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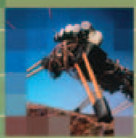
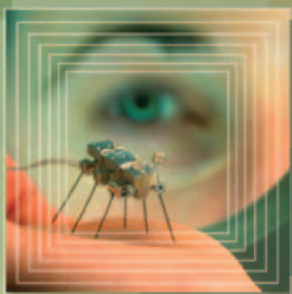
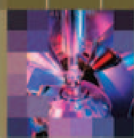
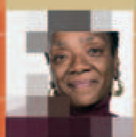


NANOTECHNOLOGY:
FROM THE SCIENCE TO THE SOCIAL

The social, ethical and economic aspects of the debate







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1 INTRODUCTION

In 2003 the ESRC published our report *The Social and Economic Challenges of Nanotechnology*, which investigated discussions taking place around the emergence of nanotechnology and what this might mean for society. This report is a follow-up to that original analysis and examines how the debate has moved on in recent years.

Our aim is to outline the general trend in the discussions on nanotechnology's future, in order to provide a context for future discussions of issues that social science might address. We first outline how the debate was initially framed, before presenting an overview of literature discussing the social and economic aspects of nanotechnology that has appeared since. Our conclusions highlight the major developments in the debate and draw out the implications of these and omissions in the discussion for the social science agenda.

The analysis is based on literature published between July 2003 and April 2006. It includes articles in academic journals, non-governmental organisation (NGO) reports, government and government body reports, and articles in the popular science literature, and is not intended to be exhaustive. Nanotechnology weblogs found on the internet add a new, albeit often confusing and unstructured, dimension to the debate, and were not in existence in 2003.

2 THE EMERGENCE OF THE NANOTECHNOLOGY DEBATE

Much of the initial commentary on nanotechnology assumed, implicitly or explicitly, that nanotechnology represented a radical discontinuity from existing science and technology, and it was largely because of this that it began to attract so much attention. This perspective was built into the heart of Eric Drexler's original portrayal of nanotechnology's promise, where assemblers would be able to manufacture anything by building from the 'bottom-up' using a feedstock of relevant atoms (Drexler, 1986). This vision was inspired by physicist Richard Feynman's speech (1959) about molecular assembly. One very forceful statement of this radical utopian view was in Jamie Dinkelacker's (2002) speculation that nanotechnology offers the potential for global material abundance and it is the loss of scarcity that has the potential for dramatic social change. >>

2 THE EMERGENCE OF THE NANOTECHNOLOGY DEBATE

>> The counter-position that created the nanotechnology debate, if that is not too grandiose, was not that nanotechnology was not a radical discontinuity, but rather that its effects would be negative not positive. Indeed, Drexler (1986) made some reference to the possibility of this radical dystopian outcome. But it was Bill Joy (*Wired* 2000) who most forcibly raised the alarm bells, pointing out how easy it would be to create destructive uses for the kind of powerful technology that radical proponents of nanotechnology were projecting. Dangerous weapons might be easier to create without large facilities or rare raw materials, and writing before the 9/11 terrorist attacks, he worried these might get into the wrong hands. Furthermore the ability to control nanomachines might be lost even to technologists. The ultimate effect of nanotechnology, particularly in convergence with Artificial Intelligence, makes 'our own extinction' increasingly likely, either through a takeover of the earth's biosphere by out-of-control, self-replicating, nanoscale robots ('grey goo'), or because humans have been replaced by their own robotic technology.

Whilst these radical views dominated much of the early discussion of nanotechnology, more moderate views of nanotechnology were expressed as its potential began to be explored. Nonetheless, even among these there remained the divide between pessimists and optimists. The reports from government bodies, such as the UK's DTI and pro-business organisations, reflected an optimistic incremental view, with an emphasis on nanotechnology as having the power to replace information technology as the major driver of economic growth, rather than being utterly transformational in its effects on economy and society. This contrasted with the incremental view of commentators from pressure groups, many of which had been involved in the debate on genetic modification (hereafter referred to as GM). These commentators, like Sue Meyer of Genewatch, implied that science can be shaped; but without more public participation and perhaps regulation, nanotechnology is likely to have adverse effects and not be used to solve important issues of poverty, social inequality, and the environment.

Inputs to the initial debate can thus be classified on two axes:

- Concepts of nanotechnology: from its being a radical socio-technical system to an incremental (perhaps indeterminate) concept.
- Assumed economic and social consequences which typically involve judgements about its merits: whether the outcomes of nanotechnology are positive or negative.

Analysis and summaries of the articles and reports falling in each grouping are presented in our earlier ESRC report, *The Social and Economic Challenges of Nanotechnology* (2003: chapter 4). Overall we concluded that much of the discussion talked as if there were a clearly defined 'Nanotechnology'. There is an 'it' that, it is assumed, we can all readily identify and agree on: 'it' will do this, 'it' will be like this. We noted a huge disconnect between grand visions of the future in the nanotechnology commentaries and the relatively unspectacular products that nanotechnology was delivering. Better sunscreens and trousers that are treated to resist stains, which are widely quoted, are useful and lucrative products, but one might be forgiven for feeling a sense of anticlimax. The current crop of products that involve nanotechnology can look, at first sight, rather mundane. This gap between what the technology is believed to promise and what it actually delivers may of course close over time. However, there are substantial scientific arguments against the feasibility of the most optimistic projections for radical nanotechnology, while social science and history would suggest that blanket optimism is also misplaced. There is an almost 'effortless' view of science and technology underlying many of the accounts as if new technologies flow easily from the daily life of the bench scientist to the market place.

The truth is that nanotechnology is not a single technology and is much less clearly defined than GM is or even was in its infancy. There is a need to move beyond thinking of nanotechnology as an 'it' for a number of reasons:

a) Nanoscience should be distinguished from its application. Nanoscience is neither new nor a radical break from normal science, rather it is a fusion of aspects of physics, chemistry, materials science and biology.

b) Nanotechnology consists of the application of nanoscience to produce marketable artefacts and products. The products of nanotechnology will exploit an increasing level of atomic-scale control over matter; but the rearranging of atoms is no different in principle from many other established industrial technologies, such as copper smelting. The argument that the technology is intrinsically to be feared because it creates something not found in nature thus has less force than the analogous arguments around biotechnology.

c) Nanotechnology is not easily abstracted from other developments, for example in biotechnology and information technology, and will itself contribute to the development of these. Moreover, there may not be many situations in which a product or artefact relies purely on nanotechnology.

d) What is under discussion is not a single technology – nanotechnology is a word that encompasses many different technologies, some old, some new, all of which have one thing in common: the manipulation and control of matter on very small length scales, lengths between the size of atoms and molecules. When so small, materials can behave differently, they may become tougher or even change colour. But the applications not only will be diverse but may have little or nothing in common apart from their length size and modernity.

Accepting that there is no single nanotechnology, we classify it by identifying three perspectives on nanotechnologies:

a) Incremental nanotechnology – developments that are essentially a continuation of the research directions of the past 50 years. This includes much colloid science and materials science, and is focused on materials that have superior or new properties as a result of their controlled nanoscale structure.

b) Evolutionary nanotechnology – the scaling down of existing technologies towards the nanoscale. Here the focus is less on simple materials and more on functional devices. This would include developments in information technology (e.g. semiconductors, memory devices) and molecular delivery (e.g. drug delivery).

c) Radical nanotechnology – fully functional nanoscale machines. This would include the proposals of Drexler and his followers, but other approaches may also lead to this outcome.

Bionanotechnology, in which naturally occurring nanomachines like molecular motors are pulled apart and reassembled, could fall into the radical category (see Jones 2004, which proposes biological design paradigms) but much of it will also be evolutionary.

Applications currently badged as 'nano' are almost all within the incremental category. The one exception is computing developments; hard drives that make iPods work, for instance, count as evolutionary nanotechnology in our scheme but were not at the time marketed as such. The stain-resistant chinos and clear zinc sunscreens mentioned above have developed from normal science. The most significant impacts of nanotechnology on society have been on the practice of science: scanning probe microscopy, single molecule technique, computer simulation and visualisation. And here the impacts are potentially large, including fast, cheap gene sequencing and the development of 'systems' approaches to biology, in which the complex mutual interactions of many biological macromolecules at sub-cellular levels are disentangled.

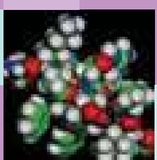
The dominance of the radical perspectives in the initial debate surrounding nanotechnology meant that it appeared in danger of becoming polarised before it had been allowed to mature. As *The Engineer* wrote, "nanotechnology research is facing a similar backlash to the one that put biotechnology on the backfoot" (Knight and Pierce, 2003). A consequence of this is that the focus of discussion, at least in the UK, became the issue of social acceptance and citizen's participation in science and regulation. The question of how and in what way nanotechnology would develop, in the absence of this, was either taken for granted or ignored; an effortless view of science and the non-problematic view of technology transfer apparently being adopted, as the issue became one of influencing the goals of the scientist rather than how science and technology proceed and interconnect.

The implication is that the social side of the debate should, as we argued in our earlier report, be broadened to include a wider set of issues, more economics, and more consideration of the social processes through which nanotechnology as an area develops and nanotechnology products emerge.

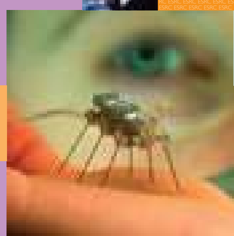
3 THE DEVELOPMENT OF THE NANOTECHNOLOGY DEBATE

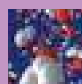
Triggered partly by the danger of polarisation of debate, public bodies like the Royal Society began around 2003 to overtly deliberate the nature and effects of nanotechnology. Reports such as our earlier ESRC report and the Royal Society's own report meant that disparate arguments have become more coherent. Here, we will examine the recent discussion and literature on nanotechnology, centring again our analysis on the two axes of (a) concepts of nanotechnology, (b) judgements about its economic and social consequences and their merits. We will show that the polarisation from the radical utopians and dystopians is becoming less dominant, as more actors have joined in the debate. The evolutionary view has become more central to discussions about the nature of nanotechnology, and the debate about the social implications or challenges has become more developed, but the impact of the evolutionary view is not prominent in this. The emphasis has though remained on debating radical effects of nanotechnology, or at least the assumed fulfilment of the aspirations of radical proponents; issues of risks and the effects on developing countries are also significant themes. The calls for public engagement that emerged from the initial debate have been acted upon, but social science investigation remains limited, particularly regarding the factors that may shape the development of nanotechnology. .

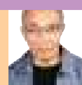
MAJOR DEVELOPMENTS



NANOTECHNOLOGY







PUBLIC ENGAGEMENT

3 THE DEVELOPMENT OF THE NANOTECHNOLOGY DEBATE

CONCEPTIONS

Reflecting the infancy of nanotechnology, and the absence of many products derived from it, discussions of different conceptions of the technology are a significant feature of the debate. Indeed this has become increasingly salient; so "the very definitions and constitutions of nanotechnology are themselves the subject of lively debate" (Macnaghten et al. 2005: 272). Three dimensions to the discussion can be identified, though these may overlap and are not clearly separated in the discussion. First are the attempts to define nanotechnology. Second are the concepts of what is achievable and how it can be achieved. Third are discussions of nanotechnology as a field of study and commerce.

Sharpening Definitions

Typically the reports on nanotechnology from governments or scientific organisations that have been produced in recent times have opened with an introduction to the concept of nano-level phenomena and the terminology surrounding their study. The UK Government, for instance, commissioned the Royal Society and Royal Academy of Engineering (RS/RAE) to produce a report on the social aspects of nanotechnology development. One of the outcomes required "was to define what is meant by nanoscience and nanotechnology" (2004: 5). After consulting widely, the RS/RAE group offered the following definitions, not dissimilar to those we used in our ESRC report:

> **Nanoscience** is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale.
>
> **Nanotechnologies** are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale. (2004: 5)

These definitions have been adopted by other organisations; for example reports from Nanologue (a European public engagement initiative) and the US NGO, The Meridian Institute, both accepted the definitions seemingly as standard. Nanologue quotes the definitions, deciding to "use [them] as [a] basis for discussion", although they still employ the term 'nanotechnology' as an all-encompassing term to capture both nano-science and its application (2005: 11). The Meridian Institute takes the RS/RAE definitions as a hook on which to hang their discussion, though it stresses that nanotechnology "is not one technology, but many, all writ small" (2005: 2). In its 2004 report, *How big can small actually be?*, the Royal Netherlands Academy of Arts and Sciences presents the RS/RAE definition which it sees as consistent with that used in the Dutch Nanoimpusporgramma:

> The ability to work at the scale of atoms, molecules, and supramolecular, individually targetable structures (from 1nm to 100nm) so as to create complex functional structures with a fundamentally new molecular organisation. (Royal Netherlands Academy 2004: 16)

While a common feature of these definitions is the need to distinguish between science and technology operating at the nano level, the term nanotechnology is also used as an umbrella concept embracing the two elements. This is most apparent in the US National Nanotechnology Initiative (NNI) definition of nanotechnology "as encompassing the science, engineering, and technology related to the understanding and control of matter" at the nanoscale (PCAST 2005: 7).

Underlying the definitions is the assumption that properties of materials do vary with length scale. This is most explicit in the RS/RAE definition of nanoscience, which contains the conditional: "where properties differ significantly". It implies that the 'nano' label can only be applied when novel properties are demonstrated at the small length scale, but if properties are not novel then it is not 'nano'. This conditionality depends not only on what material that is referred to, but also on what property is being considered. For many or most properties the physics determines some characteristic length that can be calculated for any given material. On sizes small compared to that length this property changes. This makes a very physically robust definition of 'small' but it is not much use as a general definition. Only the general feeling that many of these characteristic lengths lie somewhere in the range 10 nanometres to 1 micron allows one to tie this to a definition of the nanoscale.

For this reason, we cannot rely on science to give us a robust and objective definition of the nanoscale. This ambiguity is recognised by most practising nanoscientists. In the words of leading US nanoscientist George Whitesides, "In our enthusiasm for 'nano', we must not forget 'micro', or more generally, 'small'…development must be focused on the development of science and technology at the *right* size – and that size may range from nanometres to millimetres (for the technologies of small things): 'nano' is not always the best or only answer" [author's emphasis] (2005: 178).

Clarifying Visions

In the foreground of all discussion is the idea that nanotechnology will produce radically new products and processes. This is succinctly expressed by the Dutch *Nanoimpusporgramma* when they follow their definition of nanotechnology with the statement that:

> Nanotechnology makes it possible to develop materials and systems whose components and structures display revolutionary new physical, chemical and biological properties, phenomena, and processes associated with their nanodimensions. (Royal Netherlands Academy 2004: 16)

A key issue is whether those aspects of nanotechnology that differ from the radical vision of Drexler have the potential to have such a revolutionary impact. This is an especially pertinent question as the Drexler position plays little role in mainstream nanoscience and policy circles. The different positions on nanotechnology can be best distinguished on the basis of how authors view the three types of nanotechnology that we identified in our report. On this basis we can distinguish four distinct positions on this issue:

1 *The Drexler vision of radical nanotechnology, summarised as "the principles of mechanical engineering applied to chemistry" (Drexler 1992), is the only truly revolutionary version of nanotechnology, and is essentially well-founded. Other technologies currently being branded as nanotechnology are either useful incremental advances, or else are cases where the label is being used for marketing purposes when the technology is not nanotechnology.*

This is now a position that is held by very few, if any, academic nanoscientists or people from the nanobusiness community, particularly since a refutation of the Drexler vision by the Nobel Laureate Richard Smalley, and his subsequent exchange of letters with Drexler in Chemical and Engineering News (2003). However, it is a position that is still held by a number of futurists and writers, some of whom (e.g. Ray Kurzweil, Glenn Harlan Reynolds) have a high media profile. They may yet have a disproportionate influence on the debate, as Schummer's (2005) analysis of the impact of different actors implies may already be the case.

Reynolds is most explicit about creating a distance between the radical and the mundane. He coins four labels to differentiate types of nanotechnology:

- Fake: where it's basically a marketing term, as with nanopants.
- Simple: high-strength materials, sensors, coatings, etc – things that are important, but not sexy.
- Major: advanced devices short of true assemblers.
- Spooky: assemblers and related technology – true molecular nanotechnology, capable of making most anything from sunlight and dirt, creating supercomputers smaller than a sugar cube, etc. (Reynolds 2006, para 23).

The importance of the 'grey goo' scenario is a complicating factor in discussions of this vision. Writers like Reynolds (2006) have explicitly voiced what is essentially a conspiracy theory, that the promoters of conventional nanoscience have deliberately and cynically sought to discredit the Drexlerian vision, in an attempt to head off public concern about the "grey goo" problem (see also Berube 2006).

On the other hand, Drexler and his followers have also been concerned to distance themselves from the prospect of self-replicating nanobots. Recent comments play down the self-replication aspect as unnecessary. Instead, Drexler envisages "the development and use of highly productive systems of nanomachinery (nanofactories) [that] need not involve the construction of autonomous self-replicating nanomachines" (Phoenix & Drexler 2004: 869).

2 *The Drexler vision of radical nanotechnology is fundamentally flawed from a technical point of view. However, the products of incremental and evolutionary nanotechnology will themselves have profound and potentially revolutionary impacts.*

This is perhaps the most common position amongst those scientists who identify themselves with nanotechnology and with those from the nano-business community. A typical point of view comes from Whitesides:

> In my opinion, the most serious risk of nanotechnology comes, not from hypothetical revolutionary materials or systems, but from the uses of evolutionary nanotechnologies that are already developing rapidly. (2005: 177)

In this view, the ethical issues and societal risks arising from possibilities such as universal surveillance and human enhancement provide issues that are quite serious enough without needing to consider fanciful, science fiction scenarios such as out-of-control, self-replicating nanobots. On the positive side of the ledger, nanotechnology-led developments in new, cheap, solar cells and energy storage and transmission technologies may, by breaking the link between fossil fuel use and prosperity, provide a benign and environmentally sustainable basis for widespread prosperity (Smalley 2005).

3 *The Drexler vision of radical nanotechnology is fundamentally flawed from a technical point of view. Other technologies currently being branded as nanotechnology are useful incremental advances, but do not have the potential to have revolutionary effects.*

This position has not been widely articulated in public, but is probably held by many scientists and technologists who have not identified themselves with nanotechnology. As David Berube, a social scientist in the communications area, suggests in his book *Nano-hype*, "the majority of the science community rejects advanced or radical molecular manufacturing as a vision, instead opting for a less revolutionary and more evolutionary view that is grounded in applied nanoscience" (2006: 58).

4 *Although the Drexler vision of radical nanotechnology is technically flawed, other routes to achieve some of the goals of radical nanotechnology will be successful and have potentially revolutionary impacts.*

It has been pointed out by a number of authors, including one of us (Jones 2004), that just because Drexler's preferred route to radical nanotechnology – involving the miniaturisation of mechanical engineering concepts – may not be feasible, this does not mean that other routes to rather similarly radical outcomes are not possible. Cell biology offers remarkable exemplars of nanoscale machines and devices and of ultra-precise nanoscale chemical operations, and indeed provided some motivation for Drexler's original vision. The efficacy of biological nanomachines suggests that a radical nanotechnology could be achieved, either by copying some of the design principles used by biology (particularly *self-assembly*) and executing them in synthetic materials (*soft* or *biomimetic* nanotechnology), or by reassembling nanomachines of biological origin in synthetic contexts (*bionanotechnology*).

A closely related issue that has come into prominence since our 2003 report is the idea of *synthetic biology* (see three articles in Nature 24 November 2005). This term encompasses two somewhat distinct ideas. The first version of synthetic biology envisages taking an existing, very simple, organism, and re-engineering it with artificial genes to enable it to carry out desired functions (see www.syntheticgenomics.com); this could be considered an extreme version of bionanotechnology. The other version, in the words of the chemists Steven Benner and Michael Sismour (2005) "uses unnatural molecules to reproduce emergent behaviours from natural biology, with the goal of creating artificial life".

Central to either version of synthetic biology is, again, the idea of self-replication. This has not gone unnoticed by the Canadian NGO, the ETC Group, who also raise the issue of 'synthetic biology', where "the construction of new living systems…frequently involves the integration of living and non-living parts at the nano-scale" (2005a:10). Employing the tools of biology to achieve the goals of molecular manufacturing is tangible research, and much more plausible than scaled-down macro engineering.

Identifying the Field

Sharpening definitions and clarification of visions still does not necessarily lead to clear principles by which one can identify nanotechnology as either a field of study or commerce, and many observers remain deeply confused about what is meant or implied by the term. In the words of the distinguished bioethicist Glen McGee:

> I'm still quite clueless about what it is exactly that nanotechnology means, or to be clearer the sufficient conditions are for a thing to be correctly classed as the product of nanotechnology in as much as that moniker is opposed to something else. I have begun to read voraciously in the nanoethics literature, yet I do not understand the necessary or sufficient conditions for an activity to be nanotechnology.

Equally he is:

> Not sure what it means for a scholar to have the special set of skills and knowledge to study social, ethical and legal issues in nanotechnology; are there 'special' issues in nanotechnology that require the analog to the medical knowledge that a clinical ethics consultant must have in order to understand what it is that doctors are fighting about at the bedside? (2006, section 5)

Difficulties of demarcating the area, and hence of isolating ethical and social issues surrounding it, reflect, as ethicist Armin Grunwald (2005: 188) says, the novelty of the area, but more specifically a "cognitive fuzziness caused by a lack of knowledge of the real possibility of the technical innovations concerned". The field of nanotechnology is thus neither clearly bounded nor coherent. The diversity of perspectives, on the one hand, amplifies the problem (Gordijn, 2003).

Moreover, nanoscience may be very disconnected from nanotechnological developments, the former revolving around theory, the latter practical innovations. On the other hand philosopher Bernadette Bensaude-Vincent suggests "the rejection of Drexler's rhetoric" is acting "as a unifying principle in the otherwise heterogeneous crowd of scientists involved in nano-initiatives" (2004: part 1). Ironically, the very opposition to the Drexlerian method of achieving functional nanoscale devices through engineering may be uniting an otherwise disparate set of commentators on nanotechnology, if not scientists. But even then the connections may be weak because of the different academic subjects and domains of practical interests. Ultimately the fundamental difference in perspectives may reflect different cultures between the approaches of science (chemistry or biology) and engineering (Bensaude-Vincent 2004). These may be reconcilable but will certainly shape what is feasible to achieve by way of integration between the two, as in Gibbons et al.'s vision of "Mode 2" science where such demarcations evaporate. But Bensaude-Vincent concludes that these views of nanomachines reflect more fundamental differences in the philosophies, which are irreconcilable. Both, however, associate technology with control, and she suggests the way forward for nanotechnology is to adopt a different view of technology in which the technologist (she uses the word artisan to make the point) is "more like the ship-pilot at sea. He [sic] conducts or guides forces and processes supplied by nature, thus revealing the powers inherent in matter" (2004, part 5). An alternative way forward would be to make the field more akin to agriculture or traditional medicine.

Rather than seeing the issue of the field as a matter of definition or at least as defining it once and for all, it may be more helpful to approach it as sociological issue. It is perhaps the very diversity currently in the domain that authors are highlighting, as well as the overlap between what can be characterised as science and what as technology that makes nanotechnology interesting. The field's interdisciplinarity and crossing of currently defined scientific boundaries makes it novel and unique, and its development is itself a suitable subject for social science investigation.

SOCIAL AND ECONOMIC ISSUES

Judgements about the possible social and economic effects of nanotechnology have also sharpened since our 2003 report, with some authors identifying specific questions that need to be studied and others focusing on certain areas, such as the developing world. Recommendations for regulation are made, and programmes aimed at social participation in technology development are underway.

Since our initial report in 2003, the debate has become less dominated by radical visions. Then, we identified four broad approaches: the utopian, the dystopian, those concerned about barriers to the technology's development and those calling for regulation. These concerns can still be detected in the literature, but they have given rise to a more complex set of issues and the beginnings of social science involvement and analysis. Much of the literature is still commentary; it is still predominantly discussion rather than evidence-based research.

Situating the Debate

Much of the discussion on the social challenges raised by nanotechnology stems from the original polarisation into radical positive and negative viewpoints. It is the utopian and dystopian extremes that could be said to have sparked the interest in nanotechnology's social impacts and set the context for wider discussions. These visions dominated discussion in 2003, but as we have shown with the sharpening of conceptions, they are less influential now. Nonetheless, it could be argued that there would be no debate without this initial radical characterisation and hype. Jose Lopez argues that visions of nanotechnology's future have been shaped by a science fiction narrative device, the *novum*. In this process, a "single element [e.g. molecular assembly] is used as the axis around which a future alternative world is spun" (Lopez 2004: 25), hence radical utopian and dystopian prophecies. Gordijn calls for "the development of a more balanced ethical view" to avoid "conflict and unwanted backlashes" (2003, part 1).

Dominated by radical transhumanists, the utopian vision has changed little. In the words of the philosopher Joachim Schummer (2005) "Transhumanism is a quasi-religious movement that originated in California in the 1980s with adherents in many different countries nowadays. Transhumanists believe in futuristic technological change of human nature for the achievement of certain goals, such as freedom from suffering and from bodily and material constraints, immortality, and 'super-intelligence'. Nanotechnology, and its convergence with other technologies leading to a 'singularity' or 'spike' in the rate of technological advancement, is still heralded as curing all of humanity's ills. Ray Kurzweil (2006, para 3) epitomises this belief: "Illness…will be eradicated. Through the use of nanotechnology, we will be able to manufacture almost any physical product upon demand, world hunger and poverty will be solved, and pollution will vanish".

Proponents of molecular manufacturing have reacted to the dystopian critics by withdrawing their emphasis on the creation of independent nano robots. Phoenix & Drexler (2004: 869) state that "the development and use of molecular manufacturing need not at any step involve systems that could run amok". They and others are now more concerned about "intrinsic dangers" (Dunkley 2004: 1132) in the technology that could emerge if it gets into the wrong hands. According to Drexler, nanotechnology's dangers lie in "deliberate abuse" (Phoenix & Drexler 2004: 870). Whether it is an arms race or terrorism, "[d]eliberate development of nanoweapon systems…presents a threat that is both less remote and more challenging [than grey goo]" (Drexler 2004: 25).

Fresh fears of 'grey goo' have not been forthcoming but the dystopian view was so well stated that there may be no need to continue to write about it. Nonetheless, even Prince Charles (2004) maintained that he did not use the term in a follow-up article to his 2003 statement that attracted considerable media attention. The ETC Group has moved its emphasis from the 'grey goo' associated with molecular manufacturing to the bionanotechnological developments. It is now concerned about the possibility of 'green goo', where the merging of nanotechnology with biology will create uncontrollable self-replicating machines based on bacteria and viruses. In ETC's (2005a: 12) words, "the merger of living and non-living matter will result in hybrid organisms and products that are not easy to control and behave in unpredictable ways" leading to uncontrollable new life forms.

Aside from such developments in the utopian and dystopian scenarios, there has been a greater emphasis in the debate on the indeterminate nature of technology and the social shaping of science. The consequences are assumed not to be pregiven and thus the emphasis is on both the processes and understanding that may help shape the development of nanotechnology. Precisely how the potential social impacts of nanotechnologies should be expressed are debated; issues have become more specific, although they are often simply characterised as 'risks', and a great deal of attention has been focused on the possible toxicity or otherwise of nanoparticles. Allied to this is a concern to involve the public in shaping the terrain and social scientists have themselves been involved in this.

Shaping the Debate

The focus of some writers has been on cataloguing the issues that nanotechnology raises with a view to defining research or ethical issues surrounding nanotechnology, much as we did in the final chapter of our 2003 report. Sheremeta and Daar (2004) classify the issues into six categories: public perception and public engagement, regulatory, economic and commercialisation, equity and global governance, philosophical and ethical, and application-specific. The illustrative issues that they place under each heading are displayed in Appendix 1. Grunwald similarly presents a set of issues: the risks of nanoparticles, sustainability, privacy and control, the man-machine interface and human enhancement. Of these, only the final area, he concludes, may be specific to nanotechnology, as he stresses that these "questions are in themselves not new" (2005: 198). Other commentators, such as Nanologue (2005), Lewenstein (2005), Gordijn (2003) and Arnall (2003), also present similar lists.

Alongside the listing of issues surrounding nanotechnology have been concerns about the way in which social and economic issues have been defined. First, there is the argument that posing these as effects or implications implies that the social must always be downstream of the science. This argument is made by Wilsdon and Willis in their pamphlet *See-Through Science* (2004) and by Macnaghten et al. (2005). Science communication professor, Bruce Lewenstein (2005, part 3) stresses the need to use terms like questions and issues rather than 'implications', as the latter phrase "implies that science and technology come first" (2005, part 2). Moreover, he goes further and stresses that any attempt to set boundaries of what can be included as a social or ethical question is "necessarily an exercise of power" by those defining the boundaries. Setting the agenda in terms of issues rather than implications is, it appears to commentators such as Wilsdon & Willis, Macnaghten, and Lewenstein, more in spirit with an inclusive approach to policy-making than one centred on the government agencies; that is one founded on a more open and fluid approach to power which recognises – we might add helps to foster – what Lewenstein (2005, part 1) calls the "mutual interdependence of science, technology and society".

Secondly, there is concern that the social is being reduced to ethical issues, which in turn are simply treated as questions of risk and benefit. This leads to what the Demos group (Wilsdon and Willis, 2005: 26) have called "The tyranny of risk assessment". Reflecting a critique particularly associated with Brian Wynne and his colleagues at Lancaster (as applied to Nanotechnology in Macnaghten et al., 2005), they argue that "Questions of risk – the known uncertainties – can easily dominate proceedings and squeeze out broader discussion of unknown or unanticipated consequences" (ibid.).

This focus on risk certainly seems to have been the experience in the case of nanotechnology; the RS/RAE report, for example, emphasises the need for further study and possible regulation of nanoparticles and other possible adverse health, environmental and safety impacts of nanotechnology as seemingly the most urgent and immediate issue surrounding nanotechnology. And this emphasis on nanoparticle toxicity has been reflected in much of the media coverage of the subject. The RS/RAE report (2004: 56), in fact, claims that only applications "envisaged in the medium (5-15 years) and longer (longer than 20 years) time-scales" are likely to raise significant social and ethical concerns. Looking at more immediate effects, Nanoforum also asks: "what are the risks…; how should the knowledge be shared…; how to achieve public acceptance…" (2005, 5.3). In their State of the Future 2005 report, the UN focus entirely on how to manage and understand "nanotechnology risks" (2005: 6). A report by the Meridian Institute on nanotechnology and the poor is subtitled "Opportunities and Risks", while Colvin is concerned about the "unforeseen risks…for the environment and our health" (2004, para 1). Of those that use the phrase only Einsiedel and Goldenberg (2004: 29) qualify it as being "more broadly defined beyond physical or safety risks".

Focusing on risks leads to an overconcentration on the risks of nanosubstances to the neglect of wider social risks and uncertainties. The issues get funnelled into the possible toxicity of engineered nanoparticles, as parallels are drawn with known dangerous nanoscale substances and concerns are expressed about the "structural similarities between nanotubes and asbestos fibres" (Arnall 2003: 36). Consequently, calls for regulation have become more specific; the RS/RAE report recommends that "the adequacy of the current regulatory regime for the introduction of nanoparticles into consumer products" be reviewed (2004: 74) and Nanoforum suggests that "there must be regulations protecting the individual" (2005, 5.3.3).

While interesting and important, questions of the dangers of engineered nanoparticles to human and environmental health are technical issues with no input from social science needed; there is scope, though, for examining the social processes involved in risk assessments and the development of regulation. A focus on risk may indeed further reinforce the downstream perspective on social issues and the role of social science, as Macnaghten et al. (2005: 269) claim when they conclude that the framing of issues as risks places "the site of social science inquiry firmly 'downstream' of innovation processes" (2005: 269). The consequence of this is that social scientific research becomes only a bolt-on to satisfy demands for greater public involvement.

Another important debate concerns the impact of nanotechnology on the developing countries of the world. Many commentators argue that technological development as predetermined by the markets of the west can pose problems for the developing world. There are those who fear for developing economies if basic commodities, such as copper and cotton, were to lose their market value in the face of nano-enabled replacements; those who believe nanotechnology research could, and soon will, boost struggling economies; and those who are concerned that the full social benefits of nanotechnology will not be exploited.

Some argue that the current model of capitalism may change due to nanotechnology. For the ETC Group, changes will have an adverse effect in the short term on the developing world, with "the potential to topple commodity markets, disrupt trade and the livelihood of the poorest and most vulnerable workers" (ETC 2005a: 4) as their resources become "less necessary in the global market" (Meridian Institute 2005: 10). Sociologist Michael Mehta goes further, predicting a complete economic shift from capitalism to mercantilism should radical goals be achieved (Mehta 2004a).

Though not explicit, the different positions in the debate over how the developing world will be affected by nanotechnology reflect different perspectives on technology. There are those who argue that nanotechnology will, without intervention, alleviate global problems, as evidenced by the radicals above. Other, less radical, commentators maintain that developing countries' own research programmes do address internal sustainable development issues; according to Salamanca-Buentello et al. "developing countries are already harnessing nanotechnology to address their most pressing needs" (2005: 300).

While it is true that many developing countries have their own nanotechnology initiatives, there is debate as to how these are being directed. As Donald Maclurcan, member of the Institute for Nanoscale Technology at the University of Technology, Sydney, finds: "Early signs are that developing countries will direct nanotechnology R&D to 'value-add' to export markets, rather than use nanotechnology to promote sustainable development" (Maclurcan 2005b: 16). Potential applications of nanotechnology may well aid the achievement of the UN's Millennium Development Goals often referred to in the literature, but many maintain that society needs to guide research toward these specific aims.

The Meridian Institute, for instance, recognise that "little…investment is aimed at products that could benefit the poor…nanotechnology promises new cancer treatments, cheaper energy and purer water, but the first products offered to the public have been more airtight tennis balls" (Meridian Institute 2005: 13). The argument from commentators like Meridian is that although nanotechnology may have the potential to solve global problems, this will not happen without social shaping of the research, and without this, there are concerns that a 'nano-divide' will arise, a technological gulf between the developed 'North' and developing 'South'.

In contrast, Mohamed H. A. Hassan (2005), of The Academy of Sciences for the Developing World, has argued against this notion of an emerging North-South gap. He notes the substantial investments in nanotechnology being made by countries like India and China, and policy statements such as this one, from Turner T. Isoun, Nigeria's Federal Minister of Science and Technology: "developing countries will not catch up with developed countries by investing in existing technologies alone. [In order] to compete successfully in global science today, a portion of the science and technology budget of every country must focus on cutting-edge science and technologies" (Hassan, 2005: 66). Hassan concludes that "nanoscience and nanotechnology may prove to be the first cutting-edge field to reflect the new realities of global science in the 21st century for two reasons. First, the capabilities and accomplishments of scientists and technologists from the developing world who choose to continue to work in their home countries are growing. Second, a number of governments in the South are devising ever more sophisticated and effective science and technology policies" (2005: 65).

The gap that Hassan identifies is not between the North and South as traditionally defined; rather he comments that "there is a disturbing emergence of a South-South gap [a not quite accurate term in our opinion] in capabilities between scientifically proficient countries (Brazil, China, India, and Mexico, for example) and scientifically lagging countries, many of which are located in sub-Saharan Africa and in the Islamic world" (2005: 65).

Sharing the Debate

With the greater emphasis on the social shaping of science, calls for public engagement and more openness about science in the development of nanotechnology are another noticeable focus of the literature. In our analysis of 2003, there were calls for public engagement (e.g. from Myunsiwalla et al., 2003) and the lack of public acceptance of such an apparently novel technology was seen as a barrier to overcome. Further calls for public engagement have been outlined, particularly in the RS/RAE report where "adequately funded public dialogue" (2004: xi) is a key recommendation. Although the UK Government responded to this call and established dialogue initiatives, Macnaghten et al (2005) continue to push for greater 'upstream' engagement in technology emergence.

At the time of writing, the public dialogue initiatives that were established have not yet released their findings. The European 'Nanologue' and the UK 'Small Talk' are still conducting research; so far only NanoJury UK has published provisional recommendations. In this project, a citizen's jury heard 'testimony' from a range of experts. Key recommendations that had the broadest support from the jury reflect the concerns from scientists and social scientists about what areas nanotechnology may impact. They include: a desire for greater openness and better communication from the scientific community, wanting economic and employment benefits from the technology's development, the tackling of global social problems, and concerns over the safety of manufactured nanoparticles. For a more extensive summary of the groups involved in public engagement, see Appendix 4.

Attention has focused on the means by which to engage the public. Small Talk, for instance, asked two questions at a working lunch in January 2006: "Who are the science communication community?"; "What are the barriers to dialogue?" (Small Talk, 2006:1). These issues of how to conduct effective public engagement are still being debated. Also, there have been studies that find a low awareness of nanotechnologies among non-scientists (Cobb 2005, Anderson et al. 2005).

Often the call for public involvement in setting the agendas for science is attributed to the controversy that followed the introduction of genetically modified organisms, in Europe particularly. For authors such as scientist Vicki Colvin, public acceptance is now the major barrier to development; what was mentioned in passing in 2003 (that the rejection of the technology by a wary public would have serious negative economic impacts) is now a much bigger concern, far more than the worries about lack of investment that we found in our initial literature analysis. Many comparisons are made in the literature to the biotechnology industry, and the public backlash it faced in the late 1990s. The reason for a greater concern for public engagement in nanotechnology is thus a derivative of this. Colvin states, for instance, that those in the industry "have learned [from GM] that ignoring reasonable fears and concerns about emerging technologies can halt or even derail technology's progress" (2004, para 2). Nanoforum see a role for the social scientist in this process, in particular as providing the "mechanisms by which [the] debate can be seen to have transparency" (Nanoforum 2005, 5.4.4), acting as "arbitrators in the public debate".

Social scientists at the forefront of advocating for more participation or upstream engagement in science have welcomed the space provided by this call, and democracy group Demos (2005) and Lancaster University joined forces to develop a project built around focus groups involving a small sample of both the 'general public' and scientists. Nonetheless, as Berube (2006: 313) notes, social science researchers "are very concerned. They do not want to function as the public-relations division for commercial nanotechnology".

This concern is very much linked with policy developments in the UK, where an earlier agenda of promoting "Public Understanding of Science" has been replaced by a more inclusive programme of "Public Engagement with Science". Macnaghten et al. (2005) have argued that implicit in the old idea of "public understanding" was a "deficit model" of the public's relationship with science, in which public mistrust of science was simply a result of a lack of knowledge, and when suitably informed of the facts acceptance of science would necessarily follow. They also imply that public engagement processes can also serve as vehicles for social science investigation.

It may be, however, that understanding is required for engagement. Building on comparisons with GM, others see the need more for publicising scientific and other expert views rather than widespread public engagement, as they gauge that the backlash against GM was caused by a lack of scientific information. A simple remedy will be to counter any dissent:

> With sound technical data about nanomaterials' health and environmental impacts and a commitment to open dialogue about potential social and ethical implications with all stakeholders, nanotechnology could avoid travelling along the wow-to-yuck trajectory. (Kulinowski 2004: 19)

CONCLUSIONS TO THE LITERATURE REVIEW

In the past three years, the discursive landscape surrounding the development of nanotechnology has changed, although not dramatically. The debate on the social challenges of nanotechnology has matured in some respects, with the polarisation of the radical utopians and dystopians becoming less dominant. Positions are more nuanced; more actors have entered the arena, and there is a general consensus that nanotechnology is a diverse technology still very much in its infancy with broad positive potential. Its very nascency makes it an excellent subject for social science investigation. However, it could also be argued that the debate is not much further forward; currently, analysis of nanotechnology's potential effect on society tends to focus narrowly on the possible toxicity of nanoparticles to human and environmental health, detracting attention from discussions of nanotechnology's wider impacts. There is also an emphasis on public engagement with technological development which, while important, seems to dominate social science activity.

The discussion of conceptions of nanotechnology is less dominated by clear-cut positions and definitional issues have come to the fore. Yet strict definitions may be irrelevant as perspectives on how it is best pursued and what it can achieve become more important.

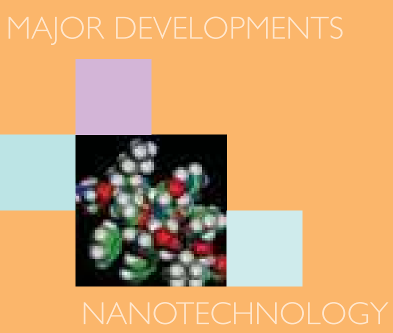
In view of the very limited appeal of the Drexlerian vision amongst practising nanoscientists, a broader debate and even downplaying of the radical views of extreme utopians and dystopians is probably to be welcomed. Indeed one could argue that, given the scientific consensus rejecting the arguments underpinning these views, they do not deserve much attention. Even our ESRC report of 2003 may have given too much space to these views. On the one hand, their role in the debate is, in our judgement, constraining the scope of the debate. But, however, they can not be ignored entirely as these radical visions have had a considerable influence on the way the debate has been framed. They will continue to influence the avenues down which the debate will go, and they are particularly likely to lead to greater consideration being given to the human enhancement issue. Moreover, because of the media profile and popular appeal of the proponents of these views, they may have a disproportionate influence on the course of debates on such issues.

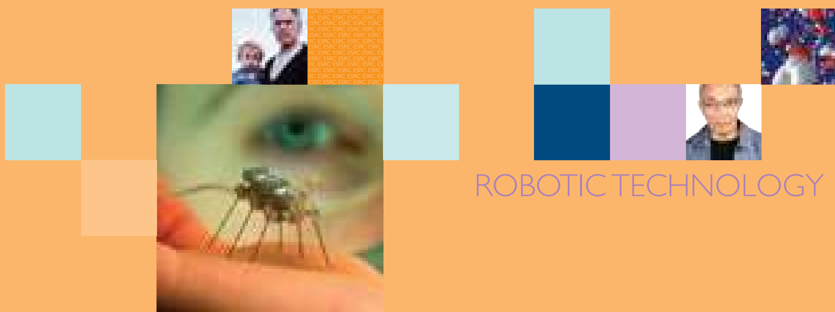
The radical futuristic perspective, as we have seen, is still prominent in the analysis of nanotechnology's potential social impacts. But much of this analysis has been aimed at identifying more precisely the areas in need of investigation. Some commentators have adopted the strategy of listing areas in which social science research can be applied, whilst other focus on more specific areas such as the potential hazards of nanoparticles, impacts of nanotechnology on the developing world and engaging society in technology development.

What is clear is that nanotechnology is viewed as novel and interesting; it is both a useful example for study and perhaps unique in its blurring of traditional scientific boundaries.

4 CONCLUSIONS AND THE NEXT STAGE

In our judgement, the scientific and commercial landscape of nanotechnology has not substantially altered so far in this decade. A growing range of products, including consumer products, which can plausibly claim to involve nanotechnology, are coming to market, as summarised in the recent inventory from the Project on Emerging Nanotechnologies at the Woodrow Wilson Institute (2006). There has been an increasing emphasis in academic nanotechnology on the potential importance of medical applications – see for example the European Science Foundation's Scientific Forward Look on Nanomedicine (2005), and the inclusion of Nanomedicine on the US's National Institute of Health's roadmap (2006). The potential long-term importance of nanotechnology in the microelectronics industry is underlined by the formal inclusion for the first time of molecular electronics and quantum computing in the 2005 edition of the International Technology Roadmap for Semiconductors (2005). The idea of synthetic biology has risen in prominence; although this is typically not linked explicitly with nanotechnology it is very closely allied.





The social processes and institutions through which nanotechnology will be developed may however have evolved. New mechanisms and networks are in embryonic form but yet may be important. In particular it is possible that while nanoscience provides the ferment for nanotechnology and can be distinguished from it, nanotechnology itself is part of the transition to "Mode 2" science (Gibbons et al., 1994), in which knowledge is generated in a fundamentally interdisciplinary fashion, explicitly in the context of application and indeed a crucial element of it. We could indeed pose the issue the other way round: can really beneficial evolutionary nanotechnology be created without the social and economic changes that create mode 2 science and technology? Such questions merit further exploration.

While discussion of the social issues has not been limited to the public-science interface, it has not extended sufficiently into these and other issues surrounding the development of nanotechnology. Nanotechnology has not as yet been used as an opportunity to develop further our understanding of what we called "the drivers and processes of decisions at the various choice points in the process of technological development" (Wood et al., 2003: 40). Allied to this there has been an almost total neglect of the economic considerations.

From our analysis of the nanotechnology field, discussion around social, ethical and environmental issues arising from the development of nanotechnology is rather unbalanced. Two broad areas – the question of the possible toxicity of nanoparticles, and questions around public engagement and the democratisation of governance of science – have so far dominated the discourse. The first of these questions is at its heart a science issue rather than a social science issue, but social science issues related to regulation and risk perception are not far from the surface. In our judgement this leaves many issues that are not being addressed. We conclude by listing some of them.

THE DEVELOPMENT OF NANOTECHNOLOGY

Nanotechnology has some distinctive features as a case study for the social science of science, as it appears to have arisen not just as a natural development from existing disciplines, but at least partly as a result of external factors. This poses a number of interesting questions:

1. Is nanotechnology developing into a distinct field – that is, are there social and institutional pressures causing scientists in well-established disciplines such as chemistry and physics to assume a new disciplinary identity?
2. Is the nucleation of the field of nanotechnology, if this indeed is taking place, an integral part of the transformation of science from Mode 1-type to Mode 2-type and is nanotechnology being developed as a field precisely by those scientists who embrace Mode 2 values?
3. Are the grand visions associated with radical views of nanotechnology influential in shaping the development of science and technology, despite the rejection by many scientists of the assumptions on which they are based?

NANOTECHNOLOGY, INDUSTRY AND THE ECONOMY

Nanotechnology poses important questions in relation to technological innovation and its relationship to wealth creation. Governments and agencies worldwide are providing substantial financial support for nanotechnology on the basis of tacit or explicit assumptions that this support will yield substantial economic dividend. These assumptions need critical examination; some questions that arise include the following:

1 Is there, or will there ever be, a nanotechnology industry?

2 Will there be 'nanotech' clusters comparable to 'biotech' and information technology clusters?

3 Will these be geographical clusters, or could there be virtual clusters?

4 Will there be clusters associated with discrete sub-areas of nanotechnology, such as (for example) bionanotechnology for diagnostics?

5 As governments look to nanotechnology as a driver of innovation and economic growth, tacit or explicit models of the innovation process are being invoked to help frame policy. Are these models of innovation applicable to nanotechnology (or indeed any other new technology)?

NANOTECHNOLOGY AND INTERNATIONALISATION

Government support for nanotechnology has included non-western countries and the EU, making it a unique and important case study in the further internationalisation of science and innovation. Questions that arise from this include:

1 What is the scope for government policy to influence innovations in the nanotechnology area, both between and within organisations, in an increasingly global economy?

2 Is there an emerging international division of labour in the development of nanotechnology?

3 Can nanotechnology make significant contributions to the development of less-developed countries? Contrasts between China and India, which are receiving most attention, with countries where nanotechnology has been given a significant role in plans but are receiving less attention, like Brazil, may be instructive.

4 Is there any truth in the caricature of the 'Wild East', i.e. a place without ethical or intellectual property-bound constraints unfairly competing with western countries?

5 As nanotechnology may be the first science in modern times in which substantial and original developments take place in non-western cultures, can it offer any insights about cultural relativism in science?

TECHNOLOGY DEVELOPMENT AND SOCIETY

The portrayal of nanotechnology in popular culture is strongly influenced by social movements outside the scientific mainstream. The significance of this unusual feature should be examined:

1. Some futurists argue that nanotechnology itself is accelerating the rate of technological change and hence social change – does this stand up to scrutiny?
2. How does nanotechnology fit into broader social movements about technology development, and do such movements depend on grand visions (positive or negative)?
3. Is there any significance to those movements, such as transhumanism, which are associated with the promotion of more futuristic visions of nanotechnology? What role do these movements have in shaping broader societal debates, such as the nascent debate about human enhancement?

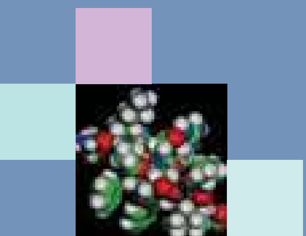
PUBLIC ENGAGEMENT

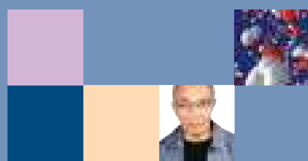
The widespread consensus about the desirability of public engagement in connection with nanotechnology should receive some critical scrutiny:

1. The public engagement activities and the methods used could be evaluated, including a cross-country comparison of the various experiments in it and the role of the dissemination of scientific knowledge within this process.
2. While accepting the force of the critique of the deficit model of public understanding, one needs to understand the origins of the public's understanding of nanotechnology, and particularly the relative influence of the various interest groups, whose visions of nanotechnology may be very different, as well as popular media, serious journalism, science fiction, and computer games.

APPENDICES

ONE . TWO . THREE . FOUR





APPENDIX I

SOCIAL AND ETHICAL QUESTIONS POSED BY SHEREMETA AND DAAR (2004)

Proposed Taxonomy of the Major Issues Likely to Face Nanotechnology Research, Development and Commercialisation in Canada

I Public Perception and Public Engagement

- What is the nature and source of public perception about nanotechnology in Canada and abroad?
- What is the nature and impact of popular representations of nanotechnology?
- What should the role of scientists be in the broad public debate about nanotechnology?
- What communication and public engagement strategies are needed to foster an authentic debate about the risks and benefits of nanotechnology?

II Regulatory Issues

- What are the effects of nanoparticles and nanomaterials on the environment and on humans?
- What ought the role of the 'precautionary principle' be in the regulation of nanomaterials and nanotechnology?
- Given their unique properties, can nanomaterials be appropriately regulated under existing regulatory regimes?
- If legislative and/or regulatory and policy reform is deemed necessary in the context of nanotechnology, unprecedented cooperation between various levels of government and various agencies within those levels of government will be needed. How can government best ensure that the regulatory framework encompassing nanotechnology will be logical, efficient, transparent and readily adaptable to technological change?

III Economic and Commercialisation Issues

A General Commercialisation Issues

- What will the economic impact of nanotechnology be? How will the economic effects of nanotechnology commercialisation impact the various economic sectors?
- If nanotechnology is a disruptive technology, what methods can we use to evaluate its impact on the economy?
- In what ways, if any, will the commercialisation of nanotechnology differ from the commercialisation of other technologies? Will there be unique opportunities for conflicts of interest to arise?

B Intellectual Property Issues

- What are the intellectual property issues that will arise in the area of nanotechnology? Will the issues be different from those encountered with other emerging technologies?
- Will the accrual and exploitation of intellectual property as part of the commercial process create unique challenges to the commercialisation of nanotechnology?

IV Equity and Global Governance Issues

- What will the impact of nanotechnology be on the developing world and on disadvantaged communities in Canada?
- How can we ensure that the fruits of nanotechnology are shared equitably by people in developing countries and by marginalised communities in Canada – and avoid the creation of a 'nanodivide'?
- Is there a role for benefit-sharing in the context of nanotech commercialisation?

V Philosophical and Ethical Issues

- What are the larger philosophical issues that need to be addressed in relation to nanotechnology?
- What will the impact of nanotechnology be on the perception and definition of normalcy, health and disease?
- How, and in what areas, will nanoscience and nanotechnology challenge the traditionally conceived concepts of privacy and confidentiality?

VI Application-Specific Issues

- What are the anticipated military uses of nanotechnology? How should they be regulated?
- What are the potential applications of nanotechnology in medicine? How will they challenge the existing ethical, legal and social frameworks?
- What are the anticipated disability and enhancement related applications of nanotechnology? How will these applications impact society?

APPENDIX 2

BIBLIOGRAPHY

Allianz/OECD. (2005) *Small sizes that matter: Opportunities and risks of Nanotechnologies*.

Anderson, A, Allan, S, Peterson, A and Wilkinson, C. (2005) The Framing of Nanotechnologies in the British Newspaper Press, *Science Communication*, 27:2, pp.200-220.

Arnall, AH. (2003) *Future Technologies, Today's Choices*, Greenpeace Environmental Trust: London.

Balbus, J, Denison, R, Florini, K and Walsh S. (2005) Getting Nanotechnology Right the First Time, *Issues in Science and Technology*, Summer 2005. Available at http://www.issues.org/21.4/balbus.html [accessed on 8 May 2006].

Benner, S. and Sismour, M. (2005) Synthetic Biology, *Nature Reviews Genetics* 6, 533-543.

Bensaude-Vincent, B. (2004) Two Cultures of Nanotechnology?, *Hyle*, 10:2, pp.65-82. Available at http://www.hyle.org/journal/issues/10-2/bensaude.htm [accessed on 4 May 2006].

Berube, D. (2006) *Nano-hype: The Truth Behind the Nanotechnology Buzz*, Amherst, New York: Prometheus Books.

Bruce, D. (2005) Making the world better?, *New Scientist*, 11 June 2005, p.21.

Cobb, MD. (2005) Framing Effects on Public Opinion about Nanotechnology, *Science Communication*, 27:2, pp.221-239.

Colvin, VL. (2004) Sustainability for Nanotechnology, *The Scientist*, 18:16, 30 Aug 2004, p.26.

Dinkelacker, J. (2002) *Transition to Tomorrow: Social Institutions at the Threshold of Nanotechnology's Molecular Epoch.*

Drexler, KE and Smalley, RE. (2003) Point-Counterpoint, *Chemical and Engineering News*, 81:48, 1 December 2003, pp.37-42.

Drexler, KE. (1986) *Engines of Creation*, New York: Anchor Press/Doubleday.

Drexler, KE. (1992) *Nanosystems: Molecular Machinery, Manufacturing, and Computation*, Wiley.

Drexler, KE. (2004) Nanotechnology: From Feynman to Funding, *Bulletin of Science, Technology & Society*, 24:1, pp.21-27.

Dunkley, RWS. (2004) Nanotechnology: social consequences and future implications, Futures 36, pp.1129-1132.

Eisensiedel, EF and Goldenberg, L. (2004) Dwarfing the Social? Nanotechnology Lessons from the Biotechnology Front, *Bulletin of Science, Technology & Society*, 24:1, pp.28-33.

ETC Group. (2005a) *A Tiny Primer on Nano-scale Technologies and 'the Little Bang Theory'*.

ETC Group. (2005b) *NanoGeoPolitics: ETC Group Surveys the Political Landscape*.

European Science Foundation. (2005) *ESF Forward Look on Nanomedicine*. Available at http://www.esf.org/esf_article.php?language=0&article=347&domain=2&activity=8 [accessed on 4 May 2006].

Feynman, R. (1959) *There's Plenty of Room at the Bottom*, 1959. Available at http://www.zyvex.com/nanotech/feynman.html [accessed 11 May 2006].

Gibbons, M, et al (1994) *The New Production of Knowledge*. London: Sage.

Gordijn, B. (2003) Nanoethics: From Utopian Dreams and Apocalyptic Nightmares towards a more Balanced View, UNESCO. Available at http://portal.unesco.org/shs/en/file_download.php/7c19013ff6599f7bfd12e38868a1fbcaNanoethics.pdf [accessed on 4 May 2006].

Grunwald, A. (2005) Nanotechnology – A New Field of Ethical Inquiry?, *Science and Engineering Ethics*, 11, pp.187-201.

Hassan, MHA. (2005) Small Things and Big Changes in the Developing World, *Science*, 309, 1 July 2005, pp.65-66.

HM Government. (2005) *The Government's Outline Programme for Public Engagement on Nanotechnologies.* Available at http://www.ost.gov.uk/policy/issues/nidg.htm [accessed on 4 May 2006].

Hornig Priest, S. (2005) Commentary – Room at the Bottom of Pandora's Box: Peril and Promise in Communicating Nanotechnology, *Science Communication*, 27:2, pp.292-299.

International Technology Roadmap for Semiconductors (2005). Available at http://www.itrs.net/ [accessed on 4 May 2006].

Jamison, A. (2005) 'On Nanotechnology and Society', *EASST (European Association for the Study of Science and Technology) Review*, Volume 24(2/3). Available at: http://www.easst.net/review/sept2005/jamison [accessed on 4 May 2006].

Jones, R. (2004) *Soft Machines: Nanotechnology and Life*, Oxford: Oxford University Press.

Joy, B. (2000) Why the future doesn't need us, *Wired*, 8:04.

Kearnes, M, Macnaghten, P, and Wilsdon, J. (2006) *Governing at the Nanoscale: People, policies and emerging technologies*, London: Demos. Available at http://www.demos.co.uk/catalogue/governingatthenanoscale/ [accessed on 4 May 2006].

Kerr, I and Bassi, G. (2004) Building a Broader Nano-network, *Health Law Review*, 12:3, pp.57-62. Available at http://www.law.ualberta.ca/centres/hli/hl_review.html [accessed on 4 May 2006].

Knight, H, and Pierce, J. (2003) To kill a technology, *The Engineer*, 21 March-3 April, pp.25-29.

Kulinowski, K. (2004) Nanotechnology: From "Wow" to "Yuck"?, *Bulletin of Science, Technology & Society*, 24:1, pp.13-20.

Kurzweil, R. (2006) Reinventing Humanity: the future of human-machine intelligence, *The Futurist* Mar-Apr 2006. Available at www.kurzweilai.net/meme/frame.html?main=/articles/art0635.html [accessed on 4 May 2006].

Lewenstein, BV. (2005) What Counts as a "Social and Ethical Issue" in Nanotechnology?, *Hyle*, 11:1, pp.5-18. Available at http://www.hyle.org/journal/issues/11-1/lewenstein.htm [accessed on 4 May 2006].

Lin, P. (2005) Nanotechnology's Dilemmas: Nanotechnology can learn much from history, *The Scientist*, 19:23, 5 Dec 2005, p.10.

Lopez, J. (2005) Compiling the Ethical, Legal and Social Implications of Nanotechnology, *Health Law Review*, 12:3, pp.24-27. Available at http://www.law.ualberta.ca/centres/hli/hl_review.html [accessed on 4 May 2006].

MacDonald, C. (2004a) Nanotech is Novel; the Ethical Issues are Not, *The Scientist*, 18:3, 16 Feb 2004, p.8.

MacDonald, C. (2004b) Nanotechnology, Privacy and Shifting Social Conventions, *Health Law Review*, 12:3, pp.37-40. Available at http://www.law.ualberta.ca/centres/hli/hl_review.html [accessed on 4 May 2006].

Maclurcan, DC. (2005a) Nanotechnology and Developing Countries Part 1: What Possibilities?, *AZojono – Journal of Nanotechnology Online*, Volume 1. Available at http://www.azonano.com/nanotechnology%20journal%202005.asp [accessed on 4 May 2006].

Maclurclan, DC. (2005b) Nanotechnology and Developing Countries Part 2: What Realities?, *AZojono – Journal of Nanotechnology Online*, Volume 1. Available at http://www.azonano.com/nanotechnology%20journal%202005.asp [accessed on 4 May 2006].

Macnaghten, P, Kearnes, M and Wynne, B. (2005) Nanotechnology, Governance, and Public Deliberation: What Role for the Social Sciences?, *Science Communication*, 27:2, pp.268-291.

McGee, G. (2006) "Nanoethics": The ELSI of 21st Century Bioethics?, *blog.bioethics.net*, 29 January 2006. Available at http://blog.bioethics.net/ [accessed on 9 March 2006].

Mehta, MD. (2004a) Some Thoughts on the Economic Impacts of Assembler-Era Nanotechnology, *Health Law Review*, 12:3, pp.33-36. Available at http://www.law.ualberta.ca/centres/hli/hl_review.html [accessed on 4 May 2006].

Mehta, MD. (2004b) From Biotechnology to Nanotechnology: What Can We Learn From Earlier Technologies?, *Bulletin of Science, Technology & Society*, 24:1, pp.34-39.

Meridian Institute. (2005) *Nanotechnology and the Poor: Opportunities and Risks*. Available at http://www.meridian-nano.org/NanoandPoor-NoGraphics.pdf [accessed on 4 May 2006].

Meyer, M. (2006) Are Co-Active Researchers on Top of their Class? An Exploratory Comparison of Inventor-Authors with their Non-Inventing Peers in Nano-Science and Technology, SPRU Electronic Working Paper Series, No. 144. Available at http://www.sussex.ac.uk/spru/documents/sewp_144.pdf [accessed on 4 May 2006].

Mnyusiwalla, A, et al. (2003) Mind the Gap: Science and Ethics in Nanotechnology, *Nanotechnology*, 14, pp.R9-R13.

Nanoforum. (2005) 4th Nanoforum Report: Benefits, Risks, Ethical, Legal and Social Aspects of Nanotechnology, *Part 5: The Ethical Aspects and Political Implications of Nanotechnology*. Available at http://www.nanoforum.org/nf06~modul~showmore~folder~99999~scid~341~.html?action=longview_publication& [accessed on 4 May 2006].

NanoJury UK. (2005) *Provisional Recommendations*. Available at http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/7249.pdf [accessed on 4 May 2006. Full recommendations seemingly not yet published].

Nanologue project. (2005) *Nanologue Background Paper on selected nanotechnology applications and their ethical, legal and social implications*. Available at http://www.nanologue.net/custom/user/Downloads/NanologueBackgroundPaper.pdf [accessed on 4 May 2006].

National Institute of Health (2006) *Roadmap for Medical Research*. Available at http://nihroadmap.nih.gov/ [accessed on 4 May 2006].

Olsen, S. (2005) Interview with Robert A Freitas Jr. Parts 1&2, *Nanotech.biz*, 4 Nov 2005. Available at www.kurzweilai.net/meme/frame.html?m=18 [Accessed on 4 May 2006].

Parr, D. (2005) Will Nanotechnology make the world a better place?, *Trends in Biotechnology*, 23:8.

Phoenix, C and Drexler, E. (2004) Safe Exponential Manufacturing, *Nanotechnology*, 15, pp.869-872.

Phoenix, C. (2003) Molecular Manufacturing: Start Planning, FAS Public Interest Report, 56:2. Available at http://www.fas.org/faspir/2003/v56n2/nanotech.htm [accessed on 4 May 2006].

President's Council of Advisors on Science and Technology (PCAST). (2005) *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*.

Prince Charles. (2004) *Independent on Sunday*, 11 July 2004. Available at http://www.princeofwales.gov.uk/speeches/health_11072004.html [accessed on 26 April 2006].

Regis, E. (2004) The Incredible Shrinking Man, *Wired* 12.10.

Reynolds, GH. (2006) 'Empowering the Really Little Guys', excerpt from *An Army of Davids* (Nelson Current, 2006). Available at http://www.kurzweilai.net/meme/frame.html?main=/articles/art0663.html [accessed on 18 April 2006].

Rodrigues, R. (2006) The Implications of High-Rate Nanomanufacturing on Society and Personal Privacy, *Bulletin of Science, Technology & Society*, 26:1, pp.28-45.

Royal Netherlands Academy of Arts and Sciences. (2004) *How big can small actually be? Some remarks on research at the nanometre scale and the potential consequences of nanotechnology*.

Royal Society/Royal Academy of Engineering. (2004) *Nanoscience and nanotechnologies: opportunities and uncertainties.*

Royal Society/Science Council of Japan. (2005) *Report of a joint Royal Society-Science Council of Japan workshop on the potential health, environmental and societal impacts of nanotechnologies*.

Salamanca-Buentello, F, Persad, DL, Court, EB, Martin, DK, Daar, AS and Singer, PA. (2005) Nanotechnology and the Developing World, PloS Medicine, 2:4, pp.300-303.

Sandler, R and Kay, WD. (2006) The GMO-Nanotech (Dis)Analogy?, *Bulletin of Science, Technology & Society*, 26:1, pp.57-62.

Schummer, J. (2005) "Societal and Ethical Implications of Nanotechnology": Meanings, Interest Groups, and Social Dynamics, *Techné: Research in Philosophy and Technology*, 8:2. Available at http://scholar.lib.vt.edu/ejournals/SPT/v8n2/schummer.html [accessed on 4 May 2006].

Sheremeta, L and Daar, AS. (2004) The Case for Publicly Funded Research on the Ethical, Environmental, Economic, Legal and Social Issues Raised by Nanoscience and Nanotechnology (NE3LS), *Health Law Review*, 12:3, pp. 74-77. Available at http://www.law.ualberta.ca/centres/hli/hl_review.html [accessed on 4 May 2006].

Small Talk. (2005) *Mid-term Review*. Available at http://www.smalltalk.org.uk/page6g.html [accessed on 4 May 2006].

Small Talk. (2006) *Working Lunch Report*. Available at http://www.smalltalk.org.uk/page6g.html [accessed on 4 May 2006].

Smalley, RE. (2005) *MRS Bulletin*, 30, June 2005, p.312.

Stephens, LF. (2005) News Narratives about Nano S&T in Major US and Non-US Newspapers, *Science Communication*, 27:2, pp.175-199.

Sweeney, AE, Seal, S and Vaidyanathan, P. (2003) The Promises and Perils of Nanoscience and Nanotechnology: Exploring Emerging Social and Ethical Issues, *Bulletin of Science, Technology and Society*, 23:4, pp.236-245.

UN University – Millennium Project. (2005) *2005 State of the Future: Executive Summary*.

United Nations, Millennium Development Goals. Available at http://www.un.org/millenniumgoals/ [accessed on 11 May 2006].

Whitesides, GM. (2005) Nanoscience, Nanotechnology, and Chemistry, *Small*, 1:2, pp.172-179.

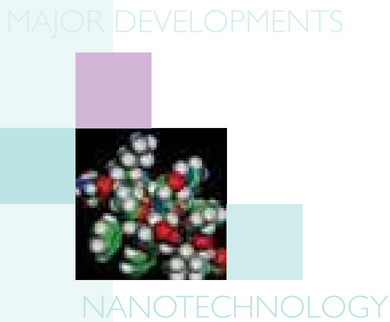
Williams-Jones, B. (2004) A Spoonful of Trust Helps the Nanotech Go Down, *Health Law Review*, 12:3, pp.10-13. Available at http://www.law.ualberta.ca/centres/hli/hl_review.html [accessed on 4 May 2006].

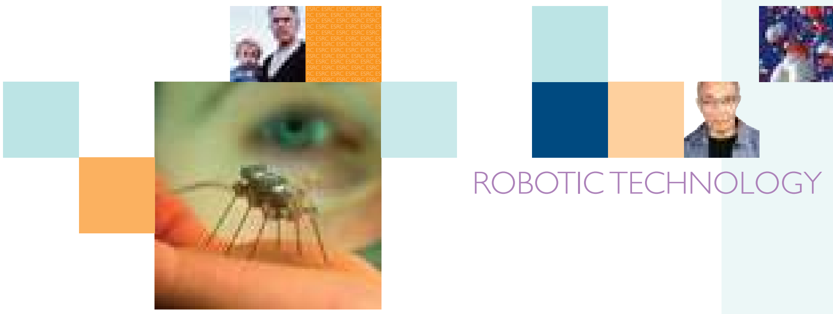
Wilsdon, J and Willis, R. (2004) *See Through Science: why public engagement needs to move upstream*, London: Demos.

Wolkow, RA. (2004) The Ruse and Reality of Nanotechnology, *Health Law Review*, 12:3, pp.14-18. Available at http://www.law.ualberta.ca/centres/hli/hl_review.html [accessed on 4 May 2006].

Wood, S, Jones, R and Geldart, A. (2003) *The Social and Economic Challenges of Nanotechnology*, ESRC. Available at http://www.esrcsocietytoday.ac.uk/ESRCInfoCentre/Images/Nanotechnology_tcm6-5506.pdf [accessed on 14 May 2006].

Woodrow Wilson Center (2006) *Project on Emerging Technologies*. Available at http://www.nanotechproject.org/index.php?id=44 [accessed on 4 May 2006].





APPENDIX 3

A LITERATURE SUMMARY

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Allianz/OECD, 2005	Nanotechnology will have a broad range of applications, although the term is not precise enough for insuring risk. The radical vision is dismissed as being "beyond our capabilities for the foreseeable future".	Focuses on nanoparticles/materials. Cosmetics, medical products/devices, food and agricultural products, automotive, sports articles, self-cleaning clothes, photovoltaics.	There is uncertainty about the potential of nanotechnology, so therefore it is difficult to have a full risk assessment. Possible dangers: toxicity and explosion hazard of nanoparticles, disruption to industry. Also possible benefits: clean water and energy, job and wealth creation, better medical diagnostics and treatment, a cleaner environment.
Anderson et al., 2005	An investigation of the presentation of nanotechnology in the press.	None mentioned.	Study 1 April 2003 – 30 June 2004. The overall picture in the British press is one of optimism; stories are often framed in science fiction terms; the Prince Charles anti-nanotechnology article in April 2003 set the scene for coverage over the next 18 months.
Arnall, 2003 [section on Nanotechnology only]	Nanotechnology is difficult to define and very young; it is not a single field. Distinction between top-down and bottom-up manufacturing; the bottom-up 'dream' is far from being realised.	Near-term applications are materials, applicable in areas of computing, drug delivery, energy and defence. Also mentions more long-term applications, such as a space elevator and nanobots.	Nanotechnology is different and disruptive: "the transition from a pre-nano to a post-nano world could be very traumatic", although the changes will be gradual in the long-term. Broad areas of implication: • Environmental – possible toxicity of nanoparticles. • Sociopolitical – economic impact of molecular manufacturing, medical ethics, the nano-divide and possible destructive uses. • Public Acceptance – scientific community must involve risk and social studies in R&D. • Regulation – precautionary principle.
Balbus et al., 2005	A "potentially limitless collection of technologies and associated materials". Materials at the molecular and atomic scale.	Innovations in cleaner energy production, energy efficiency, water treatment, environmental remediation, improved materials.	Focus on the possible toxicity of nanoparticles. Concerns about the risks. Recommend that the US government needs to do more in toxicity research, improving regulation and engaging stakeholders, otherwise nanotechnology could face a GM-style backlash.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Bensaude-Vincent, 2004	There are two different and opposing scientific cultures underlying the current nanotechnology field: engineering and chemistry.	None mentioned.	Nanotechnology is evolutionary – the concept is part of the philosophical history and traditions of science; there is a division of cultures within the nanotechnology field, leading to the debate in its potential outcomes; theoretically, nanoscience should be about domesticating molecules (as a farmer or sailor has with nature) rather than trying to control them.
Bruce, 2005	Technology is not value-free. Could be discussing any emerging technology.	Medicine.	If the technology is developed to incorporate society's broad values (early in the development process, including setting research agendas), then implications will be positive.
Cobb, 2005	'Nanotechnology' is an umbrella term; framing the technology in certain ways will influence public opinion.	None mentioned.	Study of whether negative or positive framing of nanotechnology's potential affects public perception. Publics currently lack awareness and their opinions are malleable; effective framing needs to tie in with people's values.
Colvin, 2004	Nanotechnology as a new technology and emerging field. Distinction between the science and the technology: commercial technologies for nanoparticles are still several years away.	A wide range of areas from computing to translational medicine; carbon nanotubes.	Possible toxicity of nanoparticles. Scientists must not ignore public concerns – they are now integrated into the research and development process.
Drexler, 2004	Nanotechnology is the vision originally set out by Richard Feynman in 1959 (molecular manufacturing) – scientists working at the scale co-opted the term because it was glamorous and they could attract funding.	Computers, medicine, environment and arms.	Revolutionary improvements in the fields mentioned. The risks of nanoreplicators (if control is lost – grey goo), and misuse of weapons systems. There are risks in denying the feasibility of the Feynman vision, as any dangers will then be unmanageable and the whole field would be in danger of a backlash.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Dunkley, 2004	Nanotechnology is the new frontier – new and unsettled. A Drexlerian definition – precise control of molecules, radical and powerful. Nanotechnology as a single definable entity.	Biotechnology, biometric chemistry and atomic positioning.	The eradication of ageing and disease, nano-manufacturing, the elimination of hunger and the cleaning of the environment. Nanotechnology guarantees sustainability and will bring about a new social order. Questions to ask: • How will economics be transformed? • How will the consumer society fundamentally change? • How will society be constructed? • What new sociological theories are needed? There are also questions about the family, religion and work that need to be asked. Generally utopian, but also warns that there are intrinsic dangers that could lead to a nightmare scenario.
Eisensiedel and Goldenberg, 2004	A 'strategic', 'platform' technology (like biotechnology and IT) that is transformative with a broad application; still in its infancy.	Applicable to health, environment, materials and energy, natural and industrial resources, military.	Important lessons can be learned from experiences of GM emergence – although social science involvement is too often couched simplistically as a PR exercise to gain public acceptance. Some implications are characterised as 'benefits' and 'risks'; also issues of who controls the technology; education and governance.
ETC Group, 2005a	'Nano-scale technology' as revolutionary, a collective term for techniques manipulating matter at the nanoscale, with a possibility of bottom-up assembling. The convergence of technologies – nano, bio, informatics etc – leads to the 'little BANG': Bits, Atoms, Neurons, Genes. This is the "technological quest to control all matter, life and knowledge."	Quantum (nanotube) wires to replace copper; strengthened or synthetic rubber; synthetic cotton.	Toxicity of nanoparticles; concerns about green goo – an uncontrollable merger of living and non-living matter. A detrimental impact on developing world economies as new materials will wipe out demand for natural resources (eg rubber, cotton). Power will be concentrated in multinational corporations, with the patenting of synthesised elements and decisions about what applications to develop. The convergence of technologies will lead to discrimination between 'improved' and 'unimproved' people.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
ETC Group, 2005b	Ranging from the prosaic (products which include nanoparticles) to the radical (nanobiotechnology, and the possibility of part-synthetic, part-living self-replicating nanomachines, as evidenced by research into using viruses and the like to build nano-structures).	None mentioned.	A very radical departure from what has gone before, leading to concerns that the manipulation of matter on the nanoscale will have many implications: • The possible toxicity of nanoparticles. • The inequality of distribution and control of the technology ("scientific imperialism"). • The danger of self-replicating nanobiomachines. Current moves towards regulation are self-serving to those that will profit from the technology; industry is not to be trusted. The attempts at and calls for public engagement are not addressing all the issues, and only serve to improve public acceptance.
Gordijn, 2003	The extreme visions have dominated debate. Nanotechnology is new and rapidly developing, and is many different fields rather than one distinctive field.	None really mentioned – nanoscale structures achieved by 'top-down' or 'bottom-up' methods.	Analyses the ethical debate – largely dominated by extreme visions. Sets out a plan to achieve a more balanced view from which to look at potential ethical issues: 1. Identify the specific fields of nanotechnology (each will present different ethical questions). 2. Identify the objectives of the specific field. 3. Identify if the objectives are ethically desirable. 4. Will further development/research contribute to the realisation of the objectives? 5. What are the ethical problems connected to further development? 6. Are the ethical problems surmountable?

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Grunwald, 2005	Still in early stages, the technology's future is unclear, meaning the ethical issues are too. With regard to ethics, only the realistic possibilities should be studied, not the science fiction elements.	None mentioned.	An analysis of the debate on the need for a separate 'nano-ethics'. Areas that have been so far raised: • Sustainability • Privacy and control • Engineering of nature • Human enhancement/improvement Of these, none are unique to nanotechnology, but the last perhaps calls for further ethical reflection. There is no need for a separate field of 'nano-ethics'. Nanotechnology is a good case study for ethical questions about uncertainty, and provides an opportunity to integrate ethical research into technology development.
Hassan, 2005	A transformative technology, such as steam power, electricity and the internet were.	Batteries, computer chips, drug delivery, facial creams, food processing, solar energy and water purification.	Refutes the claim that the development of nanotechnology will bring about a 'nano-divide' between the developed and developing world. In fact, argues that the developing world is well advanced in its own R&D activities, and intends to use science and technology as a means for economic development (eg China, India, Brazil). In this way, nanotechnology will have a positive impact, and will stop the monopolisation of technology by US corporations.
HM Government, 2005	Nanotechnology as based on the sharpened definitions produced by the RS/RAE report.	None mentioned.	Not specified, but outlines the various activities taking place to engage the public with the development of nanotechnology and its applications. Taking the possible implications and the need for public engagement seriously.
Hornig Priest, 2005	Nanotechnology is an example for social science to use rather than the topic.	None mentioned.	Social science is useful in showing the dynamics of the communication to the public of newly emerging technologies. However, social science should influence not just observe technology development. The idea of 'upstream engagement' still assumes that the technology arrives first as a finished product.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Jamison, 2005	There is much hype around nanoscience/technology, and there are different perspectives on it within the social science community. Observes that the terms 'nanoscience' and 'nanotechnology' are often used interchangeably.	Materials, electronics, medical, military. No specifics but there will be an invisible "technological infrastructure" through convergence.	No explicit judgement as to the positives or negative implications of nanotechnology. However, does see it as a field rich for social science study; research by Johansson into attitudes towards social aspects of nanotechnology by nanoscientists – more interested in funding for research.
Kerr and Bassi, 2004	The debate of extremes is not helpful to formulating social policy. However, "it is also important to contemplate possibilities that are not necessarily congruent with today's forecasts."	None mentioned.	No explicit applications – more guidance on how society can have a debate and foresee any implications. Recommendations that a foresight model should be used, where the long-term future is looked at with a view that "the future is not fixed and that alternatives futures exist" (thereby the extremes are unhelpful in investigating possible social impacts).
Kulinowski, 2004	An emerging and 'broad umbrella' technology, but one that holds great promise and potential; the only field of science that could solve all major global problems.	Medicine, clean energy production, sensors, new materials, new techniques for fabrication, replacement of silicon in computers, military, enhancement of products (tennis balls, stain-resistant chinos, self-cleaning glass, sunscreens).	The 'Wow' (benefits) versus the 'Yuck' (social concerns) index. The Wow index is prominent, but the Yuck index is rising for nanotechnology – societal concerns (such as potential toxicity, genetic improvement coercion, invasions of privacy and discomfort over manipulating nature) must not be ignored by scientists otherwise nanotechnology development could be derailed (as GM was rejected).
Kurzweil, 2006	Radical – the convergence of genetics, robotics and nanotechnology will lead to a "radical evolution" of the human race. Nanotechnology will create tools that allow the physical world to be rebuilt atom-by-atom.	Assemblers, medical diagnostics and drug delivery using nanoparticles, brain implants using intelligent nanobots.	Nanotechnology will be widespread by the mid- to late-2020s, leading to the eradication of disease and ageing, no more poverty, a clean environment and the enhancement of human physicality. Society will have to reconsider the definition of 'human' and redesign our institutions; scientists will also have to relinquish some of the technology as it would be too dangerous (eg self-replicating machines).

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Lewenstein, 2005	Nanotechnology seen as no different from other emerging technologies.	None mentioned.	A discussion of what should be included in a debate on social and ethical issues and how the current debate is being framed. Lewenstein advocates looking at 'issues' rather than 'implications', which imply the technology comes first and in a social vacuum; areas such as environmental, workforce, privacy, national and international politics; intellectual property, human enhancement, the history and philosophy of the technology's development; questions such as 'Who will bear the risks?', 'Who will reap the benefits?' and 'How will decisions be made?'.
Lin, 2005	Speculative and radical: "self-aware artificial intelligence systems" may be a possibility.	Nanosensors for surveillance, nano-enabled weapons, nanofactories, medicine – cellular repair.	Asks questions in 6 specific areas: regulation; environmental and health; society (privacy, human enhancement); politics and markets; personal (medicine advancements); religious and moral. Broad ranging questions that depend on the radical conception of nanotechnology (eg "Is living in the shadow of death an essential part of being human?")
Lopez, 2004	The debate on the social and ethical aspects (ELSI) of nanotechnology has been framed so far using a science fiction narrative device. A "single element is used as the axis around which a future alternative world spins."	None mentioned.	Nanotechnology is not necessarily unique or special ("Would it make sense to group all of our macro-technologies in the same way?"). The vision of the future needs to be framed in different terms for the ESLI to be fully explored.
MacDonald, 2004a	Nanoscience and nanotechnology hold much promise. There are the two extremes – utopian and dystopian – but we should focus on the short- to mid-term plausible uses.	Materials, carbon nanotubes, surveillance uses.	Three major areas: human health, environment, privacy and security. The technology is new but the ethics should be the same, and encompass several broad questions. Calls for a greater synergy between scientists, society and corporations.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
MacDonald, 2004b	Nanotechnology is a disruptive technology that is likely to alter society.	Surveillance technology: smart dust, RFID tags and increased processing power in computers.	It is a new technology but does not need a new approach to ethics. It may be that new technology will shape our values, social constructs that change over time (example of reproductive technology given). Nanotechnology may particularly change social values and standards concerned with the notion of privacy.
Maclurcan, 2005a & 2005b	Currently, nanotechnology refers to applied science exploiting phenomena of the scale; a new and diverse innovation. The author does acknowledge molecular manufacturing (Drexlerian), but does not focus on this perception. Nanotechnology is a recent classification of research, making it difficult to conduct a study into the global distribution of R&D.	TB (and other disease) diagnosis systems and drug delivery, water treatment, energy storage, production and conversion.	Nanotechnology could be of great benefit to developing countries, although there is a polarisation in the discussion as to whether it will aid sustainable development or increase exploitation. There is the potential to empower local communities but developing countries' research programmes are focusing on export markets rather than promoting sustainable development. There is already a 'nano-divide': early signs suggest that nanotechnology will add to inequality in global technology.
Macnaghten et al., 2005	The definition of nanotechnology is still under debate; the label is new, but the science is not. There is interdisciplinarity across a range of fields.	None mentioned.	Social questions are often framed as 'impacts' or 'risks' (which imply a 'downstream' introduction, as well as certainty and logic to technology transfer). The emergence of nanotechnology is an opportunity for social and physical science to integrate better in technological development, not just for social science to be used as a lubricant for commercialisation. There is also the chance for the scientific community to be more self-reflective about its own assumptions and processes.
McGee, 2006	Comparing nanotechnology's social and ethical research in the US to that for the Human Genome Project, which created a new field of 'bioethics'. Nanotechnology is difficult to define, and it is unclear if a specific field even exists.	None mentioned.	Scepticism about whether there is a separate 'nanoethics'; there are no specific issues that stand out from any other technology. However, there are interesting issues that deserve attention, even if they are not specific to nanotechnology.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Mehta, 2004b	Nanotechnology is a transformative technology.	Medicine, electronics, IT, environmental monitoring and remediation, military equipment and weapons.	Nanotechnology is a social and scientific uncertainty. Developments will probably need new approaches to regulation. There are some similarities to biotechnology developments, but the public should be included in decisions made this time.
Mehta, MD, 2004a	Looking at possible scenarios should self-assembly nanotechnology become a reality. A radical perspective, although the means to reach the vision are uncertain.	Nothing specific, but the viewpoint assumes anything will be able to be manufactured, with far fewer raw materials.	This kind of manufacturing could produce a return to a 'mercantilism' rather than the current capitalist system of economics. International trade becomes distorted, with different levels of access: a divide between 'haves' and 'have nots', and nations hoarding assemblers as gold bullion once was. The author acknowledges the paper is highly speculative, but also contends it has a cautionary tone.
Meridian Institute, 2005	Authors quote the RS/RAE definitions. Nanotechnology is diverse: not just one technology, but a huge phenomenon with much investment and interest.	Characterised as 'opportunities': clean water, energy, health (although most possibilities are too high-tech to help the poor), ICT, food and agriculture.	Characterised as 'risks': human health and environment (potential toxicity of nanoparticles); socio-economic challenges (equity); public awareness and engagement; regulatory capacity; ethical (human enhancement/surveillance); ownership and access. Responsible development by corporations is needed; accessing the 'poor' market could bring greater public acceptance of the technology.
Meyer, 2006	The interdependency between scientific research and technology development, and the increasing blurring of the boundary between the two. A study using nanotechnology research and patenting to determine if this is having a detrimental effect.	None mentioned.	The possibility of lowered research performance of more commercially active scientists. However, the study described does not find this to be the case.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Nanoforum, 2005	Nanotechnologies will affect all aspects of life: it is inferred that they have the potential to be radical. The technology is inevitable, and its development and potential all-pervasiveness should be seen as desirable. The authors have a very broad and vague (including molecular manufacturing) definition, but acknowledge that the transfer from lab to marketplace needs investment and is not a simple process.	Medicine: patient care and therapy, such as implants, screening, and human enhancement (eg neural implants); surveillance; military uses.	Social impacts will be many; the research into ethical questions should be framed using 3 ethical systems: Guardian, Commercial and Information. Three questions must be asked: • What are the risks? • How, and to whom, do we share knowledge of the risks? • How do we achieve public acceptance and equal access? Lessons from controversies such as GM crops must be learned; there is a public ignorance and lack of transparency in the scientific community. A backlash can be avoided by funding social science research and establishing bodies to look at regulation and legislation.
Nanologue, 2005	Use the RS/RAE definitions of nanoscience and nanotechnology.	3 major areas: • Energy: fuel cells, solar cells, batteries • Food packaging; antimicrobial, smart packaging etc. • Medical diagnostics: lab-on-a-chip, in-vivo diagnostic tools.	Explicitly mapping the perceived opportunities and threats for each application area, based on their own literature survey. Very focused, with numerous opportunities and threats identified in relation to specific areas: • Environmental performance. • Human health. • Privacy. • Access. • Acceptance. • Liability. • Regulation and control. Many of the issues are not necessarily unique to nanotechnology. The authors aim to provide background information from which the debate can have a platform.
Olsen, 2005	Interviewing Robert Freitas: Nanotechnology is the engineering of molecularly precise structures and machines. In the future, there will be complex nanodevices and nanorobots – it is inevitable technological evolution.	Focus on medical nanobots – in vivo devices to clean up the body (available "perhaps in the 2020s").	Almost all diseases and conditions will be curable; it will be possible to eradicate all infectious disease; medical practice will be revolutionised.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Parr, 2005	Nanotechnology is a diverse field; it is too early to say what products will emerge that will be 'revolutionary'.	Renewable energy/more efficient uses of fossil fuels, military applications, medicine.	Potential negative consequences are a nano-divide, arms race and nanoparticle toxicity. However, it is still too early to say. Social processes must be robust and policy makers/agenda setters willing to take on board the public's perspective. Need a more inclusive development process, with objectives that respond to society's demands and values, and accountable underlying governance for the technology to be accepted.
Phoenix & Drexler, 2004	Nanotechnology is a broadly used term – Drexler uses the phrases 'molecular nanotechnology' or 'molecular manufacturing' to describe his vision of engineering at the nanoscale.	A 'nanofactory' manufacturing system is promoted, rather than autonomous self-replicating nanobots.	The implications will be largely positive, and dangers are characterised as 'risks': • 'Non-replicating weapons' may be open to abuse. Questions of military power and political control. • Disruption to economies and international relations due to a decrease in international trade for resources. • Environment: nanofactories will be clean and efficient, but could produce vast quantities of products.
Phoenix, 2003	Radical: molecular manufacturing is very close to realisation. 3 types of nanotechnology: • Structural – materials. • Science fiction – roaming nanobots. • Molecular – combine chemistry and fabrication to produce precise machines and manufacturing systems at the nano scale (nanofactories). It is inevitable.	"New kinds of products and weapons".	Benefits: • Fast and cheap production (economic value & military significance). Risks: • A new unstable arms race; also criminals and terrorists easily getting hold of new smart weapons. • Surveillance – invasions of privacy. • Grey goo – theoretically possible. • Substantial economic disruption – reduction of value of capital and labour. • Difficult to prevent a black market and maintain control.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Regis, 2004	Nanotechnology is still a "fledgling discipline", but "increasingly glamorous". The debate has marginalised Drexler and the radical vision.	None mentioned.	Drexler's rejection from the scientific and political establishments means he has now abandoned his 'staple rhetoric' of self-replicating nanomachines, and wants to rename his conception 'zettatechnology'. Still believes molecular manufacturing is feasible and will be an inexpensive method of manufacturing.
Reynolds, 2006	Nanotechnology as molecular manufacturing and computing – revolutionary. Four labels/categories: Fake (a marketing term), Simple (mundane materials), Major (advanced devices), Spooky (molecular manufacturing).	Assemblers.	Possibility of a utopia of no ownership: material goods would have no value as they would be cheap and ubiquitous. Time and knowledge become the most valuable commodities. The 'simple' applications will also have a revolutionary impact, but there are dangers of deliberate misuse of the ('spooky') technology.
Rodrigues, 2006	Nanotechnologies as a range of technologies whose common feature is the length scale. An emerging technology which is largely still in the research phase.	Focus on sensors – biomedical, surveillance and security, commercial.	The development of nanoscale sensors may affect individual privacy; although all emerging technologies are often perceived to be a threat in this area, nanoscale devices have a unique issue: their size. The main concerns are the accountability of users of the technology and the potential for abuse of legitimate technology. Despite this, the benefits can be developed and the risks minimised.
Royal Netherlands Academy, 2004	Strictly defined as science and technology at the nanometre scale: "nanotechnology is production technology that is precise at molecular level; nanotechnology reveals new properties of matter that are dependent on dimensions and integrates scientific disciplines." Nanotechnology is unique and exciting, but is an incremental development of physics, chemistry and biology. The current state of nanotechnology is largely nanoscience.	Nanotechnology is widely applicable, "from medicine to materials science."	There are potential damaging effects of nanoparticles to human health and the environment (eg buckyballs and quantum dots). Self-replicating nanobots are a "highly unlikely scenario" and "entirely unrealistic". What is important is public engagement, and scientists need to inform and explain the consequences of their research. There are lessons to be learned from the GM controversy, and the introduction of new technologies should be carefully managed.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Royal Society/Royal Academy of Engineering (RS/RAE), 2004	Very sharply defined: Nanoscience: "is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale." Nanotechnologies: "are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale." It is made clear that the transference of the science to technology is not a straightforward process.	Many, put in four broad categories: nanomaterials; nanometrology (measurement); electronics, optoelectronics and ICT; bionanotechnology and nanomedicine.	Distinctions are made between health, safety and environmental impacts; social and ethical impacts; and economic and political impacts. Of the first, there is much talk about the potential toxicity of nanoparticles. All other developments are seen to not have any potential impact in this area. In the second two areas, it is believed to be too early to really examine possible implications, as only long-term (20+ years) applications will impact these areas. However, some areas of concern are mentioned: governance of the technology, who will control its development, who will benefit, civil liberties and privacy, and human enhancement (although this is seen as very futuristic). Otherwise, nanotechnologies are seen to be generally beneficial to society, although developments need to be monitored and potential implications discussed.
Royal Society/Science Council of Japan, 2005	RS/RAE report definitions – the workshop is a response to the report.	Nanoparticles and nanotubes – nanomaterials.	Largely focuses on the possible toxicity of nanoparticles and parallels with asbestos. Nanotechnology will bring economic growth. Regulation and stakeholder engagement is needed, with current research insufficient.
Salamanca-Buentello et al., 2005	Nanotechnology as "the study, design, creation, synthesis, manipulation and application of functional materials, devices and systems" at the nanoscale. Nanotechnology as a single definable entity.	Energy, agricultural, water treatment, disease diagnosis and screening, drug delivery, food processing, air pollution, construction, health screening and pest detection and control. (The top ten applications that will help developing countries.)	The authors see positive outcomes for the developing world, in potential applications, economic growth and sustainable development. They acknowledge that science and technology alone are not the 'silver bullet', but have a crucial role to play. Technology development needs to be guided, but there are no negative implications for the developing world mentioned.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Sandler and Kay, 2006	Very broad and diverse, where the diverse nature of nanotechnologies makes a GM-like backlash very unlikely.	From the mundane (improved sunscreen and paints) to the more revolutionary (human enhancement, molecular manufacturing).	Nanotechnology's incredible diversity makes a broad-based rejection by society very unlikely, and the reasons for the rejection of GMOs cannot be applied to nanotechnologies. The GM comparison promotes public acceptance as the reason for social/ethical research and public engagement, rather than democratisation of technology development.
Schummer, 2005	Nanotechnology is immature, with a lack of meaningful definitions and much hype. This makes it difficult for social science research, which is either too early (the technology is too undefined), or too late (everyone in the debate already has an opinion on social issues).	Not relevant.	Different interest groups in the nanotechnology debate are identified, each with a different conception of social and ethical issues: • Science Fiction Authors. • Scientists. • Policy makers and Science Managers • Business. • Transhumanists. • The Media and the Public. • Cultural and Social Scientists. Although nano-scientists and social scientists are best placed to comment on social and ethical implications, they have the least impact. Other groups form a 'visionary alliance' and it is this which most influences popular conceptions.
Sheremeta & Daar, 2004	Not a radical view of nanotechnology, but have identified that ethical, environmental, economic, legal and social issues that need to be researched and termed them NE^3LS.	The only specific fields mentioned are military, medicine and disability.	The authors outline the broad ethical areas that they feel should be investigated: • Public Perception & Engagement. • Regulatory. • Economic & Commercialisation. • Equity & Global Governance. • Philosophical & Ethical. • Application-specific. Aside from our ESRC report in 2003, this is probably one of the most comprehensive list of the questions that should be asked in different areas concerning the impact of nanotechnologies.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Stephens, 2005	A new, uncertain and controversial science. Uses the NNI definition.	Nanomaterials.	Analytical study of the coverage in newspapers 1988-July 2004. 'ELSI' issues become more prominent in 2004. The tone of coverage is generally positive, with a ratio of 3:1 articles favouring the sentiment that benefits outweigh risks.
Sweeney et al., 2003	National Institute of Health (US) definition – akin to RS/RAE's definition. However, discusses a series of seminars given to students on social and ethical issues during a nanotechnology summer programme, which were based on commentary by Feynman, Drexler, Kurzweil, Joy and Merkle, suggesting a radical conception.	Environmental (eg rebuilding the ozone layer with nanobots), medical (eg nanosurgery), electronic (eg molecular computers), and materials (eg 'smart' materials).	After an outline of ethical systems, the authors put forward some areas of interest relating to possible social implications: • National and global economics. • Environmental sustainability. • Pharmaceuticals. • Human life span and quality of life. • Education/workforce preparation. • Ownership of technology. • Academia/industry/government relationships. • Involvement of the public in technology development.
UN University, 2005	Nanotechnology is generally beneficial but prosaic.	Artificial blood cells, highly efficient batteries, military/terrorist uses.	A generally beneficial technology, although the risks must be examined, such as the toxicity of nanoparticles for human health and potential for environmental pollution. This report on broad global issues gives nanotechnology huge importance by devoting a whole chapter to it.
Whitesides, 2005	Distinguishes between nanoscience and nanotechnology. There is an evolutionary nanotechnology, based on scaled-down existing products. Revolutionary nanotechnology, using fundamentally new science, is still undefined, and the science is not yet translated into technology.	Microelectronics, materials science, chemistry.	There are risks (potential for harm): self-replicating machines and grey goo (the creation of a new form of life) are very unlikely; possible toxicity of nanoparticles; threats to privacy and civil liberties. The chemical industry may need to move "downstream".
Williams-Jones, 2004	Nanotechnology is an area of hype, but an important one whose social impact should be studied.	None mentioned.	None specifically, but in order to avoid the same fate as GM technology and to foster public trust in technology development, the hype and debate should not be ignored. Meaningful public engagement is essential.

AUTHOR, YEAR	PERSPECTIVE ON NANOTECHNOLOGY	APPLICATIONS MENTIONED	SOCIAL AND ECONOMIC IMPLICATIONS (explicit or implied)
Wolkow, 2004	Speculative. Sees nanotechnology as revolutionary with much potential for change. However, does acknowledge the incremental nature of much of the science, and dismisses the Drexlerian view.	Silicon molecular detectors for medical use; molecular computers (in 10+ years).	"Due to the transforming potential of these technologies, there are substantial societal implications." – this is not expanded and no implications mentioned. However, changes will be gradual and "early manifestations of nanotechnology will not be dramatic."

APPENDIX 4

NANOTECHNOLOGY PUBLIC ENGAGEMENT SUMMARY

GROUP	BACKGROUND/ PURPOSE	METHODS/ MEMBERSHIP	RECOMMENDATIONS/ MAIN POINTS/CONCERNS	LITERATURE PRODUCED
Nano Jury UK	Established as a citizen's forum to ensure public influence on the development of nanotechnologies. Sponsored by the IRC in Nanotechnology at the University of Cambridge, Greenpeace UK, the Guardian and the Policy, Ethics and Life Sciences Research Centre at the University of Newcastle.	Recommendations for how nano research should develop with social considerations as an integral part. Looking at Health, ICT, Energy and with general recommendations.	• Want technology to have a positive benefit to people's lives. • Concerned about the possible safety risks of nanoparticles. • Also possible inequalities of technology development – access for the poor.	Provisional recommendations Sep 2005; Reflections and Implications of Recommendations, Dr. Douglas Parr, Greenpeace.
NanoDialogues – Demos	To explore how social intelligence can inform decision-making in nanotechnology funding and diffusion. Funded by The Office of Science and Technology's Sciencewise project.	4 strands in partnership with various organisations: • Nanoparticles, risk and regulation, with the Environment Agency. • Bio-nanotechnology and the implications of convergence, with the BBSRC & EPSRC. • Public engagement in the corporate. innovation cycle, with a large company involved in nano R&D (tbc). • Globalisation and nano diffusion with Practical Action (http://www.practical action.org/ – 'Technology challenging poverty').	No findings yet. Key questions are: • Are existing regulatory frameworks sufficient for dealing with nanoparticles and other novel applications at the nanoscale? If not, how can they be improved? • What might be at stake in convergence between bio and nanotechnologies? How can research priorities anticipate and reflect these concerns? • What assumptions are made about public attitudes throughout the R&D process? At what stage can social intelligence be brought into the mix? • How can debates about nanotechnologies be extended to include publics in developing countries? What are the potential impacts and concerns from the perspective of communities in Kenya and Sri Lanka?	None yet.

GROUP	BACKGROUND/ PURPOSE	METHODS/ MEMBERSHIP	RECOMMENDATIONS/ MAIN POINTS/CONCERNS	LITERATURE PRODUCED
Lancaster University / ESRC – Sustainable Technologies Programme / Demos – Nanotechnology, Risk and Sustainability	Two year ESRC-funded project which "aimed to understand the social and scientific visions that are influencing nanotechnology research, and develop opportunities for 'upstream' dialogue between scientists and the wider public."	Interviews with scientists and policy-makers, observations in nanoscience labs, series of public focus groups where nanoscientists met citizens.	• Lessons can be learnt from experiences with GM. • The 'public' still have a low awareness of what nanotechnology is. • A dialogue between nanoscientists and ordinary citizens was useful, with both sides learning more about the other's perspective.	Governing at the Nanoscale booklet, April 2006. (Available at www.demos.co.uk)
Nanologue	Europe-wide dialogue on benefits, risks and social, ethical and legal implications of nanotechnologies. Overarching objective is to facilitate a dialogue among researchers, business and civil society about the benefits and potential impacts of nanoscience and nanotechnology applications. Funded by EU FP6. Led by Wuppertal Institute in Germany and features consortium partners EMPA (the Swiss Federal Laboratories for Materials Testing and Research) in Switzerland, Forum for the Future in the UK and triple innova of Germany.	The project will last 18 months. Conferences, workshops and interactive website.	None yet – have only completed the first phase, a mapping study which aims to provide an overview of current research and positions on ethical, legal and social aspects (ELSA) of selected nanotechnologies, as a basis for subsequent discussion.	Nanologue Background Paper (Sep 2005); Nanologue Mapping Study (literature study).
Small Talk	Collaborative organisation facilitating events in UK which discuss nanotechnologies – help to develop and evaluate events between stakeholders and capture opinions for policy-makers. Part of government recommendation and general trend in UK to make science more participative. Finished Feb 2006.	Working with established science communication practitioners to facilitate public discussion events.	• Concern about risks as yet unknown. • An expectation of unexpected benefits. • Concern about the impact on developing countries. General perception of nanotechnology and its impacts still vague.	Working Lunch report, 26 Jan 2006; Mid-term Review Nov 2005. http://www.smalltalk.org.uk/page6g.html

GROUP	BACKGROUND/ PURPOSE	METHODS/ MEMBERSHIP	RECOMMENDATIONS/ MAIN POINTS/CONCERNS	LITERATURE PRODUCED
Global Dialogue on Nanotechnology and the Poor	Focus on nanotechnology and its possible impacts on the developing world, led by the Meridian Institute, US independent mediation organisation. Project started in early 2004.	Publish papers, hold multi-stakeholder workshops, online consultation.	Online consultation Jan 24 – Mar 1 2005, asking for responses to the consultation paper. Comments not summarised for key points – available at http://nanotech.dialoguebydesign.net/dbyd.asp until July 2006.	Consultation paper: Nanotechnology and the Poor – Opportunities and Risks (Jan 2005).
The Nanoethics Group, Santa Barbara, CA. (nanoethics.org)	Founded in 2003 – a research & education organisation. They "have no agenda other than to keep an open mind and go where analysis & common sense lead us."	Want to open up the issues to engage the broader public. No explanation of how this is being done.	Quite radical vision of nanotechnology ('also known as molecular manufacturing'). Benefits include nanobots cleaning up the environment and repairing cells; negatives include the potential environmental and human toxicity of nanoparticles, privacy issues, "new, unimaginable forms of torture – disassembling a person at the molecular level or worse", implications for economies if anything can be manufactured easily and cheaply.	Article in The Scientist – 'Nanotechnology's Dilemmas' by Patrick Lin. Will be publishing new journal in 2007 (see nanoethics.org), but not much focus on public engagement.
Rathenau Institute	Dutch institute of technology assessment. Look at various new and existing technologies. Held a public meeting ('Small Technology, Big Consequences') in late 2004 about the social impacts of nanotechnology – kick started new project.	Nanotechnology in Focus project – Phase 1 (early 2005) scoped 5 applications expected within the next 10 years. Phase 2 (Sep 05 – Jun 06) is a dialogue between industry, nano-science, politics, government and social organisations on the social implications of the applications.	Project not yet completed.	Reports published – for outline see http://www.onderzoekinformatie.nl/en/oi/nanotechnologie/overzichtsartikel/publiek/. All reports so far in Dutch. Article in 'Technikfolgenabschatzung: Theorie und Praxis, Dec 2004.

Other groups of interest

- Nanoforum (EU network) – no public engagement activities.
- Nanotechnology Engagement Group (NEG) – overseeing and supporting UK public engagement efforts.
- Nanotechnology Issues Dialogue Group (NIDG) – coordinating UK Government departments.
- Nanotechnology Research Co-ordination Group (NRCG) – develop and coordinate the UK Government research plan into potential social implications.
- ICON (International Council on Nanotechnology – US: 'A partnership for nanotechnology stewardship and sustainability') – have a Public Communication and Outreach section, but will be more a resource for the public, rather than engaging the public in debate.