology, Nanoforum, 2007

[24] www.ec.gc.ca/substances/nsb/eng/home

[25] www.epa.gov/oppt/nano/stewardship.htm

[26] www.epa.gov/oppt/nano/nmsp-interim-report-final.pdf

[27] The Royal Commission on Environmental Pollution (RCEP) Report "Novel Materials in the Environment: 27th Report, 2008

[28] UK Government Response to The Royal Commission on Environmental Pollution (RCEP) Report "Novel Materials in the Environment: The Case for Nanotechnology", June 2009

[29] Risk Assessment of Products of Nanotechnologies, Report by Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), February 2009

[30] http://www.responsiblenanocode.org, Hilary Sutcliffe, Responsible Futures

[31] http://www.nanojury.org.uk/perspectives.html

[32] Nanodialogues: Experiments in Public Engagement with Science, Jack Stilgoe, DEMOS, ISBN 978 84180 187, 25th June 2007

[33] Which? Briefing: Nanotechnologies: Small scale, Big impact, September 2007

[34] Nanoderm – Quality of Skin as a Barrier to Ultrafine Particles, Final Report, 2007, EU funded project

QLK4-CT-2002-02678

[35] Carbon Nanotubes introduced into the abdominal cavity of a mice show asbestos-like pathogenicity, In a pilot study, Poland et al, Nature Nanotechnology 3, 423-428 (2008)

[36] Characterising the Potential Risks posed by Engineered Nanoparticles. A First UK Government Research Report from Defra, November 2005

[37] Nanosciences and Nanotechnologies: A Review of Government's Progress on its Policy Commitments. Council for Science and Technology, March 2007

[38] Response to the Royal Society and Royal Academy of Engineering Report: Nanoscience and nanotechnologies: opportunities and uncertainties, February 2005

[39] Nanotechnology - Small Matter, Many Unknowns, Swiss Re, 2004

[40] Proceedings of the Science and Technology Committee - Fifth Report, March 2004

[41] Nanoscience and nanotechnologies: opportunities and uncertainties. Report by the Royal Society and the Royal Academy of Engineering, July 2004

[42] Nanoscience and Nanotechnology: A Review of Government's Progress on its Policy Commitments, Council for Science and Technology, March 2007

[43] Consultation on a proposed Voluntary Reporting Scheme for engineered nanoscale materials. Defra, March 2006

[44] An Overview of the Framework of Current Regulation affecting the Development and Marketing of Nanomaterials. A Report for the DTI. ESRC Centre for Business Relationships, Accountability, Sustainability and Society, December 2006.

[45] Environmentally Beneficial Nanotechnologies: Barriers and Opportunities A report for Defra, May 2007

[46] Novel Materials in the Environment: The case of nanotechnology. Royal Commission on Environmental Pollution, November 2008

[47] The National Nanotechnology Initiative, Strategic Plan, December 2004, developed by the Nanoscale Science, Engineering and Technology Sub-Committee, Committee on Technology, National Science and Technology Council

[48] The National Nanotechnology Initiative, Strategic Plan, December 2007, prepared by Sub-Committee on Nanoscale Science, Engineering and Technology, Committee on Technology, National Science and Technology Council

[49] Japan's 3rd Science and Technology Basic Plan, April 2005

[50] The High-Tech Strategy for Germany, published by the Federal Ministry of Education and Research, 2006

[51] Nano-Initiative – Action Plan 2010, published by the Federal Ministry of Education and Research, 2007

[52] www.wtec.org/nb.../NANO_in_France-FRANCE-US_workshop.ppt

[53] Towards a European Strategy for Nanotechnology, published by the European Commission, 2004

[54] www.nano-taiwan.sinica.edu.tw/index.php

[55] Private Communication, Tom Warwick, NanoInk Inc.

[56] Colloidal Silica, fundamentals and applications, H.E. Bergna, W.O. Roberts. CRC Press, 2006

[57] Current and Future Applications of Nanotechnology, Chapter 1 by Barry Park, in Nanotechnology, Consequences for Human Health, Edited by R, E, Hester and R. M. Harrison, Published by Royal Society of Chemistry, 2007

Nanotechnology

ISSUE DATE 2010

This report is available to download from the following websites:

www.materialsktn.net www.nanoktn.com www.matuk.co.uk