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## **Nanotechnology – The issues**

*A response to the request for initial views on the Royal Society and the Royal Academy of Engineering study on nanotechnology, from the Royal Society of Chemistry.*

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Nanotechnology provides the potential for significant advances over the next 50 years. Applications will be broad, including; health care, medicine, security, electronics, communications and computing.

The present study should look at clarifying the definition of nanotechnology. At present the term is used to encompass a wide spectrum of nanoscience, from nanoparticles in sunscreen to the production of 'nanobots' for *in vivo* medical applications. In defining nanotechnology, distinctions need to be made between 'science' and 'technology'. A narrower definition of the type of 'technology' covered by the term may also be considered, limiting nanotechnology to technology producing functional devices fabricated and operating on the scale of nanometres, such as molecular machines and molecular electronic devices. Nanotechnology is also seen by some as a young but growing area of research which given time, will define itself more clearly.

Nanotechnology is intrinsically multidisciplinary, reliant on the basic science, analytical techniques and methodologies of a number of disciplines including: chemistry, physics, electrical engineering, materials science and molecular biology. Success in nanotechnology will require scientists and engineers to acknowledge a new multidisciplinary way of working. It is however important to recognise that this new field is reliant on the collaboration of academics highly skilled in their own disciplines and for nanotechnology to flourish, existing core science must be well supported.

Nanotechnology is often represented by two fundamentally different approaches; 'top-down' and 'bottom-up'. 'Top-down' refers to making nanoscale structures by machining, templating and lithographic techniques, whereas 'bottom-up', or molecular nanotechnology, applies to building organic and inorganic materials into defined structures, atom-by-atom or molecule-by-molecule, often by self-assembly or self-organisation. It is clear that both methodologies are likely to be important in the delivery and application of this new science and technology.

Chemists are involved in numerous areas of nanotechnology including the synthesis of inorganic, organic and hybrid nano-materials for use in nano-devices, the development of novel nano-analytical techniques, the manipulation of biological molecules such as DNA and the evolution of molecular machines. Much of chemistry already involves the control of nanodimensional objects and/or the self-assembly of molecules into larger structures. Polymer chemists and those interested in liquid crystals already practice nanoscience and the active area of supramolecular chemistry impinges directly on nanoscience and technology.

The future applications of nanotechnology could be immense and varied. It is important that the potential benefits of this area are communicated to the public by the Royal Society and others and that the public is engaged in the debate about these benefits. Proper communication of potential benefits will ensure wide support. It is however crucial that expectations of the opportunities afforded by nanotechnology are both upbeat and realistic. Over-blown claims for nanotechnology will not help in communicating the reality of scientific progress and in differentiating between science and science-fiction. Some present and possible future applications for nanotechnology with a suggested time-frame are given below. It must be recognised that the real rewards of nanotechnology are likely to be many years away. It should also be noted that not all of the technological challenges we face will be solvable by simply reducing the physical dimensions of existing materials.

Recent Media coverage of nanotechnology has centred on the fears that this new technology poses a new uncharted threat to society and needs to be regulated. It is important that these issues be carefully examined by the Royal Society study so that the public are confident that new technology will benefit society and that nanotechnology research in the UK is not hampered or held back.

The potential health, safety and environmental impacts of nanotechnology are comparable to the impact of the existing chemical, electronics and biotechnology industries and the potential hazards should be

judged in the same way. Our understanding is that current legislation should be sufficient to control the risks from nanoparticles, however research into their potential toxicity should be funded, as it may differ from that of larger particles with respect to respiratory and genetic damage. Until we develop 'self replicating machines'- artificial life, there are no issues of substance not covered by existing regulatory practices. The ethical and social issues raised are also not unique to nanotechnology and are comparable to issues raised by many existing technologies, such as the differential access to costly technology in the developed and developing worlds and issues of privacy and security.

### Potential applications and future markets for nanoscience and nanotechnology

	<i>current</i>	<i>1-5 years</i>	<i>6-10 years</i>	<i>10- 50 years</i>
<b>health care/ medicine</b>	sun screens	biological nano-sensors for diagnostics	artificial muscle  lab on a chip technology for more efficient drug discovery  targeted drug and gene delivery	nano-machines for in vivo treatment  nanopumps/valves for tissue engineering/artificial organs
<b>Energy</b>	nano-catalyst enhanced fuels for better efficiency	nanomaterials for fuel cells/batteries	more efficient solar cells using nanotechnology	nanomaterials for hydrogen storage fuel cells
<b>Security</b>		nano bar coding and tagging  nanotubes for thermal protection		
<b>Electronics</b>			carbon nanotube electronic components	nanomaterials in light emitting diodes/fsts and PV devices  single electron/molecule devices
<b>communications/ computing</b>			flat panel flexible displays using nanotechnology  high density data storage using nanomagnetic effects	faster processing using quantum computing  DNA computers
<b>Other</b>	self-cleaning windows  nanoparticles for pigments	smart/responsive nano-coatings for food packaging and other applications	lab on a chip nanotechnology for bespoke synthesis/catalysis	ultra-light materials for cheaper construction and transportation

One of the main concerns about nanotechnology voiced is that of self-replicating artificial nanomachines or 'nanite' robots as set out in Michael Crichton's book '*Prey*'. The resulting media interest in this story should not be allowed to drive an agenda for the whole of nanotechnology. The production of such self-replicating artificial assembler nano-devices is well within the realms of science fiction. Any eventual invention of self-replicating systems would need regulation and this would mirror that needed to regulate the artificial viruses that could be produced by advances in molecular biology.

The study should set out clear plans for an open debate about nanotechnology. It should set out to demonstrate that scientists are keen to discuss and disseminate their work. It is key that nanotechnology does thrive in the UK, as it offers major opportunities for the economy, building upon the UK's excellence in its science and technology base.

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