Science and Public Policy, volume 33, number 1, February 2006, pages 5–16, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, England

Nanotechnology legislation

Contradictory intent? US federal legislation on integrating societal concerns into nanotechnology research and development

Erik Fisher and Roop L Mahajan

This paper argues that the 21st Century Nanotechnology Research and Development (R&D) Act embodies an unresolved tension between two policy trends that pose a growing dilemma for future science and technology (S&T) policy makers: the imperative towards rapid technological implementation; and mounting pressure to conduct technology development with more effective regard to societal considerations. The tension emerges when comparing various 'Program Activities' set forth in the Act that require divergent policy models, by which the legislation attempts to balance international competition with concern over the perceived risks of nanotechnology applications. By prescribing the integration of societal and technical concerns during nanotechnology R&D, the Act could mark a radical shift in S&T policy in so far as it allows the consideration of societal concerns to influence technological activities and outcomes.

Erik Fisher is a professional research associate at the Center for Science and Technology Policy Research, University of Colorado, UCB 488, 1333 Grandview Ave, Boulder CO 80309-0488, USA; E-mail: Erik.Fisher@colorado.edu. Roop L Mahajan is Murphy Chair Professor of Mechanical Engineering, Department of Mechanical Engineering, 427 UCB, University of Colorado, Boulder CO 80309-0427, USA

The authors gratefully acknowledge the helpful comments of Robert Frodeman, Daniel Sarewitz, Douglas Sicker, David Kerner, and two anonymous reviewers.

CONFLICTING PRESSURES facing policy makers regarding the emerging field of nanotechnology have manifested in an unresolved tension within US legislation over the appropriate policy model for publicly funded nanoscale science and engineering (NSE). On the one hand, a steadily escalating international funding race over the massive economic and other gains projected for nanotechnology products has been used to justify an aggressive US approach to promote rapid technological development and accelerated marketplace transfer. On the other hand, heightened awareness of the role that public concerns and perceptions can play in the adoption of new technologies has occasioned extraordinary legislative language requiring research on societal concerns to be integrated into nanotechnology research and development (R&D).

The pressures mirror broader counter trends in technology policy and have produced what appear to be dueling technology policies in the 21st Cen tury Nanotechnology Research and Develop ment Act (Public Law 108-153), which was signed into law on December 3, 2003. After a brief introduction to nanotechnology and an overview of the opposing pressures mentioned above as they had been characterized before the Act's signing, this paper identifies a tension between various 'Program Activities' set forth in the Act that reflect divergent motivations behind US nanotechnology policy.

Erik Fisher is a professional research associate at the Center for Science and Technology Policy Research and a lecturer in humanities for the Farrand Academic Program at the University of Colorado, Boulder. He received a BA in Philosophy and Mathematics from St John's College (Annapolis, Maryland) in 1992 and an MA in Classics from the University of Colorado in 1995. From 1999–2003 he was the Humanities Advisor for the College of Engineering and Applied Science; he developed programs and courses to integrate humanistic and societal considerations into the technical curriculum. He is currently completing a doctorate in science and technology policy studies through the Environmental Studies program at the University of Colorado.

Dr Roop L Mahajan is Murphy Chair Professor of Mechanical Engineering, Director of CAMPmode (NSF I/UCR Center for Advanced Manufacturing and Packaging of Microwave, Optical and Digital Electronics), and Co-Director of MEDICA (MicroElectronic Devices in Cardiovascular Applications) at the University of Colorado, Boulder. He received BSME and MSME degrees from Punjab University, India, and a PhD from Cornell University in 1977. A Technical Staff Member and Supervisor with AT&T Bell Laboratories (Princeton, New Jersey), he was named a Bell Lab Fellow in 1989. Current research interests include Bio-MEMS as sensors and actuators, thermal management including carbon nanotubes, and humanistic engineering.

What is nanotechnology?

In general, nanotechnology refers to the study and manipulation of matter at the nanoscale, which ranges between approximately one and 100 nanometers (one nanometer is a billionth of a meter and is 1000 times smaller than the next largest unit of measurement, the micron.) From this understanding, nanotechnology is largely synonymous with the products and capabilities of NSE. The US National Nanotechnology Initiative (NNI) has a three-fold definition of nanotechnology/NSE that requires operating at the nanoscale, exploiting "novel" properties associated with that scale, and the ability to control or manipulate matter at that scale (NNI, 2004).

The term nanotechnology also has been employed rather broadly to refer to numerous kinds of science and engineering whose only commonality may involve some component being measured in nanometers. Conversely, it has also been used for more specific applications, most notably molecular nanotechnology, which is associated with self-replication of nanoscale devices and whose feasibility is the subject of debate (Baum, 2003).

Nanotechnology relies on techniques characterized as either top down or bottom up, or on a mixture of the two. Top-down approaches continue the trend towards miniaturization that was identified in the 1960s as Moore's Law, which (in generalized form) predicts an exponential rate of increase in the computational ability of machines. Top-down approaches consist of downscaling conventional micro-systems and micro-devices to the nanoscale (Sarro, 2004). Bottom-up approaches consist of imaging or manipulating matter at the level of atoms and molecules (Kawai, 2003). In this case, "atoms and molecules are integrated to form devices, shaping the system atom by atom" (Sarro, 2004).

Since nanotechnology is associated with numerous fields, applications, and techniques, it can be difficult to differentiate among existing, converging, and emerging forms of research. This difficulty is compounded by the tendency of scientists readily to identify themselves with the field. As one author states, "Researchers who once called themselves materials scientists or organic chemists have transmuted into nanotechnologists" (Stix, 2002). In part, this tendency may be because of the efforts of researchers to acquire funding. It has also been suggested that broad usage of the term is warranted to the extent that it symbolically represents a "set of capabilities at the atomic scale" that form the basis for a "technology revolution" (Marburger, 2003).

Conventionally, nano-science and nano-engineering represent clearly distinct stages of nanotechnology development and consist of extending existing sciences (for instance, chemistry) and engineering fields (for instance, fabrication) into the nanoscale to yield new fields (for instance, nanochemistry and nanofabrication). Oftentimes, however, the traditional categories of science and engineering depend upon, drive, and overlap with, one another.

In the case of nanoscale research, for instance, "nanoscale imaging, molecular manipulation, and the extension to molecular devices" are all "closely correlated" (Kawai, 2003). The very term nanotechnology rhetorically highlights technology as the defining feature of the enterprise, emphasizing the role played by invention as opposed to discovery and stressing products, capabilities, and societal outcomes as the objectives of R&D.

Material behavior at the nanoscale is more accurately described by quantum than classical mechanics and can demonstrate properties that do not naturally emerge at, or above, the micro-scale. The prospect of exploiting these properties has been readily used to capture the imagination. In 2003, US National Science Foundation (NSF) Deputy Director Joseph Bordogna stated that, in addition to enhancing computer speed and memory, nanotechnology would enable "materials that are stronger, lighter and smarter by orders of magnitude" (Mokhoff, 2003).

Technologist Ray Kurzweil (2003b) claimed that "portable manufacturing systems will be able to produce virtually any physical product from information for pennies a pound, thereby providing for our physical needs at almost no cost." Speaking to Congress, Kurzweil (2003a) declared that "Nanotechnology and related advanced technologies of the 2020s will bring us the opportunity to overcome age-old problems, including pollution, poverty, disease, and aging." Novel properties at the nanoscale may or may not lead to novel products and consumer applications, let alone the removal of social and natural afflictions, but they will undoubtedly have profound implications for modes of production and enabling technologies.

Wide-ranging lists of impacts have become almost commonplace. In 2000, the NNI listed potential applications in materials and manufacturing, electronics and computer technology, medicine and health, aeronautics and space exploration, environment and energy, biotechnology and agriculture, and national security among the "pervasive" impacts of nanotechnology (National Science and Technology Council, 2000b). Similarly, potential military applications in computers and electronics, sensors, materials, robotics, human-embedded systems, satellites, and chemical and biological weapons "span all areas of warfare" (Altmann, 2004). In short, nanotechnology could have impacts that extend to "all functional behavior of material that is influenced by nanoscale structure" (Marburger, 2003).

Nanotechnology also marks the convergence of engineered systems with fundamental physical, chemical, neurological, and biological processes. Precise and sustained interactions between human technologies and the building blocks of life suggest considerably advanced possibilities. Sensors integrated into the human body at smaller scales than are presently possible could significantly alter non-invasive monitoring, providing greater capabilities to observe, record, detect, and address biological activities. Such advances would further blur the boundaries between the human body and the machines that monitor it, just as predicted advances in artificial intelligence would further blur distinctions between human and machine intelligence.

Existing techniques and products that make use of nanoscale properties are, in most instances, a far cry from what futurists deem possible. Moreover, scientists lack comprehensive knowledge of the physical laws governing nanotechnology systems. Still, there is considerable confidence among researchers and business leaders that nanotechnology represents the 'next step' in technological advancement. Nanotechnology has accordingly been described as promising virtually unlimited opportunities to "remake the world" (Crow and Sarewitz, 2002). Such promises translate into economic opportunities and competitive goads for governments around the world.

Nanotechnology marks the convergence of engineered systems with fundamental physical, chemical, neurological, and biological processes: precise and sustained interactions between human technologies and the building blocks of life suggest considerably advanced possibilities

International competition

The international pursuit of nanotechnology had become decidedly pronounced during the five-year period preceding the passage of the 21st Century Nanotechnology Research and Development Act. Emphasizing that the contest was one of significant proportions, the NSF had estimated that the nanotechnology market would have an economic impact of over US$1 trillion by the year 2015 (Roco and Bainbridge, 2001: 5).

Mihail Roco, chair of the National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering, and Technology traced the race back to 1997 and noted that worldwide investments in nanotechnology took a sharp turn upwards in 2000 (Roco, 2003a). This increase corresponded to the creation of the interagency governmental NNI that Roco stated was soon afterwards emulated by other countries (Roco, 2003b). Roco reported that international nanotechnology funding increased seven times from 1997 to 2003, and that at least 30 countries had created national nanotechnology programs or "activities," bringing the then current worldwide investment in nanotechnology to approximately US$3 billion in 2003 (Roco, 2003a; 2003b.).

A history of the rapid growth in US federal funding for nanotechnology appears in Figure 1 (Huang,

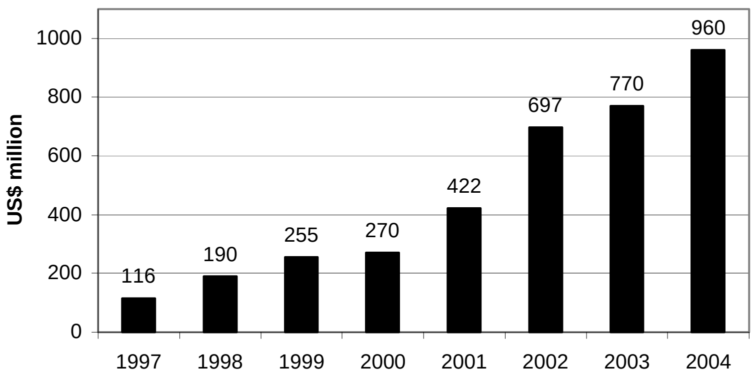

Figure 1. US Federal funding for nanotechnology
Note: Not adjusted for inflation

2004; National Science and Technology Council, 2003; Roco, 2003a). That nanotechnology has had "broad bipartisan backing" (Choi, 2003) in the US is suggested by the fact that the second Bush administration has funded nanotechnology even more assertively than did the Clinton administration, which began the NNI.

While the bulk of revolutionary products was a long way off in 2003, nanotechnology funding was reported to be producing impressive results of another kind. References to NSE in peer-reviewed scientific journals had grown "dramatically" (Mnyusiwalla *et al*, 2003) from just over 3,500 in 1997 to an estimated 10,000 in 2002 (ETC Group, 2003a). Likewise, US nanotechnology patents reportedly had increased from just over 2,000 in 1995 to 6,425 in 2002 (Roco, 2003b).[1] Nevertheless, international competition over nanotechnology was cited to suggest that the US did not have "a commanding lead" as it did in other global technological "megatrends" such as biotechnology, information technology, and nuclear energy (Roco, 2002).

Regardless of the benefits and attractions that nanotechnology may have held for them, US policy makers were, prior to the passage of the Act, under pressure not to be out-competed on the global field. According to one source at the time, "government officials worry that perhaps for the first time in recent memory, the United States does not have a clear advantage" in nanotechnology, a field which Benjamin Wu, Deputy Undersecretary for Technology at the US Department of Commerce, deemed "crucial" for the future economic health of the country (Hines, 2003).

The specter of failing to win the nanotechnology race was also a pronounced theme among business leaders in the private sector during this period. In his congressional testimony, Alan Marty (2003), advisory board member of the Nanobusiness Alliance, urged the House Committee on Science to act "aggressively" in funding nanotechnology, stating:

> "nanotechnology is not dominated by the United States. In several areas of nanotechnology the US is being outpaced by foreign competition. Japan, EU, Russia, Korea, and China are all significant players in the field of nanotechnology."

A similar message came from Christine Peterson (2003), president of the nonprofit Foresight Institute who, in a separate hearing, advised the Committee that failure to develop nanotechnology would "amount to unilateral disarmament" adding that this would be "militarily disastrous."

While a prominent motivation behind US nanotechnology policy would thus appear to have been keeping pace with international competition, the pressure to consider and address societal concerns over nanotechnology represented a substantial counter-weight.

Societal concerns

Despite efforts to increase the pace of nanotechnology development, the success of nanotechnology will not depend on scientific discoveries and technological development alone. These are necessary conditions, but they are hardly sufficient. Commercialization efforts must take into account public opinion, which has the power to dampen economic projections. Counterbalancing the numerous 'benefits' promised by nanotechnology proponents in 2003 was a litany of 'concerns' raised by others about its possible risks, ethical implications, and democratically legitimate pursuit.

The optimistic depiction of nanotechnology as the "next industrial revolution" (National Science and Technology Council, 2000a; 2003) had been questioned by suggestions that it might in the process become the "next asbestos" (ETC Group, 2003a; Mnyusiwalla *et al*, 2003). Prominent entrepreneur and scientist Bill Joy (2000) was well known for stating that nanotechnology-enabled developments could ultimately threaten human survival, either because of superior artificial intelligence (a concern explicitly cited in the Act) or unstoppable self-replication of nano-sized robots out-competing humans for natural resources (the 'grey goo' scenario).

Popular fiction writer Michael Crichton (2002) had vividly depicted horrific scenes of nanotechnology run amok in his work, *Prey*. In 2003, both the ETC Group (2003a) and Greenpeace (Arnall, 2003) released reports critical of nanotechnology. The ETC report may have influenced Prince Charles, the Prince of Wales, to call for precautionary approaches towards nanotechnology, resulting in renewed public references to 'grey goo' in April of 2003 (ETC Group, 2003b).

Less sensational downsides of nanotechnology were routinely raised by ethicists, policy analysts, scientists, and those concerned with its unfettered pursuit. These concerns included: a broad range of product-related societal, ethical, security, health, and environmental issues; process-related political issues of power and choice; and economic issues of distribution.

Many of the specific risks associated with nanotechnology may ultimately come to nothing. Yet, as emerging technologies interact with their human and natural environments, they can give rise to unintended consequences. This much was stated by Sarewitz and Woodhouse (2003), who claimed "we can be reasonably sure that specific nanotechnology applications will have impacts not readily controlled or even understood by those creating or using them." These impacts can be both positive and negative, both reversible and irreversible.

While it is nearly impossible to predict accurately specific forms of unintended consequences in many cases, the simple knowledge that they will occur could therefore be said to entail a responsibility to anticipate them nonetheless. Additionally, while public perceptions and intuitive judgments about risk can be "highly unreliable" (Sunstein, 2002), hasty strategies to deal with or discount them might be similarly injudicious (National Research Council, 2002).

As had been well documented, public resistance to new technologies can jeopardize their commercial success (Cobb and Macoubrie, 2004). For instance, public concerns were not successfully addressed during the advent of the nuclear power industry, when "dramatic opposition" was "engendered in the face of expert assurances of its safety" (Slovic, 1987). This failure led to massive costs for the US nuclear power industry.

More recently, public perceptions about genetically modified (GM) agriculture have been blamed for unrealized profits (*Economist*, 2000), spurring fears that warnings about nanotechnology could "lead the public to exaggerated fears of the unknown, undercutting support for nanotechnology funding" (Altman and Gubrud, 2002). At least a few studies had suggested that nanotechnology, like GM agriculture and nuclear power before it, could be seen as embodying many of the characteristics of a technology ripe for public resistance. Berube (2003) cited the MAST project report (1989) as evidence that nanotechnology falls into similar categories as made previous transformative technologies vulnerable to exaggerated risk perceptions.[2]

The temptation to ignore or dismiss societal concerns about nanotechnology, as the National Research Council (2002) had already noted, could ironically risk making them worse and could risk repeating the nuclear and agricultural biotechnology public relations failures of the past. Economic considerations alone, therefore, gave decision makers a strong motivation to address these concerns (National Research Council, 2002). Speaking six days after the presidential signing of the Act, Philip J Bond (2003), Undersecretary for Technology at the US Department of Commerce, stated:

> "The Act … mandates the establishment of a center and research into the societal and ethical consequences of nanotechnology. … As a business proposition we must identify legitimate ethical and societal issues and address them as soon as possible."

In light of the relative infancy of nanotechnology, this high-level recommendation to factor ethical and societal issues into policy decisions, and to do so early, is notable.

In the case of GM agriculture, public confidence in regulatory systems, or lack thereof, played a key role in public attitudes and perceptions (National Academy of Sciences, 2000; Taylor and Tick, 2003). In a public opinion survey conducted a few months after the Act's passage, Cobb and Macoubrie (2004) find a correlation between lack of trust and heightened perception of risk: "A majority of Americans report low trust in business leaders within the nanotechnology industry to protect them from potential risks." This finding is reportedly in keeping with earlier research that "public fears about technology risks are less about risks directly attributable to a technology than the social and regulatory context in which they are embedded" (Cobb and Macoubrie, 2004).

Addressing societal concerns about nanotechnology may thus require careful consideration and restructuring of the policies that influence its social and regulatory context. Traditional risk assessment, communication, and management frameworks would, accordingly, need to be expanded (for instance, from distinguishing between rational and irrational risk perceptions) to include earning and maintaining public trust in regulatory competency and capacity.

Early consideration of the ethical and societal implications of nanotechnology would represent a departure from such traditional frameworks. In fact, this had been a prominent topic of discourse among Government agencies involved in nanotechnology. The NSF had sponsored a national conference in 2000 and a subsequent report in 2001 on the societal implications of nanotechnology. Also, it had funded multiple research and educational projects related to the subject. Furthermore, in April of 2003, the US Congress held a public hearing on the societal implications of nanotechnology, in part to answer how "research and debate on societal and ethical concerns" can be "integrated into the research and development process" (House Committee on Science, 2003a).

At this hearing, Langdon Winner (2003) stated that technology policy is normally seen as steered only by "a few designated stakeholders." Winner therefore expressly cautioned the House Science Committee against creating a nano-ethics program that would institutionalize a disconnection among societal concerns, research, and science and technology policy. He had in mind the Ethical, Legal, and Societal Implications (ELSI) program of the Human Genome Project, a program that had been regularly criticized for lacking the capacity to influence policy (Kitcher, 2001; Sarewitz, 1996; Wolfe, 2000). If it was to

To influence the development of policy, federally funded consideration of societal issues pertaining to nanotechnology would need to be integrated as an important parameter into either R&D policy or R&D itself, if not both

influence the development of policy, as opposed to being a 'stand alone' entity, federally funded consideration of societal issues pertaining to nanotechnology would need to be integrated as an important parameter into either R&D policy or R&D itself, if not both.

Impressively, the 21st Century Nanotechnology Research and Development Act mandates both forms of integration. At the same time, however, the Act contains language antithetical to this approach. Thus, each of the two driving trends — rapid development in the name of competitiveness and a more considered approach in the name of social acceptability — tends to result in a different and distinct technology policy model for US nanotechnology R&D.

Nanotechnology legislation

The 21st Century Nanotechnology Research and Development Act (2003) marks the first time that the US Federal Government established a program-wide multi-year funding cycle for nanotechnology. As Roco stated, "For the first time, nanotechnology will be institutionalized in the federal government" (Choi, 2003). The Act establishes a National Nanotechnology Program (NNP) and authorizes US$3.7 billion for nanotechnology R&D from fiscal year (FY) 2005 to FY 2008. The legislation does not explicitly lay out the objectives of the NNP. Instead, it defines eleven Program Activities,[3] which, in turn, reflect the various motivations discussed above. We group these Activities into three main categories: techno-scientific; global-economic; and ethical–societal.

General objectives

Seven of the Program Activities are concerned with general objectives, methods, and resources pertaining to technological aspects of nanotechnology funding, research, training, and application. This first group includes Activities (1) – (4), (8), (9), and (11). Activity (1) articulates the governing techno-scientific objective of the legislation: "developing a fundamental understanding of matter that enables control and manipulation at the nanoscale" (all references to Program Activities are from Public Law 108-153). Methodologically, this first grouping of Activities emphasizes a major theme of note: interdisciplinarity.

Specifically, Activities (2), (4), (8), and (9) explicitly require cultivating "interdisciplinary" projects, collaborations, centers, and perspectives. The interdisciplinary nature of nanotechnology R&D can be attributed to at least two main factors, in addition to the mission-oriented nature of the NNP: anticipated applications, which are likely to involve numerous existing industrial sectors; and the fundamental lack of scientific and technological understanding. Importantly, the Act's emphasis on interdisciplinarity also suggests a high level of coordination of R&D on the part of NNP technology administration.

Global-economic considerations

Of the four remaining Program Activities, three can be grouped together as focused on meeting global-economic pressures and opportunities. Activities (5), (6), and (7) prescribe "ensuring … global leadership," "advancing productivity and industrial competitiveness," and "accelerating" nanotechnology deployment, respectively. The first two of these three make explicit reference to the United States in competitive global terms, closely suggesting national policy goals. In this respect, all other Program Activities could be interpreted as the means for advancing Program Activity (5): "ensuring United States global leadership in the development and application of nanotechnology".

If Activities (5) and (6) represent major policy objectives driving the NNP, Activity (7), which calls for "accelerating the deployment and application of nanotechnology research and development in the private sector, including startup companies," designates the traditional means used to achieve them: rapid technological deployment. In addition to cutting-edge research and post-industrial expertise, US legislators expect new technological products. Balancing the rate at which these products are deployed with the need to develop them deliberatively and responsibly is a central policy problem the Act should, but does not, resolve. Framing the NNP in terms of winning a global race through accelerated development and commercialization of nanotechnology is only one possible option, and an extreme one at that, among conceivable policy alternatives.

Societal considerations

The "first to market" concept latent in Program Activity (7) contrasts with the final remaining Program Activity, which forms its own group and prescribes the means by which societal considerations are to be addressed. Program Activity (10) begins:

> "ensuring that ethical, legal, environmental, and other appropriate societal concerns, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity, are considered during the development of nanotechnology."

Whether Program Activity (10) is intended to be an additional means of achieving the objective of global leadership or represents an objective in and of itself, is unclear from the legislation. Either way, a *prima facie* reading of the term "consideration" would suggest careful reflection upon technological options in relation to societal concerns. Such an approach would not be likely to be encouraged, however, by the tendency to move hastily from the lab to the marketplace. Then again, it would be consistent with an interdisciplinary approach that requires new perspectives and a highly coordinated administration. The legislation appears to prescribe *both* hastiness and reflection; if so, it contains an inherent contradiction.

The Act's explicit mention of "artificial intelligence which exceeds human capacity" warrants special attention, since it is a surprisingly specific reference to highly controversial scenarios involving the demise or at least surpassing of humans by their own creations. A generous interpretation of the intention behind this particular reference would see it as precautionary in so far as it is meant to safeguard against a vastly uncertain, yet even more vastly serious, possibility. Given the gravity of the potential consequences, in other words, regardless of their immediate likelihood, it would be wise to keep them in mind as researchers develop the means that could enable them. On the other hand, a cynical reading would see this reference, and most of what is outlined in Program Activity (10), as a direct but empty concession to the power of popular but 'irrational' worries, designed to lull them into complacency.

This line of inquiry in turn begs the questions of what is meant by "societal concerns" and how they are to be attended to. The phrase, "considered during" leaves open who does the considering, how, to what end, and with what authority. On one reading, scientists and engineers, humanists and social scientists, citizen groups and external regulators might consider the societal dimensions of technological decisions with an eye towards influencing nanotechnology development as seems appropriate to them. On another, societal concerns might be (perhaps rather pointlessly) contemplated by one or more groups in relative isolation from nanotechnology R&D, which would occur independently of societal considerations and therefore be impervious to them. Without further clarification, these questions might remain unresolved.

The Act, however, lists the following four strategies by which the consideration is to occur. Collectively, these paragraphs can shed light on the above questions. As Program Activity (10) continues, it mandates that the consideration is to take place by means of:

> "(A) establishing a research program to identify ethical, legal, environmental, and other appropriate societal concerns related to nanotechnology, and ensuring that the results of such research are widely disseminated;
> (B) requiring that interdisciplinary nanotechnology research centers … include activities that address societal, ethical, and environmental concerns;
> (C) insofar as possible, integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans; and
> (D) providing, through the National Nanotechnology Coordination Office …, for public input and outreach to be integrated into the Program by the convening of regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate."

These strategies mark a progression from minimal to more direct action in terms of shaping nanotechnology development with regard to societal considerations.

Paragraph (10)(A) represents a necessary step if the NNP is to be minimally effective in calibrating technological development to societal concerns. By itself, the generation and dissemination of research results is not very likely to encourage or enable significant changes in an R&D system not traditionally inclined to seek out external influences on the conduct of its own work—especially if this would threaten to slow its pace or application.

Barring an indisputable revelation concerning the hazardous consequences of a given nanotechnology application (which would be "widely disseminated" even without a law requiring this), paragraph (10)(A) promises little in the way of policy influence from what could be a mountain of research on societal concerns. In combination with the following strategies, however, such research could have significant policy impacts.

Paragraph (10)(B) goes a step further, since it requires activities that address societal concerns to occur proximately to technological research. The use of the term "interdisciplinary" here furthermore suggests that this term characterizes the relationship between the activities addressing societal concerns and the technological research. Strategy (10)(B), however, does not specify any necessary connection between these activities and the technological research itself.

Consequently, nothing so far in Program Activity (10) prevents research centers from carrying on discrete 'societal concerns activities' that take place proximately to and simultaneously with technological R&D, and yet are otherwise unrelated to it. There is no explicit linkage between the societal research of (10)(A) and activities of (10)(B) on the one hand, and nanotechnology R&D on the other, that would make certain these are actually interdisciplinary as opposed to, say, fragmented or even mutually hostile.

Paragraph (10)(C) changes this pattern. It contains an explicit direction to integrate — that is, to incorporate, assimilate, and combine — nanotechnological research and societal concerns research. The integration of research that spans technological and societal disciplinary expertise is a radical form of interdisciplinarity. Frodeman (2003) has described this kind of exchange as "deep" interdisciplinarity and we have referred to it as "techno-humanistic" (Fisher and Mahajan, 2003). Regardless of the terms used to describe it, the interdisciplinary integration prescribed in (10)(C) potentially allows research on societal considerations to shape the course, and hence the outcomes, of nanotechnology R&D.

Hitherto, to the best of our knowledge, no federally funded self-critical technological program has integrated the consideration of societal issues with the 'nuts and bolts' development of its resultant technological products. Naturally, different advocacy groups will offer conflicting interpretations as to what is "possible" regarding such integration efforts. Congress has, meanwhile, opened the door to this discussion, which will in part turn on questions regarding the ethical and societal nature of technological decisions and how to engage them.

What is possible regarding deep interdisciplinarity at the federal R&D level, and what should guide its implementation, are weighty questions indeed. Interpretations of the Act will need to establish what room technological activities do allow for integrating research on societal considerations and what R&D would actually look like in this case. The deepest disagreements are likely to be over the purpose, feasibility, and consequences of deep interdisciplinarity, questions that get at the heart of US technology policy.

With these questions in mind, it is instructive to note that (10)(C) specifically refers to bringing about improvements in "quality of life." Quality of life is typically understood in distinction to 'standard of living'; an analogous contrast is that between "social need" and "market demand" (Sarewitz, 1996). This is essentially the contrast that emerges between the dueling policies implicated by Program Activities (7) and (10).

Paragraph (10)(D) supplements (10)(C) by enhancing the expertise internal to technological disciplinary and interdisciplinary activities with external public input. Program Activity (10) thus encompasses both "deep" and "wide" integration, where "wide" refers to activities that cross academic, industrial, and public venues (Frodeman, 2003). The Act elsewhere makes reference to the citizen boards described in (10)(D) with respect to their integration into multiple levels of the NNP. While reminiscent of the Danish institution of citizen panels, such wide integration as prescribed in (10)(D) is otherwise rare, just as the deep integration prescribed in (10)(C) is essentially "unheard of" in federal US technological research (Winner, 2004).

In summary, the Act envisions in Program Activity (10) a new form of R&D in which 'non-technological' concerns and research explicitly influences the design and development of technologies, presumably resulting in more socially acceptable outcomes and hence more commercially robust products than if these concerns had been ignored or left to external mechanisms. At the same time, the Act contrasts this somewhat 'socially conservative' vision with the more 'commercially conservative' one entailed by Program Activity (7).

Mixed models

The tension between Activities (7) and (10) resembles that between the two trends outlined earlier. International pressures seemingly justify a rapid and accelerated approach to technology development, while the potential pressure of societal concerns entails modifying the traditional policy model in favor of an alternative, more considered, deep and wide interdisciplinary approach.

These two distinct approaches do not necessarily constitute conflicting definitions of technological progress. Both seek to maximize the societal benefits of modern technology and correct for the negative unintended consequences that even these very benefits (which are seldom uniform) can have. Both also recognize that progressive technology operates within competitive constraints and societal contexts. A key difference between them is in how societal outcomes and considerations are factored in.

The traditional policy approach to R&D follows what is known as the linear model. Included among the assumptions implied by this model are that societal benefits are relatively uniform and unproblematic and that they flow more or less automatically from basic research and its applications (Bush, 1945; Pielke and Byerly, 1998). Accordingly, R&D traditionally has been constrained exclusively by scientific, technological, and (to a limited extent as the process moves forward) economic considerations.

Considering negative unintended consequences and other societal concerns during technology development would not be deemed possible or desirable by adherents of the linear model. Any negative unintended consequences resulting from introducing new technologies into greater societal contexts would accordingly be assumed to be corrected by market forces, remedial technology, cultural adaptation, or post-R&D regulatory processes.

In contrast, numerous alternative accounts maintain that such external and *ex post facto* mechanisms

International pressures seemingly justify a rapid and accelerated approach to technology development, while the potential pressure of societal concerns entails an alternative, more considered, deep and wide interdisciplinary approach

are often too late or too slow or otherwise inadequate to mitigate and avoid unnecessary and unacceptable harm and thus best serve society. These and other emerging (or in some cases, re-emerging) accounts suggest that, consistent with the deep interdisciplinarity outlined in the 21st Century Nanotechnology Research and Development Act, it is possible (for instance, Bijker, 1995; Bucciarelli, 1994; Schot and Rip, 1996) as well as desirable (for instance, Allenby, 2000/2001; Guston and Sarewitz, 2002; Sarewitz, 1996; Steelman, 1947) to make technological decisions with societal concerns and considerations in mind. While there is not a single policy model that such accounts clearly share and uphold, it is fair to say that all demonstrate and/or recommend some form of R&D that integrates technological and societal considerations.

Evidence that this type of 'integrated' approach is gaining ground in the US is suggested in what amounts to a growing trend in US federal science and technology policy to incorporate societal considerations into R&D, albeit in diverse ways and across a wide variety of contexts. Numerous programs claim to address societal implications of technological activities, including, but not limited to, the Human Genome Project's ELSI program, the NSF's "broader impacts" review criterion, Internal Review Board (IRB) protocol for research on human subjects, the US Global Change Research Program's "Human Dimensions" program, and the President's Council on Bioethics. While these programs are not analogous, each one claims to supplement technological considerations with societal ones. None of them, however, goes the distance that the Act does in potentially redefining R&D as a cooperative, deep interdisciplinary confluence of technological and societal research streams.

Conclusion

The congressional response to the perception of opposing pressures surrounding nanotechnology has resulted in antithetical legislative language which, in turn, prescribes mixed models for R&D. Depending on how it is implemented, the Act could emerge as a shrewd piece of legislative rhetoric, reducing societal research and related activities to a sideshow in order to push rapid nanotechnology development past a potentially wary public, or as a tool for ushering in a prudent new paradigm in technology development; this would require a radical re-evaluation of the relationships among technological activities, their products, and the associated outcomes.

Several signs can suggest to critics that Congress had little intention of seeing the most radical of the strategies for accomplishing Program Activity (10) implemented. For instance, an amendment requiring that at least five percent of the NNP appropriations be "set aside for research on societal and ethical implications of nanotechnology" was defeated in the House Science Committee (House Committee on Science, 2003b). Conversely, Office of Science and Technology Policy director John Marburger, speaking the day the Act was signed into law, described the provisions related to societal concerns as "heavy machinery" that "indicates an extraordinary level of interest in these issues within Congress" (Marburger, 2003).

The fact remains that Congress has constructed an alternative policy model that could, in any number of forms, permeate the NNP. While not negotiating the differences between the colliding policies it has produced, Congress has outlined a pluralistic prescription that, depending upon implementation, could allow a responsible and rigorous societal outcomes-oriented approach to nanotechnology development. Such pluralism may ultimately have been motivated by conflicting political, economic, or other considerations. In its hybrid makeup, however, the Act allows a great deal of flexibility in terms of anticipating and adapting to present and future uncertainties.

Whether and to what extent deep interdisciplinary R&D will be implemented could depend on a variety of agents operating in various capacities throughout the NNP. The National Science and Technology Council, taking into account the advice and recommendations of the National Nanotechnology Advisory Panel, is designated in Section 2(c) of the Act to determine the goals of the NNP. A strategic plan is required within one year of the Act's signing.

The National Research Council, under the arrangement of the National Nanotechnology Coordination Office, is designated in Section 5 to assess the need for ensuring the responsible development of nanotechnology. A review containing the results of this "one time study" is required by June 10, 2005. While regulation that defines compliance with R&D policies relating to societal concerns may eventually be developed at higher levels, at least the initial characterizations of Program Activity (10) fall within the domain of the expert funding agencies, such as the NSF, who are now presumably required to invoke and apply the provisions when determining and awarding NSE grants.

The congressional balancing act between winning the global nanotechnology race and responding to the prospect of public resistance to the new technology is indicative of a more general convergence of larger trends that poses a growing dilemma for science and technology policy makers. In short, blindly obeying the technological imperative to push forward innovations as quickly as possible may jeopardize both the public interest and, ironically, the necessary public support for such innovations. On the other hand, without international cooperation, US policy makers will be greatly reluctant to risk slowing technological activities and limiting productivity, thus sacrificing competitive advantage.

The legislation analyzed here may amount to a clash or a compromise between the two perceived policy alternatives of rapid versus responsible nanotechnology development. A clash would tend to produce a societal considerations program that ultimately functions as a smokescreen. A compromise would represent an evolutionary step towards a new paradigm, whether intended by lawmakers or thrust upon them by the pressures of more or less intact democratic processes.

The new paradigm for technology development latent within the 21st Century Nanotechnology Research and Development Act is in some sense a logical continuation of a trend towards more systematically incorporating societal considerations into science and technology. While it is presently an immense challenge to envision what federally funded scientific and engineering processes will look like with societal, ethical, and environmental considerations built into them, it seems doubtful that the conditions behind this trend will go away. The US Congress has, wittingly or not, laid down a nascent vision towards which future R&D policy seems slowly but steadily to be creeping.

To the extent that R&D will in the future include assessing and addressing negative unintended consequences and other socially unacceptable outcomes, achieving global leadership in nanotechnology will need to be redefined. In this case, the deceleration and/or shaping of technological development and deployment by measures designed to garner social acceptance may in fact lead to more 'quality' in so far as technological outcomes are more robust and effective. This in turn suggests a scenario that, far from threatening longstanding US national objectives and priorities, might represent a more sustainable way of advancing them.

It would be unwise to dismiss too quickly Program Activity (10) as nothing more than a mere instance of crafty public relations. If for no other reason, the same level of close reading that reveals it to be a potential reform of the R&D system also reveals it to be a potential contradiction of R&D policy models. The result of an aggregate political process, the legislation raises the possibility for deep interdisciplinarity on multiple levels within the NNP, although it fails to clarify the purposes and mechanisms that would lead to the realization of this possibility. We submit that a new R&D model, even if it remains somewhat of a hybrid, ought to be implemented in order to assure that techno-scientific activities are shaped by the consideration of societal concerns, more than they are at present.

Appendix 1. Program Activities of the National Nanotechnology Program laid out in section 2(b) of the 21st Century Nanotechnology Research and Development Act

(1) developing a fundamental understanding of matter that enables control and manipulation at the nanoscale;
(2) providing grants to individual investigators and interdisciplinary teams of investigators;
(3) establishing a network of advanced technology user facilities and centers;
(4) establishing, on a merit-reviewed and competitive basis, interdisciplinary nanotechnology research centers, which shall—
  (A) interact and collaborate to foster the exchange of technical information and best practices;
  (B) involve academic institutions or national laboratories and other partners, which may include States and industry;
  (C) make use of existing expertise in nanotechnology in their regions and nationally;
  (D) make use of ongoing research and development at the micrometer scale to support their work in nanotechnology; and
  (E) to the greatest extent possible, be established in geographically diverse locations, encourage the participation of Historically Black Colleges and Universities that are part B institutions as defined in section 322(2) of the Higher Education Act of 1965 (20 U.S.C. 1061(2)) and minority institutions (as defined in section 365(3) of that Act (20 U.S.C. 1067k(3))), and include institutions located in States participating in the Experimental Program to Stimulate Competitive Research (EPSCoR);
(5) ensuring United States global leadership in the development and application of nanotechnology;
(6) advancing the United States productivity and industrial competitiveness through stable, consistent, and coordinated investments in long-term scientific and engineering research in nanotechnology;
(7) accelerating the deployment and application of nanotechnology research and development in the private sector, including startup companies;
(8) encouraging interdisciplinary research, and ensuring that processes for solicitation and evaluation of proposals under the Program encourage interdisciplinary projects and collaborations;
(9) providing effective education and training for researchers and professionals skilled in the interdisciplinary perspectives necessary for nanotechnology so that a true interdisciplinary research culture for nanoscale science, engineering, and technology can emerge;
(10) ensuring that ethical, legal, environmental, and other appropriate societal concerns, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity, are considered during the development of nanotechnology by—
  (A) establishing a research program to identify ethical, legal, environmental, and other appropriate societal concerns related to nanotechnology, and ensuring that the results of such research are widely disseminated;
  (B) requiring that interdisciplinary nanotechnology research centers established under paragraph (4) include activities that address societal, ethical, and environmental concerns;
  (C) insofar as possible, integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans; and
  (D) providing, through the National Nanotechnology Coordination Office established in section 3, for public input and outreach to be integrated into the Program by the convening of regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate; and
(11) encouraging research on nanotechnology advances that utilize existing processes and technologies.

Notes

1. These patent figures are revised in Huang *et al* (2004) as follows: 1,627 in 1995 and 4,623 in 2002. According to their analysis, the top five countries in 2003 for nanotechnology patents were the US (5,228), Japan (926), Germany (684), Canada (244), and France (183). Importantly, they note that "only a fraction of these patents … are expected to fully satisfy the NNI definition of nanotechnology".
2. These claims do not appear to be borne out by the results of Cobb and Macoubrie's (2004) survey, which found a generally favorable public perception of nanotechnology.
3. See Appendix 1 for a reproduction of Section 2(b) of the Act, which lists the eleven Program Activities.

References

21st Century Nanotechnology Research and Development Act of 2003. 2003. Public Law no 108-153, 117 STAT. 1923.

Allenby, Brad 2000/2001. Earth systems engineering and management. *IEEE Technology and Society Magazine*, **19**(4), Winter, 10–24.

Altmann, Jürgen 2004. Military uses of nanotechnology: perspectives and concerns. *Security Dialogue*, **35**(1), March, 61–79.

Altmann, Jürgen and M A Gubrud 2002. Risks from military uses of nanotechnology: the need for technology assessment and preventive control. In *Nanotechnology: Revolutionary Opportunities and Societal Implications, 3rd JOINT EC-NSF Workshop on Nanotechnology*, 31 January–1 February, Lecce, Italy, eds. M Roco and R Tomellini. Luxembourg: European Communities.

Arnall, Alexander Huw 2003. Future technologies, today's choices: nanotechnology, artificial intelligence and robotics; a technical, political and institutional map of emerging technologies. London: Greenpeace Environmental Trust.

Baum, Rudy 2003. Nanotechnology: Drexler and Smalley make the case for and against 'molecular assemblers'. *Chemical and Engineering News*, **81**(48), December, 37–42. Available at <http://pubs.acs.org/cen/coverstory/8148/8148counterpoint.html>, last accessed 13 February 2005.

Berube, David M 2003. The rhetoric of nanotechnology. Draft chapter, May, University of South Carolina. Available at <http://www.cla.sc.edu/cpecs/nirt/papers/Berube_2003a.pdf>, last accessed 9 January 2004.

Bijker, Wiebe E 1995. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge: MIT Press.

Bond, Phillip J 2003. Technology administration: nanotechnology: economic opportunities, societal and ethical challenges. Keynote address at NanoCommerce 2003, Chicago, Illinois, 9 December.

Bucciarelli, Louis L 1994. *Designing Engineers*. Cambridge MA: MIT Press.

Bush, Vannevar 1945. Science the endless frontier. Office of Scientific Research and Development Washington DC: United States Government Printing Office.

Choi, Charles 2003. Analysis: nano bill is not just a grand gesture; it promises real results. *United Press International*, 5 December. Available at <http://www.smalltimes.com/document_display.cfm?document_id=7049>, last accessed 19 July 2004.

Cobb, Michael D and Jane Macoubrie 2004. Public perceptions about nanotechnology: risks, benefits and trust. *Journal of Nanoparticle Research*, **6**(4), August, 395–405.

Crichton, Michael 2002. *Prey*. New York NY: Harper Collins.

Crow, Michael M and Daniel Sarewitz [2001] 2002. Nanotechnology and societal transformation. In *AAAS Science and Technology Policy Yearbook*, eds. A H Teich, S D Nelson, C McEnaney and S J Lita. New York: American Association for the Advancement of Science.

Economist 2000. Dry season. 2 November.

ETC Group 2003a. The big down: from genomes to atoms. Available at <www.etcgroup.org>, last accessed 9 January 2004.

ETC Group 2003b. Nanotech and the precautionary prince. Available at <www.etcgroup.org>, last accessed 13 February 2005.

Fisher, Erik and Roop L Mahajan 2003. "Humanistic enhancement of engineering: liberalizing the technical curriculum. *Proceedings International Conference on Engineering Education*, 21–25 July, Valencia, Spain.

Frodeman, Robert 2003. Philosophy of science policy. National Endowment for the Humanities' Dialogues between Two Cultures lecture series, University of Colorado, Boulder, 3 April.

Guston, David and Daniel Sarewitz 2002. Real-time technology assessment. *Technology in Society*, **24**(1–2), 93–109.

Hines, Christine 2003. Nanotechnology: small miracles foreseen; some lawyers say trend will rival semiconductors and the Internet. *New York Law Journal*, 13 November, 5.

House Committee on Science 2003a. Hearing charter, societal implications of nanotechnology. Available at <http://www.house.gov/science/hearings/full03/apr09/charter.htm>, last accessed 27 April 2004.

House Committee on Science 2003b. Report 108-89. S Boehlert, US House of Representatives, 108th Congress, 1st Session.

Huang, Zan, H Chen, Z Chen and M C Roco 2004. International nanotechnology development in 2003: country, institution, and technology field analysis based on USPTO patent database. *Journal of Nanoparticle Research*, **6**, 325–354.

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

Kawai, Tomoji 2003. Nanotechnology for the future MEMS. *Proceedings IEEE Sixteenth Annual International Conference on Micro Electro Mechanical Systems*. 1–3 January, Kyoto, Japan.

Kitcher, Philip 2001. *Science, Truth, and Democracy*. New York: Oxford University Press.

Kurzweil, Ray 2003. Congressional testimony, Hearing before the Committee on Science, US House of Representatives, 108th Congress, 1st Session, 9 April.

Kurzweil, Raymond 2003b. Promise and peril. In *Living with the Genie: Essays on Technology and the Quest for Human Mastery*, eds. A Lightman, D Sarewitz and C Desser. Washington DC: Island Press.

Marburger, John 2003. Opening address. Workshop on Societal Implications of Nanoscience and Nanotechnology, National Science Foundation. Available at <http://www.ostp.gov/html%5CjhmremarksSocImpworkshop.pdf>, last accessed 24 February 2005.

Marty, Alan 2003. Congressional testimony, Hearing before the Committee on Science, US House of Representatives, 108th Congress, 1st Session, 19 March.

MAST, Molecular and Atomic Scale Technologies 1989. Policy research project on anticipating effects of new technologies. Texas: Assessing Molecular and Atomic Scale Technologies (MAST), Lyndon B Johnson School of Public Affairs, The University of Texas at Austin, Austin.

Mokhoff, Nicolas 2003. U.S. official calls for closer cooperation on nanotechnology, *EE Times*, 9 December. Available at http://www.eetimes.com/story/OEG20031209S0008>, last accessed 9 January 2004.

Mnyusiwalla, Anisa, Abdallah S Daar and Peter A Singer 2003. 'Mind the gap': science and ethics in nanotechnology. *Nanotechnology*, **14**, R9–R13.

NNI, National Nanotechnology Initiative 2004. What is nanotechnology?. Available at <http://nano.gov/html/facts/whatIsNano.html>, last accessed 13 February 2005.

National Academy of Sciences 2000. Genetically modified pest-protected plants: science and regulation. Committee on Genetically Modified Pest-Protected Plants, National Research Council. Washington DC: National Academy of Sciences.

National Research Council; Division of Engineering and Physical Sciences; Committee for the Review of the National Nanotechnology Initiative 2002. Small wonders, endless frontier: a review of the National Nanotechnology Initiative. Washington DC: National Academies Press.

National Science and Technology Council, Committee on Technology, and Interagency Working Group on Nanoscience, Engineering and Technology 2000a. National Nanotechnology Initiative: leading to the next industrial revolution, supplement to President's FY 2001 budget. Washington DC: NSTC.

National Science and Technology Council, Committee on Technology and Subcommittee on Nanoscale Science, Engineering, and Technology 2000b. National Nanotechnology Initiative: the Initiative and its implementation plan. Washington DC: NSTC.

National Science and Technology Council; Subcommittee on Nanoscale Science, Engineering and Technology 2003. National Nanotechnology Initiative: research and development supporting the next industrial revolution, supplement to the President's FY 2004 budget. Washington DC: NSTC.

Peterson, Christine 2003. Congressional testimony, Hearing before the Committee on Science, US House of Representatives, 108th Congress, 1st Session, 9 April.

Pielke, Roger A Jr and Raymond Byerly Jr 1998. Beyond basic and applied. *Physics Today*, **51**(2), 41–46.

Roco, Mihail C 2002. National Nanotechnology Initiative and a global perspective. Paper presented at Small Wonders: Exploring the Vast Potential of Nanoscience, National Science Foundation Symposium, Washington DC. Available at <http://www.nano.gov/smwonder_slide.pdf>, last accessed 9 January 2004.

Roco, Mihail C 2003a. Government nanotechnology funding: an international outlook, National Science Foundation, 30 June. Available at <http://www.nsf.gov/home/crssprgm/nano/intpersp_roco_june30.htm>, last accessed 9 January 2004.

Roco, Mihail C 2003b. Broader societal issues of nanotechnology. *Journal of Nanoparticle Research*, **5**(3–4), August, 181–189.

Roco, Mihail C and William S Bainbridge 2001. Societal implications of nanoscience and nanotechnology. Arlington VA: National Science Foundation.

Sarewitz, Daniel 1996. *Frontiers of Illusion: Science, Technology, and the Politics of Progress*. Philadelphia PA: Temple University Press.

Sarewitz, Daniel and Edward Woodhouse 2003. Small is powerful. In *Living with the Genie: Essays on Technology and the Quest for Human Mastery*, eds. A Lightman, D Sarewitz and C Desser. Washington DC: Island Press.

Sarro, P M 2004. M3: the third dimension of silicon. In *Enabling Technology for MEMS and Nanodevices*, eds. H Bates *et al*, pp. 1–19. Advanced Micro and Nanosystems, vol 1. Weinheim, Germany: Wiley-VCH.

Schot, Johan and Arie Rip 1996. The past and future of constructive technology assessment. *Technology Forecasting and Social Change*, **54**, 251–268.

Slovic, Paul 1987. Perception of risk. *Science*, 236, 280–285.

Steelman, John R 1947. Science and public policy. Washington DC: United States Government Printing Office.

Stix, Gary [2001] 2002. Little big science. In *Understanding Nanotechnology*. New York: Warner Books.

Sunstein, Cass R 2002. *Risk and Reason: safety, law and the environment*. Cambridge: Cambridge University Press.

Taylor, Michael R and Jody S Tick 2003. Post-market oversight of biotech foods: is the system prepared?. Washington DC: Pew Initiative on Food and Biotechnology. Available at <http://pewagbiotech.org/research/postmarket/PostMarket.pdf>, last accessed 19 July 2004.

Winner, Langdon 2003. Congressional testimony, Hearing before the Committee on Science, US House of Representatives, 108th Congress, 1st Session, 9 April.

Winner, Langdon 2004. Personal interview by Erik Fisher, University of Colorado, Boulder, 15 April.

Wolfe, Audra 2000. Federal policy making for biotechnology, executive branch, ELSI. In *Encyclopedia of Ethical, Legal and Policy Issues in Biotechnology*, vol 1, eds. T H Murray and M J Mehlman. New York: John Wiley and Sons.