38 Anticipatory Governance of Nanotechnology: Foresight, Engagement, and Integration

Daniel Barben, Erik Fisher, Cynthia Selin, and David H. Guston

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I. INTRODUCTION

The widespread understanding that nanotechnology constitutes an emerging set of science-based technologies with the collective capacity to remake social, economic, and technological landscapes (e.g., Crow & Sarewitz, 2001) has, in itself, generated tangible outcomes. In the first years of the new millennium, governments around the world created national nanotechnology programs that spent billions of dollars (Roco, 2003), reconfigured institutional arrangements, and constructed new sites for research and development (R&D). Large transnational corporations have similarly made significant investments in R&D at the nanoscale, and venture capitalists have funded start-up companies—often launched by university researchers—specializing in a broad array of nanotechnologies (Lux Research, 2006). Many of these actors present nanotechnology as an enabling platform for other transformative innovations that will become even more powerful through its "convergence" with biotechnology, information technology, and cognitive science. The magnitude and speed of such transformations demand critical reflection on the role of technology in society and the composition of desirable futures. The presumed nascent state of nanotechnology suggests that critical reflection along with other forms of response may actually contribute to such outcomes. Nanotechnology thus affords crucial opportunities for researchers in science and technology studies (STS) to participate in the construction of safe, civil, and equitable nanotechnological developments.

The future prospects for nanotechnology, or nanoscale science and engineering (NSE), are fundamentally uncertain. In its novelty, complexity, uncertainty, and publicity, nanotechnology represents "postnormal science" (Funtowicz & Ravetz, 1993). It thus occasions new approaches to the conduct of research evaluation and assessment that require the engagement of a variety of potential users and stakeholders in the production of knowledge (Gibbons et al., 1994), as well as new organizations that span the boundary between knowledge production and public action (Guston, 2000). Not only is it unclear which scientific and technological potentials out of the many that theoretically exist might actually come to pass, but the shape and desirability of eventual sociotechnical outcomes may in part depend on the work of these new interactions and approaches. Indeed, nanotechnology can also be thought of as a metaphor for even more inchoate potential futures of other new technologies, the history of technological emergence, and the role of technoscience in destabilizing social systems—for better and for ill.

The case of nanotechnology thus has broader applicability, for such fundamental uncertainties pose challenges for science and technology decision making in public and private sectors, as well as for STS scholarship. The challenges for STS include the continued consideration of the place of its scholarship, especially when—as explored below—it is invited by policy makers and others to have a role in the pursuit and development of science and technology. Accepting this invitation, as this chapter suggests, may mean not only attending to areas of research that are not fully developed, but also attempting to create a different scope, scale, and organization of STS research.

Notably, a great deal of the study of the societal aspects of nanotechnology is bound up in the rhetoric of novelty. With this in mind, this chapter provides a brief overview of how prominent actors define nanotechnology and frame some of the societal issues associated with it. Set within this disputed context of the novelty of NSE itself and its attendant societal issues, the chapter then surveys a unique set of policies that has emerged across several countries. Generally, these policies do not presume the automatic provision of social goods from NSE research. Instead, policy mandates call for nanoscale R&D to be situated within broader social processes. Next, the chapter considers some of the unique interactions that, in part inspired by these policies, have emerged among STS researchers and policy makers, scientists, and the public by reviewing and analyzing some key features of foresight, engagement, and integration that mark these efforts. Finally, the chapter emphasizes the novelty of the scope, scale, reach, and context of much of this STS research. Specifically, the authors believe that the main contribution of this largely unprecedented multipronged, large-scale STS approach to nanotechnology is the creation of a broad capacity for "anticipatory governance" (Guston & Sarewitz, 2002).

II. DEFINING NANOTECHNOLOGY AND ITS ISSUES

No definition can encompass the complex research and policy realm that nanotechnology signifies (Woodhouse, 2004). Nevertheless, a variety of scientific and bureaucratic interests seek a concrete definition. In the United States, the National Nanotechnology Initiative (NNI) has tinkered with its original definition, most recently defining nanotechnology broadly as "the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications" (NNI, 2007). The nongovernmental standard-setting body, ASTM International, similarly defines nanotechnology as "a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension between approximately 1 and 100 nanometers (nm). Such applications exploit the properties, distinct from bulk/macroscopic systems, of nanoscale components" (Active Standard E2456-06).

Such definitions fall under the conception of "mainstream nanotechnology" (Keiper, 2003), which is largely an immediate extension of chemistry and materials science that originally might not have attracted much political attention or funding, and clearly exclude "molecular nanotechnology" (Drexler, 2004), which focuses on longer-term, directed self-assembly techniques that critics characterize as science fiction but which lent a great deal of verve to early nanotechnology promotions. The NNI situated nanotechnology between mainstream and molecular conceptions so that investment, which had in part been conceived as a response from the physical sciences to the exploding biomedical research funding of the 1990s, included biology. And like genetic engineering before it, nanotechnology under these definitions blurs boundaries not only among technical disciplines but also between science and engineering and between research and manufacturing—thus building in the promise of economic payoffs from research at the onset. The bridging of disciplines as well as the hyperbolic promises to society mark nanotechnology as the "new frontier."

However sufficient broad definitions might be for promoting research programs, they are hard for social scientists to operationalize. Bibliometric research has struggled to define nanotechnology in order to track its intellectual and geographic dynamics. Such work (e.g., Porter, Youtie, & Shapira, 2006) has identified four broad and overlapping areas of inquiry—nanodevices and electronics, nanostructure chemistry and nanomaterials, nanomedicine and nanobiology, and metrology and nanoprocesses. This categorization nearly replicates a taxonomy derived by the Royal Society and Royal Academy of Engineering (2004). The definition of nanotechnology is furthermore expected to change over time. For instance, prominent nanotechnology "roadmaps" predict an evolution from nanomaterials to passive nanosystems to active nanosystems (Roco & Renn, 2006). It is thus more accurate to talk of a plurality of nanotechnologies, even while acknowledging the prominence and persistence of the abstract singular term resulting from a combination of advances in instruments and research communities (Mody, 2006) and political agendas and alliances (McCray, 2005).

Frank and brazen optimism on behalf of nanotechnology—even the government sponsors who eschew the molecular nanotechnology vision hail it as "the next industrial revolution"—contrasts with equally compelling arguments about its unintended consequences (Sarewitz & Woodhouse, 2003), giving rise to an urgency to address issues of equity, ethics, and engagement. However, the almost protean form of nanotechnologies conspires with broad time horizons to further complicate the recognition and critique of related cultural, ethical, legal, educational, economic, and environmental (henceforth "societal") issues. While issues need not be new to warrant consideration, a particular search for novelty has accompanied the societal debate: What is new about nanotechnologies that leads to pressing societal issues?

As implied in the definitions quoted above, the standard technical explanation for novelty stresses the properties of matter that manifest at the nanoscale. Thus, although nanotechnologies reinforce the continuing miniaturization that leads to the potential unobtrusiveness, embeddedness, and ubiquity of microtechnologies and nanotechnologies, there are also new electrical, optical, magnetic, and mechanical properties derived from surface-to-volume ratios, quantum mechanics, and other rules that apply to small sizes, numbers, or aggregates of particles. This uniqueness means, for example, that some nanoparticles are able to permeate boundaries previously seen as impervious, e.g., the blood-brain barrier. Much of the publicity accorded to nanotechnology has thus been due to a lively discourse on risk assessment that has focused on the toxicological profiles of a range of engineered nanoparticles (e.g., carbon, silver, titanium dioxide) that may not match that of their larger counterparts.

A number of observers have catalogued societal issues that emerging nanotechnologies may raise. The early treatment by Roco and Bainbridge (2001), for example, includes "implications" of economic, political, educational, medical, environmental, and national security import, as well as potential consequences for privacy and global equity (the "nanodivide") and a sea change in what it means to be human through the possibilities of nano-enabled enhancements. Moore (2002) divides the "implications" of nanotechnology into three categories: social, including environmental, health, economic, and educational; ethical, including academic-industry relations, abuse of technology, social divides, and concepts of life; and legal, including concepts of property, intellectual property, privacy, and regulation.

As Lewenstein (2005b) argues, such lists—while thoughtful and relatively complete—frame nanotechnologies in a determinist fashion as things that have "implications" for society but are not themselves influenced by society. Similarly, Baird and Vogt (2004) reframe most of these issues in terms of "interactions," and they add to their list what they call "hypertechnology"—the too-fast pace of innovation. Grunwald (2005) recapitulates many of these issues as well, arguing however that they are not novel enough to warrant the name "nanoethics," which now appears in the title of a journal launched by Springer in 2006 and in an entry in Macmillan's *Encyclopedia of Science, Technology, and Ethics* (Berne 2006a).

While the novelty of the societal issues surrounding nanotechnologies may not be as obvious as the novelty of some nanoscale properties, nanotechnologies clearly have inspired a great deal of attention. The next section picks up on the theme of novelty regarding the role of STS in the development of nanotechnologies, as national governments have summoned social scientists to participate in their initiatives.

III. THE POLICY MANDATE

Since the late 1990s, public and private sector decision makers have promoted NSE as a linchpin for creating economic wealth and solving a vast number of societal problems. Correspondingly, governments around the world have invested heavily in NSE, attempting to create internationally competitive national infrastructures of NSE R&D by tying together the "triple helix of industry, government and academia" (Etzkowitz & Leydesdorff, 2000).

The emphasis on economic advantage and the transformative capacities of nanotechnologies helped catalyze the rapid growth of NSE R&D and commercialization programs, but it also took shape against cautionary discursive backgrounds developed by such prominent individuals as Bill Joy (2000) and Charles, the Prince of Wales (2004), as well as activist groups such as Greenpeace (Arnall, 2003) and the ETC Group (2003). Months after the inauguration of the NNI, Joy presented a catastrophic vision of self-replicating "nanobots" and considered "relinquishment" as a strategy for avoiding this disastrous fate (Joy, 2001). Less spectacular than Joy's "grey goo" scenario, biotechnology also began to be associated with nanotechnology, in particular the widespread experience of skepticism, criticism, and antagonism in the fields of agricultural and food biotechnology and embryonic stem cell research. The ETC Group (formerly, Rural Advancement Foundation International, or RAFI), which forged coalitions between activists in the global North and South to work against agricultural biotechnology and related intellectual property rights, has repeatedly called for a moratorium on particular forms of NSE R&D because of environmental health and safety concerns.

Sensitive to these activist responses, policy makers appear to have been infected with "nanophobia-phobia" (Rip, 2006) from dystopian doomsday scenarios (Bennett & Sarewitz, 2006) and genetically modified foods in Europe (NRC, 2002). They have responded by sponsoring a more proactive approach to societal issues that emphasizes not only the study of ethical, legal, and social issues but the integration of social science research and public interventions into the R&D process (Fisher & Mahajan, 2006a). Distinct from policies promoting biotechnology research, nanotechnology policy does not approach R&D as if it would automatically produce the most desirable outcomes. Instead, policy makers now endorse a conception of R&D that requires the integration of broader societal considerations in order to serve the public good and support decision making.

Under the language of "responsible innovation," government institutions in the United States and European Union, among others, have thus proposed integrating social science research into NSE programs at an early stage (Commission of the European Communities, 2004; NSTC, 2004). In an effort to advance socially desirable outcomes for NSE, policies have prescribed broader guidelines for integrating societal concerns and perspectives, thus inviting STS research to play a formative role in the sociotechnical context of developing nanotechnologies.

The move is particularly compelling in the case of the United States because it occurs in a political context that, since the closing of the congressional Office of Technology Assessment, has paid little attention to technology assessment. Several European nations and EU institutions have also become much more receptive to public engagement in the aftermath of large-scale technoscience controversies, including HIV-tainted blood, "mad cow" disease, and GMOs. Before the U.S. Congress passed the Twenty-First Century Nanotechnology Research and Development Act in 2003 (Public Law 108–153), STS scholars Langdon Winner and Davis Baird testified to Congress about the integration of STS research with NSE. Winner (2003) recommended "open deliberations about technological choices" that would occur at early, premarket stages, yet disparaged the idea of creating a field of "nanoethics" based on the model of bioethics. In order to avoid a "drift toward moral and political triviality" on the part of social and ethical researchers he suggested engaging broader publics, from ordinary citizens to laboratory researchers. Likewise, Baird (2003) proposed instituting the collaboration of ethics researchers with nanotechnology researchers in the laboratory. The criticality of early intervention drew from decades of research into the generation and shaping of technologies (e.g., Collingridge, 1980; Dierkes & Hoffmann, 1992; Sørensen & Williams, 2002).

The resulting legislation went "beyond assessment" (Fisher, 2005) and differed from earlier efforts at institutionalizing reflexivity, such as the Human Genome Project's Ethical, Legal, and Social Implications (ELSI) program. Significantly, the legislation—and other policies like it around the world—explicitly invoked the notion of "integrating" societal research and public inputs into NSE R&D and policy. It also implied that such efforts should influence NSE (House Committee on Science, 2003), presenting practical challenges for STS researchers and creating a new, more active role for social science.

Other nations and political entities have supported similar attempts at fostering collaborations among scientists and engineers, social scientists, and the interested public. The European Union (Commission of the European Communities, 2004), the Netherlands (De Witte & Schuddeboom, 2006), the regional government of Flanders, Belgium (Flemish Institute for Science and Technology, 2006), and Brazil and Colombia (Foladori, 2006) have all not only instituted social science research on nanotechnologies, but notably link that research in an integrated fashion to decision making.

The envisioned collaborations across academic cultures suggest pressure to contribute to the social shaping of nanotechnologies in two respects: (1) Social scientists are expected to provide NSE researchers with contextual awareness of the interdependencies among science, technology, and society, thus allowing broader social perspectives to have greater influence on the design and conduct of R&D and its outcomes. (2) Social scientists are expected to learn details of nanotechnologies and the conditions of their emergence, thus allowing them to better elaborate assessments of societal impacts and interact with publics accordingly. The rationales underlying these two motivations—the quality of nanotechnological development and the enrollment of social scientists—point in different directions, suggesting tensions between the diverging expectations. New collaborations between natural and social scientists will thus be an increasingly important activity and site of inquiry.

IV. FORESIGHT, ENGAGEMENT, AND INTEGRATION

Whether summoned and enabled by the policy initiatives described above, local public groups, or individual research laboratories, STS researchers are "being invited in" (Rip, 2006) to engage with NSE in multiple modes and a variety of settings. Together, such endeavors face at least three general challenges: the anticipation and assessment of nanotechnologies that are in the process of emerging; the engagement of publics that are mostly still latent; and the integration of broader considerations into R&D contexts that have been largely self-governing. This section surveys some of the STS research inspired by such considerations, while pointing to some of the challenges—both analytic and practical—to STS and its researchers.

Foresight

Although by one count there were in early 2007 more than 350 NSE products in commerce (WWIC, 2007), these products alone or in collection offer nothing like the societal transformation promised for nanotechnologies. The emergent quality of nanotechnologies means that many discussions are about potential—often bordering on hype (Berube, 2006)—and therefore many social science interventions are analytically attuned to the future.

The future is diversely manifest as scenarios of use, broader comprehensive visions, sociotechnical scenarios, metaphorical-symbolic expectations, and expectations of technoeconomic potentials (Borup & Konrad, 2004). Prominent expectations about nanotechnologies run in two directions: toward an elixir for postindustrial ills through seamless interactions with nature, instantaneous and nonpolluting production, and unprecedented wealth and health (Drexler, 1986; Anton, Silberglitt, & Schneider, 2001; Wood, Jones, & Geldart, 2003) and toward an Armageddon wrought by self-replicating nanobots (Joy, 2000) or, more soberly, environmental hazards, unintended consequences (Tenner, 2001), shifts in privacy and security (MacDonald, 2004), and greater economic inequalities (Meridian Institute, 2005). The act of attaching oneself to the short or the long term, to the mundane or the exotic visions, is often an act of affiliation with "serious" science or with science fiction (Selin, 2007). As elixir or armageddon, the futures of nanotechnologies have become a focus of the popular press, government programs, and industry analyses.

STS investigations in foresight, each with a different theoretical and empirical approach, have focused sociological interest on expectations (Selin, 2007; Van Lente, 1993; Brown & Michael, 2003), visions (Grunwald, 2004), or "guiding visions" (Meyer & Kuusi, 2004), future imaginaries (Fujimura, 2003), and emerging irreversibilities (van Merkerk & Rip, 2005). Expectations research often employs actor-network theory (ANT), while Rip's scenario work draws from co-evolutionary theory (Rip, 2005). Lösch's (2006) investigations into nanotechnology's futuristic visions argue for discourse theory (e.g., Luhmann, 1995) to crystallize the distributed nature of "the future" as a means of communication. There are also investigations drawing on literary theory and the role of science fiction in the development of nanotechnologies (Milburn, 2004) and the moral vision of its practitioners (Berne, 2006b). Each of these perspectives provides its own prescription for what to do analytically with the future (e.g., trace agency, identify communicative pathways, employ a cultural critique).

There are several distinct approaches to anticipating the longer-term implications of nanotechnologies: forecasting, public deliberation, scenario development, foresight, and vision assessment. Forecasting can be set apart from these other approaches in its orientation toward accurate predictions and allegiance to technological determinism.

However, the methods of forecasting and predictive modeling figure prominently in roadmapping exercises and also address powerful industrial and governmental actors' need for limiting uncertainty (Bunger, forthcoming). The other approaches share a more pluralistic epistemology that suggests multiple futures and intrinsic uncertainty, due at least to the heterogeneous production of technology and society.

Public deliberation exercises often treat the future as a linguistic effect, that is, talk about the future. In 2005, the EU launched a 6th Framework project called Nanologue (2007) in order to "establish a common understanding . . . and to facilitate a Europe-wide dialogue among science, business and civil society about its benefits and potential impacts." After a mapping and polling exercise, the study created, also through participatory methods, three scenarios which then were circulated in order to help structure the debate about responsible innovation. The Center for Nanotechnology in Society at Arizona State University (CNS-ASU) also uses scenarios to help frame debates about the societal implications of new technologies. Different from the Nanologue scenarios, the CNS-ASU scenarios are co-constructed in a large-scale, virtual format through multiple wiki sites. These scenarios serve as inputs for public engagement as well as for social scientific analysis.

While scenarios are often synonymous with foresight, foresight includes such diverse methodologies as life cycle assessment, Delphi studies, cross-impact assessment, future-oriented bibliometrics, and novel ways of performing technology assessment. These sorts of interventions are usually strongly linked with technological innovation and seek to integrate reflection with everyday decision making. Foresight thus aims to enrich futures-in-the-making by encouraging and developing reflexivity in the system.

Building reflexivity in innovation systems highlights a key feature of nanotechnology foresight: the connection with decision making and governance. Sorting through certainties and uncertainties and determining viable options need not be idle speculations, but can be a means toward prudent action. The Danish government, for example, supported a Green Technology Foresight project (Joergensen et al., 2006) in order to support its priority setting. The project was an unparalleled effort to interview and engage a diverse selection of actors working in NSE. The United Kingdom Economic and Social Research Council commissioned the James Martin Institute for Science and Civilization to create scenarios about converging technologies which describe alternative trajectories for the development of nanotechnology and are intended to inform ESRC's research strategy. The Woodrow Wilson International Center also has a foresight and governance project that focuses on the emergence of nanotechnologies by using scenarios, public deliberation, and risk analysis with a particular eye to effecting policy.

These projects are novel in their focus on early intervention, their use of methodologies that have a nuanced relation to futures, and their attempts to allow NSE researchers to characterize the outcomes of their knowledge production. These interventions are thus unique experiments in handling the demands of postnormal science by seeking to build reflexivity through foresight.

Engagement

NSE has only recently become known to wider constituencies as a new interdisciplinary and cross-sectoral field. However, social scientists who have specialized in the analysis of the Public Understanding of Science and Technology (PUST)—a field that has developed in the past four decades in the context of contested technologies, starting with nuclear power—have already brought to bear on NSE-related issues the vast array of research instruments on the public perception and acceptance of S&T. Even so, this research can only portray publics who have a vague idea of nanotechnology (Bainbridge, 2002). Thus the finding that the general public is largely in favor of nanotechnology does not necessarily carry much insight, and it is likely to change with further development of nanotechnology or with social events (Currall et al., 2006). The same may be true for the correlation between public perception of risks and trust in regulatory systems (Cobb & Macoubrie, 2004).

As described above, the policy mandates for public involvement in nanotechnology go beyond opinion polls to more substantive engagement that is consonant with the shift in some of the literature from public understanding of to public engagement in S&T (Lewenstein, 2005a). Thus, new roles for social scientists have been created that extend beyond the supposedly independent and external analysis of public perceptions and understandings to new kinds of engagement with publics.

Over the last two decades, science museums have become more prominent intermediary actors in communicating S&T issues to the public. The Science Museum of London, for example, has gained an exemplary prominence in combining its traditional role of exhibiting vast collections of items with a new role of sponsoring and conducting PUST studies, which include experiments with public participation (e.g., Durant, 1992; Durant, Bauer, & Gaskell, 1998). With the advent of NSE, science museums have become part of significant efforts to educate and engage the public. The U.S. National Science Foundation has committed 20 million dollars over five years to science museums under the auspices of the Nanoscale Informal Science Education Network (NISE Net), which brings together museum professionals, researchers, and informal science educators to inform and engage the public about NSE through traditional museum exhibits and less traditional public forums and Internet venues.

NSE has also been the site of more direct forms of public participation and engagement. Nanojury UK, a consensus conference or citizens' panel held in the United Kingdom in 2005, demonstrates a commitment to upstream engagement in nanotechnology, where "upstream" means involving the public in detailed activities at a time when they have very little substantive knowledge of the issues (Rogers-Hayden & Pidgeon, 2006).

In France, public debates have been organized by NGOs and in some cases sponsored by local officials facing anti-nanotechnology activism. For instance, Entreprises Pour l'Environnement (Companies for the Environment) sponsored a so-called "citizen consultation" in October 2006.

In the United States, consensus conferences focusing on nanotechnologies have been held in university communities in Wisconsin (Powell & Kleinman, forthcoming) and North Carolina (Hamlett & Cobb, 2006), and the CNS-ASU is conducting an integrated set of six consensus conferences in a National Citizens' Technology Forum. The Center for Nanotechnology in Society at the University of California, Santa Barbara (CNS-UCSB) is conducting participatory exercises, as is the University of South Carolina, and several nano-in-society groups have collaborated with NISE Net in hosting public forums. Despite the mandate in U.S. nanotechnology law for public engagement, social science reflection on approaches to and experiences with public engagement is more advanced in Europe (Joss & Durant, 1995; Abels & Bora, 2004), where such activities have been part of the toolkit of parliamentary technology assessment and have been continually pioneered, particularly in the context of biotechnology (e.g., the large-scale GM Nation exercise in the UK [Steering Board, 2003]).

Integration

The anticipatory and engagement exercises described above are meant to be taken up into ongoing sociotechnical processes to shape their eventual outcomes. While numerous sites of science and technology governance allow for "sociotechnical integration" to be observed, facilitated, or affected (Fisher, Mahajan, & Mitcham, 2006), there has been gathering interest in "revisiting" (Doubleday, forthcoming) one of the classic sites of STS scholarship—the laboratory. Here, at the myth-laden headwaters of scientific knowledge, traditional laboratory studies mingle with more interactive approaches and collaborations, as the considerable but often unacknowledged role of laboratory researchers in implementing and influencing research policies has been cast as an intricate part of the networks of agency that shape NSE, its technological trajectories, and sociotechnical outcomes (Macnaughten, Kearnes, & Wynne, 2005).

As noted, the call for social and natural scientists to work "together in dialog" (Baird, 2003) is unique neither to STS nor to nanotechnologies. More novel is the provision of resources by governments to the task—and the opportunities that have in several cases emerged only as a result of invitations extended by laboratory directors to social scientists and humanists (e.g., Giles, 2003). In accordance with emerging opportunities, several research, education, and engagement programs have sought to encourage "prospective and current nanotechnology researchers to engage—in a thoughtful and critical manner—with [societal] issues as an integral part of their research endeavors" (Sweeney, 2006: 442). The nature of these programs has varied, and some of them overlap with programs of public engagement, foresight, and imagination and of identifying and analyzing ethical and societal issues. What stands out as characterizing many of these efforts is the interest in increasing the reflexivity of the actors and social processes that comprise the objects of study.

Alongside the ethnographic studies of NSE laboratories that have begun to emerge (Glimell, 2003; Kearnes, Macnaghten, & Wilsdon, 2006), several university-based integration-oriented laboratory research projects have also been undertaken (NSTC, 2004). By and large, such "new ethnographies" (Guston & Weil, 2006) seek to "develop the capacity of nanoscientists to reflect on the wider societal dimensions of their work"

(Doubleday, 2005). An implicit and in some cases explicit focus on changes in laboratory practices resulting from the presence and interactions with social researchers can be seen in these projects. One study documents concrete changes in NSE research practices as a result of an iterative protocol for the "modulation" of research decisions (Fisher & Mahajan, 2006b). Another describes the construction of a "trading zone" at the outset of NSE research that informed the eventual project selection (Gorman, Groves, & Catalano, 2004). Attempts to integrate social and humanistic considerations into laboratory and other technoscientific decision processes thus push empirical science studies in new directions. The act of emphasizing the reflexive elements of participant-observation in laboratory studies is a move toward "ethnographic intervention": the integration of social research into technoscientific research by means of collaboratively developed feedback mechanisms that stimulate a more self-critical approach to knowledge generation (Fisher, forthcoming).

Integration projects also include private sector partnerships with nongovernmental organizations (Demos, 2007; Krupp & Holliday, 2005). Together, laboratory integration projects exhibit three, somewhat overlapping trends: efforts to address environmental health and safety considerations (Krupp & Holliday, 2005); efforts aimed at long-term reflective capacity building, such as creating "citizen scientists" (Kearnes, Macnaughten, & Wilsdon, 2006) or occasioning ethical reflection (Berne, 2006b); and efforts that are able to shape the course of R&D work with respect to broader societal considerations (Fisher & Mahajan, 2006b; Gorman, Groves, & Catalano, 2004). The latter trend simultaneously suggests new capacities on the part of STS researchers to influence sociotechnical processes, and challenges to understand the limits of such budding capacity.

V. AN EMERGING PROGRAM

In light of the policy mandates discussed in section III, the STS research and engagement activities described in section IV can be conceived in terms of an emerging yet coherent program that represents a potentially significant development for STS. Such a program is developed at the interface of and in close interaction with key social processes that underlie research conduct, policy making, public education, and the collective anticipation of nanotechnologies. In this way, such a program suggests an evolution in the capacity of STS researchers and institutions to act across a broad front of networks and systems. The fact that this development has largely coincided with the rise of nanotechnology as a cultural and political construct raises opportunities and challenges, as well as ironies, for the STS community. In this section, we describe characteristics that are visible within many smaller- and larger-scale STS research and engagement activities. We then characterize the emerging program as one of building capacity for anticipatory governance. Finally, we consider several questions, motivations, and criticisms that an STS program of this sort will be likely to face in the future as it co-evolves with other new, emerging, and converging technologies.

"Ensemble-ization"

To characterize these developments in STS occasioned by its engagement with nanotechnologies, we employ the concept of a "research ensemble," a term that Hackett and his colleagues (2004) use in the context of large-scale fusion research. According to Hackett et al. (2004: 748), a research ensemble denotes an arrangement of "materials, methods, instruments, established practices [. . .] ideas, and enabling theories;" such ties are co-produced by researchers and policy makers to connect a research group to others both within its own field and beyond, and "influences the group's performance and the work of its members." An ensemble so defined helps stage the work that can be accomplished "through interactions with other groups and with policy makers" (ibid.). We choose this concept—as opposed to others, such as systems, networks, boundary organizations, configurations, and the like—because of its concrete focus on the interactions between the work of research groups and the wider social and policy processes that can influence this work.

While we cannot completely theorize the process of "ensemble-ization" here, we maintain that STS engagement with nanotechnologies reveals something of a trend toward it in two central respects: the first has to do with relations among the components of the STS research ensemble, and the second concerns the relation of the ensemble to its objects of study. In the first case, the plurality of methodologies and actors in various large-scale STS entities represent research ensembles at a scale of coordination, collaboration, and focus hitherto not found in STS. The pragmatic mobilization of multiple research technologies—foresight, engagement, and integration—around the single problem of the societal aspects of nanotechnologies creates a tightly arranged, resource-endowed entity that requires coordination, application, and management. In this first sense of ensemble-ization, several large-scale STS entities focused on nanotechnology have begun to surface since the year 2003. Each includes activities focused on anticipation and foresight, public engagement, and sociotechnical integration. This multi-method, mission-driven, action-oriented research characterizes a potentially new form of STS research.

Principal examples include the U.S. Centers for Nanotechnology in Society at UCSB and ASU and the NanoSoc program in Flanders, Belgium. Each is closely related to formal government science policy, and each includes a coordinated set of anticipatory, engagement, and integration activities. Others, such as the Dutch NanoNed research consortium, are part and parcel of government-funded science programs, even if not stemming directly from parliamentary decree. Still others, such as the network of STS scholars and activists in the United Kingdom that centers largely around Lancaster University and the nongovernmental organization Demos, situate their work in the context of statements by policy makers. This group has developed the notion of "upstream public engagement," used alternative future scenarios with publics, and studied future imaginaries in laboratory settings.

Such research ensembles not only represent the larger-scale coupling and coordination of STS researchers and methodologies, but they also embody an increased ability to act. They are evolving with respect to their origin and goals, as is particularly evident with respect to the development of several entities out of or in parallel with policy mandates. Moreover, as shown earlier, both larger and smaller projects seek to facilitate and even participate in the framing and co-construction of dialogues, agendas, expectations, and—notably—decisions pertaining to nanotechnological development trajectories. Thus, STS engagement with nanotechnologies exhibits a second trend toward ensemble-ization insofar as STS research ensembles seek to interact with some of the existing ensembles of science, technology, and policy making that have hitherto been isolated from broader societal influences.

For instance, the upstream engagement activities in the United Kingdom that are focused on the nanoscale are intended to "shape the trajectory of technological development" (Wilsdon, 2005). Similarly, the NanoNed consortium includes a component of constructive technology assessment which, like upstream engagement, has long sought to introduce a more extensive and nuanced array of participants in order to "influence design and technical change" (Schot, 2005). The "real-time technology assessment" at the core of the CNS-ASU ensemble is a coordinated collection of approaches meant "to build into the R&D enterprise itself a reflexive capacity that [. . .] allows modulation of innovation paths and outcomes in response to ongoing analysis and discourse" (Guston & Sarewitz, 2002).

Thus, in the facilitation of interactions, whether among various publics or between STS researchers and various publics, these STS ensembles are aligned with the notion of constructing and shaping decision processes, research practices, levels of public trust, and the transparency of policy processes. Research ensembles help specify linkages among research groups that in turn affect the performance and work of such groups, thus embodying forms of mediation between science and society. As such, they not only can map the "connection between policy and knowledge production" (Hackett et al., 2004: 751), but their alteration and expansion—through STS interventions—can thus shape these very connections.

Anticipatory Governance

As we have suggested, the futuristic discourse of nanotechnologies, as well as their fundamental technical and social uncertainties, requires the cultivation of a societal capacity for foresight, by which we mean not only formal methodologies but also more generalized abilities to bridge the cognitive gap between present and future. Whether through foresight, public engagement exercises, or ethnographic intervention, visions and their assessment have played a prominent role in both representations of and STS research on nanotechnologies. The forward-looking, engagement-oriented, and results-seeking characteristics of this STS research distinguish it from prior work in PUST, ELSI, and observational laboratory studies. The growing capacity to act that the ensemble-ization of STS, both in relation to itself and to its objects of study, builds what we elaborate here as "anticipatory governance" (Guston & Sarewitz, 2002).

Anticipatory governance implies that effective action is based on more than sound analytical capacities and relevant empirical knowledge: It also emerges out of a distributed collection of social and epistemological capacities, including collective self-criticism, imagination, and the disposition to learn from trial and error. For, although action and outcomes are emergent qualities of human choice and behavior, they rarely, if ever, proceed from certainty or prediction, and neither are they based on the simple intentions of individual actors or policies. Rather, as the concept of "anticipation" is meant to indicate, the co-evolution of science and society is distinct from the notion of predictive certainty. In addition, the anticipatory approach is distinct from the more reactionary and retrospective activities that follow the production of knowledge-based innovations—rather than emerge with them. Anticipation implies an awareness of the co-production of sociotechnical knowledge and the importance of richly imagining sociotechnical alternatives that might inspire its use.

In parallel, the notion of "governance" commonly refers to a move away from a top-down government approach to an approach where management by people and institutions becomes possible without detailed and compartmentalized regulation from the top (Lyall & Tait, 2005: 3). The activities implicated by the concept of governance are diverse, ranging from the technological determinism latent in the idea of nanotechnology as the "next industrial revolution" (NSTC & IWGN, 2000) to the radical expression of technological choice in calls for a moratorium. But between adapting to a coming revolution and halting development exists an array of governing options: licensing, civil liability, insurance, indemnification, testing, regulation, restrictions on age or other criteria (rather than on ability to pay), labeling, modulation of designs and research practices, and so on. Some options, like labeling and life cycle analysis, complement private sector governance by providing more complete information necessary for market efficiency. Some, like civil liability and indemnification, distort markets for important reasons of justice or critical technology development. Anticipatory governance seeks to lay the intellectual foundation for (any of) these approaches early enough for them to be effective.

Beyond the role of STS ensembles described above, we can cite two additional but still nascent examples of anticipatory governance: On the macro level, "acceptance politics" (Barben, 2006) denotes the political strategies and practices concerned with influencing the public acceptance of controversial phenomena like nanotechnologies and thus the choice of governance mechanisms. For example, many actors involved in NSE perceive biotechnology and particularly genetically modified organisms as the strategic background against which to shape public acceptance or rejection (e.g., Mehta, 2004; David & Thompson, forthcoming). On the micro level, "midstream modulation" (Fisher, Mahajan, & Mitcham, 2006) refers to the demonstrated phenomenon of a nanoscale engineering research group to adjust its own practices according to broader "upstream" and "downstream" societal contexts, principally as a result of observing decision processes and imagining additional technical alternatives.

Anticipatory governance comprises the ability of a variety of lay and expert stakeholders, both individually and through an array of feedback mechanisms, to collectively imagine, critique, and thereby shape the issues presented by emerging technologies before they become reified in particular ways. Anticipatory governance evokes a distributed capacity for learning and interaction stimulated into present action by reflection on imagined present and future sociotechnical outcomes. STS researchers, projects, and subfields are being tethered together and linked to the contexts they seek to study with the aim of incrementally building the capacity to more broadly anticipate and participate in shaping things to come.

Opportunities, Challenges, and Ironies

Insofar as the policy mandates implicitly rely on STS tenets and expertise, they present a clear opportunity for the STS community to reconceive if not reinvent forms of foresight, engagement, and integration (Macnaughten, Kearnes, & Wynne, 2005). At the same time, the opportunity challenges the community, raising questions of its growing capability to participate more directly and intentionally in shaping sociotechnical change—as well as dilemmas about how far to go in seeking to influence change and pitfalls of ill-conceived approaches to anticipation (Williams, 2006).

Each arena we have examined—foresight, engagement, and integration—sets particular obstacles for researchers. In following the future-oriented discourse of NSE, for example, there is a risk of avoiding or downplaying the present by centering debate in the future. That is, many of the societal issues posed by nanotechnologies, including questions of equality, privacy, and human enhancement, can be meaningfully framed in the present as well. The choice of concentrating on future scenarios rather than on current practices bears a similar ethical burden as the choice to invest resources on "transformative" research rather than to address current ills. Moreover, talk about the future, whether connected to analytical projects, participatory experiments, or scenario-building collaborations with NSE researchers demands that STS researchers be involved explicitly in the construction of possible futures. Because anticipation is performative, there is no sidestepping this responsibility (as opposed to, say, Gieryn's [1995] prescription regarding boundary work that good constructivists watch it rather than do it).

With regard to engagement exercises, the concept of acceptance politics raises the specter of the cooptation of STS research for the purpose of legitimating nanotechnologies and pacifying publics. In conducting participatory investigations into the future of NSE, STS researchers must create constructive links with relevant stakeholders, thus raising the question that the researchers must answer: Who are the carriers of legitimate or authorized visions of nanotechnological futures?

Finally, integration demands a sophisticated balancing of scholarly objectives, the politics of the laboratory, and the prospects for progressive alteration of the research agenda and its anticipated outcomes. The responsibilities of the participant-observer, whether "lab-based sociologist" or "embedded humanist," are likely to be different when the context of the research is a laboratory setting within a larger shared community, university, political system, and culture, as opposed to a geographically and culturally distant setting. Further, episodes that are not necessarily part of the envisioned "sociotechnical integration"—for example, the mistreatment of animal or human research subjects, research misconduct, intellectual property disputes, and the like—may surprise the participant-observer, creating conflicts of commitment even within a framework that incorporates a concept of the public good. In seeking to influence policy and decision making, even in as innocuous a setting as the laboratory, STS researchers subject themselves to being influenced in a heightened way.

How can STS scholarship respond to the rather generous invitations from policy makers to partake in creating the future of nanotechnologies while both retaining its critical perspective and avoiding falling prey to Winner's critique of academic distance? To what end does STS participate in the normatively charged contexts it seeks to describe, and at what cost to its academic integrity and credibility?

Such questions have provoked periodic self-critical reflections (e.g., Fuller, 2005) and injunctions (Jasanoff, 1999). They are reminiscent of the concern, voiced in Winner's congressional testimony, that previous ELSI research may have been co-opted by its patrons. Importantly, the question of acting to what end presents both normative and pragmatic challenges. The challenges of understanding what "socially desirable" goals are and assessing whether present arrangements are likely to produce desired results surface long-standing debates in the STS community about the role of researchers in influencing their objects of study. These concerns have also been expressed in language of the "entanglement" of social and humanist researchers with nanotechnology programs. Having been invited to consider nanotechnology, they lend weight and credibility to an otherwise "malleable, plastic, and elusive" notion that embodies a particular set of agendas: "if [nanotechnology] has social impact, it must be real" (Nordmann, 2006).

Ironically, as STS becomes better endowed with resources, more highly coordinated, and more entangled within innovation systems, it becomes more like its objects of study. In developing ensembles with the ability to anticipate, engage, and integrate, STS researchers become more visible and significant participants in their own right, and—perhaps for the first time—instruments of governance themselves.

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