1 Introduction

1.1 Hopes and concerns about nanoscience and nanotechnologies

1 Nanoscience and nanotechnologies are widely seen as having huge potential to bring benefits in areas as diverse as drug development, water decontamination, information and communication technologies, and the production of stronger, lighter materials. They are attracting rapidly increasing investments from governments and from businesses in many parts of the world; it has been estimated that total global investment in nanotechnologies is currently around €5 billion, €2 billion of which comes from private sources (European Commission 2004a) (see also Table 1.1). The number of published patents in nanotechnology increased fourfold from 1995 (531 parents) to 2001 (1976 patents) (3i 2002). Although it is too early to produce reliable figures for the global market, one widely quoted estimate puts the annual value for all nanotechnologies-related products (including information and communication technologies) at $1 trillion by 2011–2015 (NSF 2001). Although many people believe that nanotechnologies will have an impact across a wide range of sectors, a survey of experts in nanotechnologies across the world identified hype ('misguided promises that nanotechnology can fix everything') as the factor most likely to result in a backlash against it (3i 2002).

2 Against this background of increased research funding and interest from industry, several non-governmental organizations (NGOs) and some nanotechnologists have expressed concerns about current and potential future developments of nanotechnology. These include uncertainties about the impact of new nanomaterials on human health, questions about the type of applications that could arise from the expected convergence, in the longer term, of nanotechnologies with technologies such as biotechnology, information technology (IT) and artificial intelligence, and suggestions that future developments might bring self-replicating nano-robots that might devastate the world (Joy 2000; ETC 2003a). Others have questioned the adequacy of current regulatory frameworks to deal with these new developments, and whether applications will benefit or disenfranchise developing countries (Arnall 2003).

3 The media has reflected the hopes and concerns about nanoscience and nanotechnology.

4 In January 2003 the Better Regulation Task Force (BRTF) published its report *Scientific Research: Innovation with Controls* (Better Regulation Task Force 2003), which included a consideration of nanotechnologies. Its first recommendation was that the UK Government should enable the public, through debate, to consider the risks of nanotechnologies for themselves. Other recommendations advocated openness in decision making, involving the public in the decision-making process, developing two-way communication channels and taking a strong lead over the handling of any issues of risk to emerge from nanotechnologies. In its response to the first recommendation, the Government stated that there was currently no obvious focus for an informed debate, but that it was initiating work that would 'examine whether there were any areas of nanotechnology which raise or will raise specific safety, environmental or ethical issues' that would warrant further study (UK Government 2003).

Table 1.1 Examples of public funding for research and development (R&D) in nanoscience and nanotechnology (source: European Commission 2004a).

Country	Expenditure on nanoscience and nanotechnologies
Europe	Current funding for nanotechnology R&D is about 1 billion euros, two-thirds of which comes from national and regional programmes.
Japan	Funding rose from $400M in 2001 to $800M in 2003 and is expected to rise by a further 20% in 2004.
USA	The USA's 21st Century Nanotechnology Research and Development Act (passed in 2003) allocated nearly $3.7 billion to nanotechnology from 2005 to 2008 (which excludes a substantial defence-related expenditure). This compares with $750M in 2003.
UK	With the launch of its nanotechnology strategy in 2003, the UK Government pledged £45M per year from 2003 to 2009.

1.2 Terms of reference and conduct of the study

5 In June 2003, following its response to the BRTF, the UK Government commissioned the Royal Society and the Royal Academy of Engineering (the UK's national academies of science and of engineering, respectively) to conduct an independent study on nanotechnology. The terms of reference of our study, jointly agreed by the Office of Science and Technology and the two Academies, were as follows:

- define what is meant by nanoscience and nanotechnology;
- summarise the current state of scientific knowledge about nanotechnology;
- identify the specific applications of the new technologies, in particular where nanotechnology is already in use;
- carry out a forward look to see how the technology might be used in future, where possible estimating the likely time-scales in which the most far-reaching applications of the technology might become reality;
- identify what environmental, health and safety, ethical or societal implications or uncertainties may arise from the use of the technology, both current and future;
- identify areas where regulation needs to be considered.

6 The two academies convened a multidisciplinary working group of experts in science and engineering, medicine, social science, consumer affairs, ethical issues and the environment to conduct this study (see Annex A for a list of Working Group members). The study was conducted independently of Government, which was not involved in the selection of the working group members or its methods of working, and which did not view the report before it was printed. We received much written evidence, and we held a series of oral evidence sessions and workshops with a range of stakeholders from the UK and overseas. The volume of evidence that was sent in for the Working Group to consider and follow up extended the time taken to complete this project beyond that originally anticipated. At the outset of the study it was agreed that the report should include public concerns and that data should be collected about public awareness of nanotechnology, which could form important baseline data. The market research company BMRB International was commissioned to research public attitudes to nanotechnology, which took the form of two workshops and a short market survey. The evidence was published as the project progressed and comments were invited through a dedicated website (www.nanotec.org.uk). A detailed description of the conduct of the study can be found in Annex B. We are extremely grateful to all those organisations and individuals who contributed to the study; they are listed in Annex C. Their contributions can be found on our website and are available on the CD at the back of the hardcopy version of this report. In the report these contributions have been referred to as evidence. The report was peer reviewed by a small group of Fellows from the two academies (listed in Annex A) before being considered by the two academies. It has been endorsed by the Council of the Royal Society and approved for publication by the Royal Academy of Engineering.

1.3 Report overview

7 In Chapter 2 we introduce nanoscience and nanotechnologies, and explain the definitions of each that we used during the study. In Chapter 3 we give examples of key current research, and current and potential future advances in: nanomaterials; nanometrology; electronics, optoelectronics and ICT; and bio-nanotechnology. We also look at the benefits they are currently providing and might provide in the short, medium and longer term. In Chapter 4 we look at current and possible future industrial applications of nanotechnology, and examine some of the barriers to its take-up by industry. In Chapters 3 and 4 we have provided an overview (rather than a detailed assessment) of current and potential future developments in, and applications of, nanoscience and nanotechnologies, against which health, safety, environmental, social and ethical implications (addressed later in the report) could be considered. The Taylor report (DTI 2002) reviewed the state of nanotechnology applications in industry in the UK and proposed a series of actions to accelerate and support increased industrial investment in the exploitation of nanotechnology in the UK. It was not our intention to critique or update the Taylor report or to identify research priorities for nanoscience and nanotechnology. The House of Commons Science and Technology Committee has recently evaluated the implementation of the recommendations of the Taylor report (House of Commons 2004a).

8 In Chapter 5 we evaluate the potential health, safety and environmental implications of nanotechnologies, and in Chapter 6 we consider the potential social and ethical implications. In both chapters we identify the main gaps in knowledge related to the potential impacts of nanotechnologies. Chapter 7 outlines the results of our commissioned research into public attitudes to nanotechnology in Great Britain, and considers the role of multi-stakeholder dialogue in the future development of nanotechnologies. The implications of our conclusions for the current regulatory framework are

outlined in Chapter 8. Finally, Chapters 9 and 10 contain our overall conclusions and list our recommendations.

1.4 Next steps

9 We look forward to the response to this report from the UK Government and from the other parties at whom the recommendations are targeted. This study has generated a great deal of interest among a wide range of stakeholders, both within the UK and internationally. As far as we are aware it is the first study of its kind, and we expect its findings to contribute to the responsible development of nanoscience and nanotechnology globally. The two academies will continue to participate in this important area. The issues raised and conclusions reached in this report can be debated through the discussion section of the dedicated website (www.nanotec.org.uk). We will hold an open meeting in London to discuss the report's findings shortly after its publication.