The Case of the National Nanotechnology Initiative

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For Fred Block and Matt Keller, *State of Innovation: U.S. Federal Technology Policies, 1969-2008*

Several decades of research have established that markets often shortchange long-range research, especially in high-risk technologies whose calculable value to a given firm is far smaller than their eventual social value. The common term for this problem is “market failure,” and the shared perspective of most of the contributors to this volume is that government agencies need to correct market failure, particularly by being an investor of last resort for valuable research that may take years or decades to come to fruition. The “developmental state” can aim at types of scientific, economic, and social progress that are well over the horizon of any individual firm or consortium. Taken as a whole, this volume encourages federal, state, and other US governments to embrace their proper role as long-term investors and enlightened, flexible, decentralized managers and problem-solvers in relation to the colossal technical and economic challenges the US currently confronts.

I am going to discuss the National Nanotechnology Initiative (NNI), and more specifically its reporting of nanoscale research, as an instance of a developmental federal role. My analysis intersects with those of many other contributions to this volume, and four of them are particularly relevant at the start.

I. Avoiding Network Failure

I agree with Josh Whitford and Andrew Schrank that a focus on market failure should not eclipse the equally important problem of “network failure.” The NNI explicitly aimed at creating national network effects, and these need to be assessed and, where necessary, improved.

The same goes for Erica Fuchs’s analysis of the Defense Advance Research Projects Agency (DARPA), which my analysis of DARPA’s nanoscale research reporting may complement. Fuchs shows that DARPA plays an important networking function, and given its distinguished history of sponsorship in computer science and other areas would seem well suited to serve as one of the major federal cures for market failure. And yet Fuchs turns up many complaints about DARPA’s procedures, including one that should rank high on anyone’s list of sources of network failure: DARPA resources are more likely to flow to researchers who are already well-connected to DARPA. Networks improve on markets through their superior powers of coordination. Networks improve on hierarchies through more efficient and more equitable distribution. But if a network is nepotistic or elitist, and in effect allows the rich to get richer which ignoring innovations that come from the research “poor,” then it simply replicates the weaknesses of both hierarchies and concentrated markets. DARPA may operate as an example of the *developmental network state*. Or it may (and at the same time) operate as a *bureaucratic-market state*, in which firms or laboratories with either large market resources or special network placement have incumbent advantages that reduce overall innovation. Some influential network analyses of research and development in research-intensive industries underplay the extent to which networks can function like hierarchical markets.[1]

The third piece is by John A. Alic, who makes the crucial point that “Innovation bubbles up through organizations, often from deep within them, with heterogeneous contributions from heterogeneous employees.” He makes similar points about the importance of end-users for technological development. We could wrench Alic into our network terms and say that he insists on the full-spectrum network, one whose bit players, edges, bottoms, and outer limits are as important as the central players to the overall health of the innovation system.

Finally, this injunction to look at the entirety of an innovation system is in effect operationalized by Chris Knight's chapter on photovoltaic (PV) development. Knight examines R&D policy and practice, but spends much of his time on implementations at the municipal level. His investigation shows that rates of PV adoption depends on fixing problems that exist far from the research centers of a technology's R&D networks. For example, US installation costs are a higher percentage of overall PV system costs than they are in Europe in large part because of the absence of standardized building and electrical codes. PV innovation that leads to massively increased use depends on R&D at the high-end centers like Stanford and various University of California campuses, but equally on the actions of innovative local actors like the Sacramento Municipal Utility District and county planning and development officials.

Thus the business of "creating and bolstering networks" (Whitford and Schrank) needs to seen as creating and bolstering complete and internally non-prejudicial networks, by which I mean that "top" vs. "bottom" and "core" vs. "periphery" do not become pronounced to the point that interaction is skewed, distorted, or interrupted. Networks are continuously evolving entities that need to be analyzed and also designed, supported, and orchestrated at their edges and from below. Much recent commentary stresses the extent to which technology development networks need to be inclusive, that is, involving lead customers or engaging the public. I would make this point by saying that effective networks are those whose parts are of sufficiently similar status to communicate, interact, and collaborate as necessary. Stanford electrical engineers, UC Davis contracts and grants officers, the Sacramento utility's project managers, county planners, contractors in the field, and buyers of PV module for their house or apartment need to be able to communicate and collaborate with each other. To do this, mechanisms need to be in place, but for the mechanisms to work, the actors that are networked by these mechanisms must be *equal enough* to be taken seriously by one another, and to be truly addressed.

Here I will not attempt to assess equality as a factor of relations between DARPA and its broader public. I will instead analyze DARPA's form of address to that broader public, and suggest the need for improvement. Before I turn to this issue, however, I will elaborate further on the importance of the public to sustainable technological development – and on the full network dispersal of innovation as such.

II. The Centrality of the Peripheral Public

I am going to do this by discussing an important recent history of technology, David Edgerton's volume, *The Shock of the Old: Technology and Global History since 1900* (Oxford, 2007). Edgerton's title is obviously saying, "The old is important too." The book has a huge number of examples of old technology and low technology that continue to affect society long after they supposedly peaked. Hybrids spring from every page: there are the traditional Thai long boats joined to V-8 car engines - remember the flying-boat chase scenes in the Bond film Tomorrow Never Dies? Edgerton always stresses the overlooked efficiency of old tech in new situations. For example, he traces Rwanda's "spectacularly fast genocide" in 1994 in part to the machetes stockpiled in advance: "most victims were killed machetes (38 per cent), clubs (17 per cent) with firearms accounting for only 15 per cent of deaths."

Edgerton is right that we underestimate the role of the old. But his second and most important theme concerns why we do this. His explanation is that we make the mistake of centering our histories of technology on laboratory innovation rather than on use. We date advancement and progress from the moment a technology appears or is first applied, and downplay the long and winding road of adoption, imitation, diffusion, improvement, recycling and hybridization. And yet it is this long haul that decides the impact of a technology on society, and not its exciting first revelation.

For example, steam power "was not only absolutely but relatively more important in 1900 than in 1800." Similarly, "the world consumed more coal in 2000 than in 1950 or 1900." If we date steam power from its earlier appearances in Britain in the 1700s, we will identify it with the "dawn of the industrial revolution," wrongly see its importance as ended by other energy forms (oil, electricity), and miss steam's long and influential presence in later decades. If we do look at use rather than invention or first adoption, we can, to take another case, recognize the continuing importance of coal to China's current round of spectacular industrialization, and appreciate the extent to which China may "win" at new technologies like nanotechnologies precisely by using the old.

Innovation not only rests on the old as well as the new, but further, does not increase in a linear way from increased R&D spending, and does not lead in a linear way to higher gross domestic product (GDP). Edgerton points out that "In the 1980s Italy overtook the United Kingdom in output per head . . . while spending much less on R&D than Britain did" (109). Similarly, "Spain was one of the most successful European economies in terms of rates of growth in the 1980s and 1990s, and yet this is a country which spends less than 1 per cent of GDP on R&D." Edgerton notes that the USSR spent as much or more of its GDP on R&D than did the US in the 1960s and 1970s, and yet is regarded as "having contributed practically nothing novel to modern industry" (110). Or take China vs. Japan. Japan has long had one of the highest rates of R&D spending in the world, but "while China has transformed itself and flooded the world with manufactures, the much more innovative Japanese economy has been, by comparison, stagnant" (109). This kind of data - which has been known by specialists since the 1960s – suggests that imitation is at least as important as innovation to economic growth.

Imitation must be carefully defined. It is not simply copying, replication, or infringement, though of course sometimes it is. Imitation is more generally a form of *development* of a technology that already exists. It is not a breakthrough or an invention that seems to come from nowhere. It is instead most often continuous improvement, tinkering, evolution, and adaptation. And above all, it comes from all over – imitation is development that generally exists in a network.

The US also appears to be an example of the importance of imitative development. It had high rates of growth in the later 19^{th} and early 20^{th} century while it was applying itself to borrowing and adapting technology first developed in Europe. This pattern continued, and may explain much of the "golden age" growth of the 30 years following World War II.

A more familiar feature of US R&D is also crucial to the post-World War II period: the US benefited from massive Cold War military investment and from its long experience with the highly skilled coordination of large-scale engineering projects. The most famous of these was the "Manhattan Engineering District" that produced the atomic bomb during World War II. As Edgerton points out, this "buil[t] on decades of experience in large-scale research and development" (199). The federal government provided network coordination, but the elements to be coordinated came from all over and arrived in large part through the processes of borrowing, imitation, and the adaptation of existing work. The same combination of adaptation and coordination helps explain the important role of very large firms in the innovation process. Major advances have continuously come from companies like BASF, Hoechst, Bayer, AGFA, General Electric, AT&T, IBM, Du Pont and Eastman Kodak: "all these firms were already very large, innovative in 'science-based' technologies, and employed an abundance of scientists and engineers" (193). They created internal R&D operations, and these generally remained productive for decades at a time. "At least fifteen out of the twenty-three firms listed as the top R&D spenders in 1997 (and 2003) were formed before 1914" (194).

Looking at the old and the new side-by-side and over time suggests that there has never been such a thing as "closed innovation," in which development took place inside one institution or cluster. Analysts like AnnaLee Saxenian *Regional Advantage*, Clayton Christensen *The Innovator's Dilemma* and Henry Chesbrough *Open Innovation* have made much of a new dependence on networks that no company or even nation can control. The history of technology suggests that there is nothing new about the sheer dispersal, the boundary crossing, the institutional mixing and sharing, or the global scale of invention. A whole range of motives, participants, organizations, and sectors are always involved in any major technological wave.

Most crucially for ours purposes, however, is that Edgerton's accumulated examples confirm the view that the most effective innovation networks are those that rest firmly on the ground. It has always been true, he argues, that "most invention has taken place in the world of use (including many radical inventions) and furthermore has been under the direct control of users" (187). A full history of technology puts practitioners of every kind at the center of innovation throughout history. It puts use at the center of invention. It puts the street and the shop next to the state-of-the-art academic lab. It puts imitation at the heart of invention. It truly displaces the "linear model" (from bench to bedside, from lab to market, from specialist to customer, from agent to recipient, from producer to consumer, from smart to dumb). It discredits the basic categorical distinctions on which that model generally rests. It concludes that in the deepest sense, the history of technology is the history of everybody -- that is, of everybody's uses of it.

What this means in turn is that there is no "downstream" (public) to try to push "upstream" (scientific laboratories), because in the history of technology, there is no "upstream." In other words, the upstream consists, at different points in a technology's history, of *all* of a technology's active users. Technology develops variously all over a global field, one that mixes technique, infrastructure, know-how, facilities, social frameworks, and social needs.

Technological innovation is a fundamentally socio-cultural process, which of course means that the study of the history of technology must become as radically interdisciplinary as technology itself. Economists and historians need to work together regularly. Institutional sociologists need to be there too. So do specialists in cultural and artistic change, which are part of the same process. The intellectual task needs to be seen in all its profound difficulty before it can be resized and broken down enough for progress to be made on its parts, correctly interrelated to one another. Social choice would also be part of this analysis. As Edgerton puts it, "the twentieth century was awash with inventions and innovations. . . . we are free to oppose technologies we do not like." We are free "to research, develop, innovate, even in areas which are considered out of date by those stuck in passé futuristic ways of thinking."

It we admit, then, the power of the old, grant the importance of networks, accept the major role of various governments in coordinating those networks, agree that use is indissociable from invention, and then embrace the origins of use in a vast public that is creating and innovating routinely with whatever is at hand, we are ready to ask an important question about a vital federal government initiative like the NNI: how is it involving the general public in the new waves of nanoscale research?

Avoiding Network Failure:

III. An Unprepared Partner: The US Government's Nanotechnology Strategy[2]

There is not question that, in spite of decades-old political controversies, the U.S. government has long had the world's most enormous program of basic research. Although the federal government funds only about 28% of all R&D, about 70% of this total is "D" – product development organized by corporations.[3] Around 60% of basic research in the US is funded by the federal government.[4] Importantly, most of this federal research is *not* explicitly trying to compensate for market failure by supporting basic research that will fill market niches that happen to be a long way down the road. Most federal research seeks to address the government's own missions, particularly military missions, which in turn account for 60% of the federal R&D budget.[5] Rather than being the servant of market forces often criticized on the left, or demanded on the right, the federal government is the 800-pound gorilla of basic research, and is a gorilla with a mind of its own. Our question is, again, is this mind focused on creating and sustaining networked partnerships that will support the social uptake of the effects of scientific research? Did the nanotechnology initiative focus this mind?

Nanotechnology is something of an ideal case. In the 1990s, it was a domain of scientific research that had great momentum and major potential for good social impacts. The field had seen a remarkable boom in publications, and one of its major scientific spokespersons, Richard C. Smalley, had recently received a Nobel Prize (Chemistry 1996) for his co-discovery of the fullerene molecule, and was popularizing such soon-to-be defining "nano" characteristics as self-assembly and nano-phenomenon molecular electronics.[6]

By the late 1990s, nano seemed poised for a major acceleration through better funding and national coordination. A 1997 meeting of major scientists in the field led to a report claiming that nanotechnology's "application areas include the pharmaceutical and chemical industries, nanoelectronics, space exploration, metallurgy, biotechnology, cosmetics, the food industry, optics, nanomedicine, metrology and measurement, and ultraprecision engineering -- there are practically no unaffected fields." It added, "efficient conversion of energy, materials, and other resources into products of high performance will be a strategic necessity in the next century."[7] Two years later, an overlapping group of science and policy figures conducted a similar workshop, this time sponsored by the White House's National Science and Technology Council, and was prepared to issue much stronger conclusions. They called for the creation of a "grand coalition" – "a cooperative national program involving universities, industry, government agencies at all levels, and the government/national laboratories." This coalition would be embodied in "a national nanotechnology initiative in fiscal year 2001 that will approximately double the current Government annual investment of about $255 million (in fiscal year 1999) in R&D supporting nanoscience, engineering and technology."[8]

The National Nanotechnology Initiative (NNI) was indeed drafted, passed, announced by President Bill Clinton at Cal Tech in January 2000 and put into effect later that year.[9] An important step in its passage was the communication to policymakers of nanotechnology's broader social impacts. Some of these appeared when the House of Representatives Committee on Science heard testimony about the value of the nanotechnology, including Smalley's claim that nanoscience was "about to enter a golden new era.[10] The Committee's report, "Unlocking the Future," has a long section on "science for society," which sang the praises of publicly-funded science with practical benefits.[11] In 2002, NNI leaders issued a 500-page report on nanotechnology's impact on "human performance" that included an eloquent call for large government nano-funding with high social benefits from none other than the former Republican Speaker of the House and "small government" activist Newt Gingrich.[12] Discussions of nanotechnology's social benefits were essential to garnering political support. The harmonization of scientific, economic, and social impacts was something of a policy marvel, and a tribute to the institutional skill of its leading advocate M.C. Roco and his colleagues.

And yet for all its focus on public outcomes, the public was neither invited in nor present for the genesis of the NNI. Societal impacts were most frequently reduced to economic impacts, and the leading rationale for the NNI was economic competition with other countries.[13] The agenda-setting hearings and meetings did not include testimony from members of the public who had knowledge or experience of the effects of technology policy, or desires for technology. The pool of experts where were in attendance did not include experts on societal implications. As the science scholars Ira Bennett and Daniel Sarewitz put it, "social scientists and humanists had little if any engagement with nanotechnology during the 1980s and 1990s, leaving the consideration of societal implications to technologists like [Eric] Drexler, [Ray] Kurzweil, and [Bill] Joy, to activists like Pat Roy Mooney, and to science fiction authors." In addition to this limited cultural range, the NNI came into being through a "top-down process." [14] The pubic did not appear as an active character in official discussions, but as a recipient: an audience to be persuaded, as students to be educated, as reactors to risk events to be managed, and as beneficiaries of the hard work of scientists and businesspeople.

When society did appear, it was in a distanced and attenuated form. Striking examples can be culled from the NNI's "Human Performance" conference, which covered promising topics such as "Expanding Human Cognition and Communication" and "Enhancing Group and Societal Outcomes." While there is no doubting the commitment of the participants to enhancing human abilities, the presentations uniformly subordinated human factors to technological developments. Society itself, social life, is all but non-existent, and always improvable if not largely replaceable by computer networks and other forms of associative technology.[15]

One particularly striking example occurs when the report expressed a desire to use nanotechnology to "to help overcome inequality between people, isolation of the individual from the environment, injustice and deprivation, personal and cultural biases, misunderstanding, and unnecessary conflict. In the broadest sense, it will be a powerful enhancer of communication and creativity, potentially of great economic and social benefit." But the imagined enhancer is called "The Communicator," and I quote part of its description at length in an attempt to convey correctly the tone as well as the idea. The Communicator will consist of

> nano/info technologies that let individuals carry with them information about themselves and their work that can be easily shared in-group situations. Thus, each individual participant will have the option to add information to the common pool of knowledge, across all domains of human experience — from practical facts about a joint task, to personal feelings about the issues faced by the group, to the goals that motivate the individual's participation.
>
> The Communicator will also be a facilitator for group communication, an educator or trainer, and/or a translator, with the ability to tailor its personal appearance, presentation style, and activities to group and individual needs. It will be able to operate in a variety of modes, including instructor-to-group and peer-to-peer interaction, with adaptive avatars that are able to change their affective behavior to fit not only individuals and groups, but also varying situations. It will operate in multiple modalities, such as sight and sound, statistics and text, real and virtual circumstances, which can be selected and combined as needed in different ways by different participants. Improving group interactions via brain-to-brain and brain-machine-brain interactions will also be explored.[16]

Avoiding Network Failure:

The authors seem unaware of the Orwellian structure of this idea, or of its hive-mind overtones. The closest thing to The Communicator in my own recent reading appears in John Scalzi's remarkable science fiction novel *Old Man's War* (2005), where a Communicator-style mind-mesh is called the BrainPal. But Scalzi presents the BrainPal as a military device that enhances soldiers through their controlled coordination, thus underwriting the Colonial Defense Forces' more-or-less permanent aggression against every other species in the universe. The BrainPal offers absolutely no capacity to improve or enhance social relationships, which continue in Scalzi's correct assessment to depend on socio-cultural factors (identifications, power relations, divergent economic interests, romantic attachments, communal experience, etc.) that cannot be resolved through enhanced communication alone. Something like The Communicator will not begin to be even a tolerable idea until its authors can concretely describe social settings and factors that exist independently of technological enhancements.

This report's discourse is marked at all points by the problem of the Distant Society. The nano-based enhancement projects do *not* start from or refer to people or social groups who live out and articulate individual or social needs that they would like nanotechnology to address, and which *then* offer their expertise in applying nanotechnology to those needs. Social conditions are abstract, remote, and underdescribed; the people who comprise those conditions are not present.

What about a fallback position, in which governmental agencies can establish the conditions of equitable private-public partnerships not by actually including the public in "upstream" deliberations, but by at least acknowledging and presenting the results of public funding? This would mean conveying the impact of the presence – if not of the public voice and will – of public money. The public pays for a lot of research, and its contribution could be granted, explained, and narrated as a progress story in which social actors play an important role in the improvement of their own society.

Our research group looked for these kinds of narratives of public contribution, ones that linked the public to developments with major public impact. We looked for a nanoscale technology that was in use, and that had been funded by the NNI, and then sought records that tracked development through the following sequence:

b. NNI funding TO

A federal agency (e.g. NSF) TO
Funding program and calls TO
Funded research TO
Disclosures of inventions and publications TO
Patents TO
Licenses TO
Development and products

This list is far more linear than development ever is. Another problem with our list is that once the money arrives at (a) the public contribution disappears.[17] But we used this sequence as a the baseline for our search for public documents that would explain "science progress" to interested members of the public by showing where public funds had wound up and what they had done.

We started with the Defense Department's Advanced Research Projects Agency (DARPA). The Department of Defense receives about a third of NNI's annual funding,[18] and DARPA, widely credited with creating the "ARPANET" that led to the Internet, is arguably a leading government agency in taking on high-risk projects that might be total losses or, on the other hand, lead to something like the post-1960s revolution in information technology that is widely believed to have proven the economic impacts of high-tech research.[19]

In fact, no public documentation of DARPA nanoscale progress actually exists. What one finds by spending many hours searching systematically on the DARPA site is a series of lists of topic areas tied to reported accomplishments. Looking at any given year's budget estimates reveals separate items of interesting but unrelated subjects that are scattered throughout the report.[20]

Typical copy reads as follows: "electronically controlled microinstruments offer the possibility of nanometer-scale probing, sensing and manipulation for ultra-high density information storage ‘on-a-chip’, for nanometer-scale patterning, and for molecular level analysis and synthesis. These microinstruments for nanometer-scale mechanical, electrical and fluidic analysis offer new approaches to integration, testing, controlling, manipulating and manufacturing nanometer-scale structures, molecules and devices.”[21] Non-specialists could not guess from this kind of reporting that the research in question is actually tied to a very important natural phenomenon (giant magnetoresistance or GMR) that led to massive improvements in hard disk storage that transformed the PC industry in the late 1990s, resulted in Nobel Prizes in 2007, and has been turned by at least one historian into a very interesting true story of discovery.[22]

We switched gears and sought to follow one subject area through several years of DARPA reporting. We selected “nanoscale/Bio-molecular and Metamaterials” for the first decade of the 2000s. Each of the early years offers a summary that takes up a few lines of text. Each description says very little about the actual research, and nothing about potential applications. The report on FY 1999 did anchor a major theme of nanoscale research in which materials are designed in the hope of replicating the capacity of biological systems to self-assemble: “Exploited recent advances in materials design and processing to demonstrate nanostructural control of materials properties with an emphasis on emulating the complex microstructure and scale of biological materials.” From 2000-2003, there is some overlap in topics related to this idea but no sequencing, accumulation, general tendency, or systematic mutual referencing. The level of non-specificity omits the stakes, the value, the financial sources, and the potential implications of possibly groundbreaking work. Reading through the entries offers a combination of overlap and disconnection that is not easy to describe.[23]

For 2004, the reporting adds additional components, and at the same time starts to repeat itself in an unsettling pattern of cutting-and-pasting. From one year to the next, large sections of the summaries appear to have been block-copied from the year before.

24 The reports do not link funded laboratory activity to the formal reporting. The text conveys a lack of interest in convincing the reader that public finance is being used for clearly-articulated ends. It also conveys a surprising absence of advancement and learning.

Finally, in the estimate for FY 2009, a series of accomplishments can be gleaned from various pages of text.[25] But no cluster of goals, patterns, systematic developments, or public objectives appears. There is no way for a non-specialist – not just a physicist, say, but someone actively engaged with the subdisciplines in question - to understand the interconnection among the projects. Even more fundamentally, there is no reporting of the effects of a major public effort like the NNI. Which projects were funded with nano-specific money, how was the money used, what areas were developed, and what were the outcomes? Nearly ten years after the NNI began, there is no way of answering the question of the impact of the NNI on project development, research, and discovery as they converge towards platforms and products with often promised public impacts.

Rather than creating coherent development narratives, nanotechnology analysts tend to use standardized forms of output metrics – publication and patent counts, coupled with impact metrics based on citation analysis. These methods demonstrate significant growth curves, and are often used to suggest that the promise of a field like nanotechnology to transform society is on its way to being fulfilled.[26] Sometimes international comparisons are made, and such comparisons have clear policy uses in encouraging politicians to improve the funding of a competition in which the US may be losing ground to rivals.[27] Growth curves convey the clear impression of progress and acceleration, and nearly all areas of nanoscale research have seen major increases in activity in the US and elsewhere over the past two decades.

But publications and patents do not literally equal development, production, and use. Publications signify scientific research activity rather than economic impact and social adoption, and are almost always valuable primarily for further scientific research. Patent activity is similarly ambiguous: most patents do not recoup the cost of their filing and prosecution with the patent office, most patents go unused, only a few patents earn the vast majority of royalty revenues, and patents can be used to block innovation as well as stimulate it.[28] The construction of patent claims often express business strategies towards rivals as well as research results. At the same time, patents do not solve problems of technology development: they do not in themselves address component integration, manufacturing cost, and a hundred other problems that must be solved before an invention is ushered forth into society. A growth curve in publications and patents has a great *symbolic* value, and operates successfully as a *sign* of funded activity – actually, as a displaced and veiled index of scientific and related types of administrative labor. A growth curve can *represent* the growth of knowledge that arises from relationships among society, government, and corporations. But a growth curve does not *describe*, track, or narrate the stages of that development, or suggest, before its realization, where development will lead, or what society will get out of it.

This situation recalls our question: can a government help create the conditions of an equitable network that includes the general public? In the case of this well-developed, high-quality initiative, the NNI, my current answer is no, and for three reasons. First, this initiative is distant from society: society, in the sense of concrete actors, disparities, desires, diversities, is not present in its ongoing activity. A multi-agency program that *imagines* its profound social utility needs to do so through a proximate attachment to that society that it does not yet have. Secondly, the government, as represented here by the NNI, does not address society, in the sense of describing society's contribution and society's concrete potential benefits *as tied to that* contribution. Finally, it offers symbolic innovation indicators rather than the narratives of that progress that would reflect society's founding funding role, and its profound knowledge of its own needs that is not currently being used.

IV. Narratives and Networks

I want to conclude with a suggestion about how the NNI might play a more effective role in creating networked partnerships among all the social actors that are actually involved.

We do have some standard mechanisms for creating partnerships between the public and the government. Government agencies try to communicate with society through procedures such as "public comment" that can include hearings and invitations from citizens group, community organizers, activists, and various non-governmental agencies. The history of anti-corporate mobilization offers many examples of interventions that made government procedures more interactive, and many of these interactions continue. They are less common on technical subjects where most of the public lacks the background to participate equitably, or even to feel interested in the first place. Science studies scholars have created focus groups and other mechanisms of structured feedback that involve some up-front education. Though these can lay the groundwork for social partnerships, they are labor-intensive, highly localized, expensive, and not scalable to society as a whole.[29]

A more effective mode through which government agencies could reconnect with the public is by telling accurate stories of the trail "from bench to bedside." This would mean narrating the actual story of scientific development that the government makes possible. In such a story, obstacles, conflict, crises, and overcoming would not be buried under thick coats of varnish. Social actors would be present in these stories, and in them social actors would not be *subordinated to* but would be in fact *equal partners with* the corporations that manufacture and sell the eventual product.

The story would overcome the national tendency – which long predates the NNI -- to treat laboratories as black boxes, scientists and businesspeople as the prime movers, and society as a backward but ultimately grateful recipient of technical knowledge. The story would move from public funding through laboratory research, and dwell on the intellectual and physical labor involved. The cruel irony of the habituation of the scientific community to quantitative and yet symbolic indexes of science progress is that they eclipse the effort, the amazement, the astonishing and tireless labor of science – the very thing that links it to every other kind of familiar work all over the world. These stories would feature the discoveries, the transfer of discoveries into some development process, and the arrival of the good or service into society at large.[30] All the actors, inside and outside formal R&D structures, would exist together inside a larger process of social self-governance, in which aims and means are collaboratively established and managed.

Such networks are not easy to sustain, precisely because of the institutional variety and perceived status differences that need to be negotiated. But the first step is creating narratives about the interactions that take place within the knowledge-creation processes that have existed all along. These require new efforts of social imagination inside the government agencies that have so much influence over pubic interests. The good news is that a public that can *read* and *appreciate* its own long-term historical role in the creation, use, recreation, and adaptation of transformative technology will more effectively improve that technology by linking it to the public's long-term needs.

NOTES

This material is based upon work supported by the National Science Foundation under Cooperative Agreement No. 0531184. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

1 One important example is Walter W. Powell, et al. "Network Dynamics and Field Evolution: the Growth of Interorganizational Collaboration in the Life Sciences." *American Journal of Sociology* 110.4 (2005): 1132-205. After suggesting that accumulative advantage has the "weakest support" among their various explanations for the shape of the industry, and rejecting the possibility of excessive concentration, the authors note that "a very small core of perhaps one or

two dozen organizations are routinely placed in the center, and their node size grows somewhat over the period." They then equate centrality and advantage with "multiconnectivity," and conclude, **"**The key story, in our view, is less the issue of the nature and distribution of resources and more how these institutional features promoted dense webs of connection that, once in place, influenced both

subsequent decisions and the trajectory of the field." But this "dense web of connections" may in effect function as a monopoly that raises barriers to entry for new players. Webs of connection are often designed to do this in conformity with a given firm's business model, which is most likely to target the *most* innovative entrants (since these are the most threatening).

2 Special thanks to John Munro of the History Department at UCSB for providing excellent research assistance for this section and the next. Thanks as well the UCSB Faculty Senate Council on Research.

3 See National Science Foundation, *Science and Engineering Indicators 2008*, Chapter 4, http://www.nsf.gov/statistics/seind08/c4/c4h.htm

4 Ibid. See also See Organization for Economic Cooperation and Development, Main Science and Technology Indicators 2008/2, http://www.oecd.org/dataoecd/9/44/41850733.pdf

5 David C. Mowery, "What does economic theory tell us about mission-oriented R&D?" in D. Foray, ed., *The New Economics of Technology Policy* (Edward Elgar, forthcoming); NSF, op cit.

6On publication growth, see Bennett, Ira and Daniel Sarewitz, "Too little, too late? Research policies on the societal implications of nanotechnology in the United States" (Phoenix, AZ: Arizona State University, Consortium for Science, Policy, and Outcomes. 2005), http://www.cspo.org/ourlibrary/documents/Sci as Cult2.pdf. On nanoscience themes, see Richard C. Smalley, "Discovering the Fullerenes," Nobel Lecture December 7, 1996, http://nobelprize.org/nobel_prizes/chemistry/laureates/1996/smalley-lecture.pdf

7 M.C. Roco, "Introduction," World Technology Evaluation Center, Richard Siegel, Evelyn Hu, and M. Roco, eds, *WTEC Workshop Report on R&D Status and Trends* (1997), http://www.wtec.org/loyola/nano/US.Review/01_01.htm.

8Interagency Working Group on Nanoscience, Engineering, and Technology, *Nanotechnology Research Directions: IWGN Workshop Report* (1999), pp iii-iv, xix-xxiv, http://www.wtec.org/loyola/nano/IWGN.Research.Directions/chapter00.pdf. An insider's list of milestones can be found in M.C. Roco, "Long View for Nanotechnology R&D," American Academy of Nanomedicine Symposium, September 6, 2008: 6, http://www.nsf.gov/crssprgm/nano/reports/NNI_08-0906_Roco@Nanomedicine_LongViewUS_50sl.pdf

9 The White House press release on the NNI is available at http://clinton4.nara.gov/WH/New/html/20000121_4.html

10 House of Representatives Committee on Science, 105th Congress. My understanding of the NNI's origins has benefitted from the excellent history of the NNI written by my CNS colleague W. Patrick McCray, "Will Small be Beautiful? Making Policies for our Nanotech Future," *History and Technology* Vol. 21, No. 2, June 2005, pp. 177–203. Smalley citation from McCray.

11 "Unlocking our Future: Toward a New National Science Policy" (September 1998), http://www.access.gpo.gov/congress/house/science/cp105-b/science105b.pdf.

12Mihail C. Roco and William Sims Bainbridge, "Converging Technologies for Improving Human

Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science" (NSF: Arlington, VA, 2002): 36-55, http://www.wtec.org/ConvergingTechnologies/1/NBIC_report.pdf

13 McCray, op cit. Gingrich offers the "Human Performance" report's best summary of the consensus position: "If we want this economy to grow, we have to be the leading scientific country in the world. If we want to be physically safe for the next 30 years, we have to be the leading scientific country in the world. If we want to be healthy as we age, we have to be the leading scientific country in the world" (Roco and Bainbridge, op cit 39.

14 Bennett and Sarewitz, op cit.

15 In Roco and Bainbridge, Ibid., see, for example, "Theme B Summary," pp 97-101, "Theme D Summary," pp 275-277, Sherry Terkel, "Sociable Technologies: Enhancing Human Performance When the Computer is not a Tool but a Companion," pp 150-58.

16 Ibid., p 276.

17 The "linear model" of R&D has been soundly critiqued within science and technology studies and among various specialists, but remains important in communication with policymakers. For an influential account of the inadequacy of the linear model, and of a better alternative, see Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation* (Washington DC: Brookings Institution Press, 1997).

18 National Nanotechnology Initiative: FY 2009 Budget & Highlights, http://www.nano.gov/NNI_FY09_budget_summary.pdf

19 Among the many works on this topic, see for example Glenn R. Fong, "ARPA Does Windows: The Defense Underpinning of the PC Revolution," *Busines and Politics* 3:3 (2001): 213-37 (criticizing orthodox market-based explanations of technological and economic progress).

20 Our primary grouping was

DoD FY 2000/2001 Budget Estimates, February 1999: http://www.darpa.mil/Docs/DARPAFY20002001PB2-991.pdf

DoD FY 2001 Budget Estimates, February 2000: http://www.darpa.mil/Docs/FY2001BudgetEstimates.pdf

DoD FY 2002 Amended Budget Submission, February 2001: http://www.darpa.mil/Docs/pres_bud_fy02.pdf

DoD FY 2003 Budget Estimates, February 2002: http://www.darpa.mil/Docs/pres_bud_fy03.pdf

DoD FY 2004/2005 Budget Estimates, February 2003: http://www.darpa.mil/Docs/FY04PresBud.pdf

DoD FY 2005 Budget Estimates, February 2004: http://www.darpa.mil/Docs/DoDFY2005BdgtEstFeb04.pdf

DoD FY 2006/2007 Budget Estimates, February 2005: http://www.darpa.mil/Docs/DescriptiveSummaryFebruary2005.pdf

DoD FY 2007 Budget Estimates, February 2006: http://www.darpa.mil/Docs/FY07_Final.pdf

DoD FY 2008/2009 Budget Estimates, February 2007: http://www.darpa.mil/Docs/FY08_budg_est.pdf

DoD FY 2009 Budget Estimates, February 2008: http://www.darpa.mil/Docs/DARPAPB09February2008.pdf

21 DoD FY 2001 Budget Estimates, February 2000, p 14. http://www.darpa.mil/Docs/FY2001BudgetEstimates.pdf

22 W. Patrick McCray. "From Lab to iPod: A Story of Discovery and Commercialization in the Post-Cold War Era," Technology and Culture, 50, 1 (2009): 58-81.

23 DoD FY 2000/2001 Budget Estimates, February 1999: http://www.darpa.mil/Docs/DARPAFY20002001PB2-991.pdf From page 16, under "FY 1999 Accomplishments": "Nanoscale/Biomolecular Materials. ($ 1.350 Million). Exploited recent advances in materials design and processing to demonstrate nanostructural control of materials properties with an emphasis on emulating the complex microstructure and scale of biological materials."

DoD FY 2001 Budget Estimates, February 2000: http://www.darpa.mil/Docs/FY2001BudgetEstimates.pdf

From page 18 under "FY 1999 Accomplishments":

Nanoscale/Biomolecular Materials. ($ 6.306 Million)

Demonstrated the applicability of nanostructural materials in defense applications such as armor, high strength fibers, coatings and electronics.

Explored novel concepts in biomolecular materials and interfaces.

Developed single molecules and nanoparticles that exhibit electronic functionality and measured their intrinsic electronic properties

DoD FY 2002 Amended Budget Submission, February 2001: http://www.darpa.mil/Docs/pres_bud_fy02.pdf

From page 19, under "FY 2000 Accomplishments":

Nanoscale/Biomolecular Materials. ($ 9.233 Million)

Explored novel processing schemes for the formation of nanoscale/biomolecular and spin-dependent materials, interfaces, and devices.

Explored the capabilities of quasicrystals, amorphous metals, metamaterials, carbon nanotubes, quantum dots, and other nanostructured/biomolecular materials for enhancing the structural and functional performance of DoD systems

DoD FY 2003 Budget Estimates, February 2002: http://www.darpa.mil/Docs/pres_bud_fy03.pdf

From page 32, under "FY 2001 Accomplishments":

Nanoscale/ Biomolecular Materials ($6.574 Million)

Demonstrated enhanced performance from materials and processes incorporating nanostructured components.

Demonstrated the use of quantum chemistry for the theoretical design of new nanoscale/biomolecular/multifunctional materials and structures.

24

A. DoD FY 2004/2005 Budget Estimates, February 2003: http://www.darpa.mil/Docs/FY04PresBud.pdf

- *This year the format and wording changed…*

- From page 30 (which those cited in Budget Estimates A-D, deals with Materials Sciences), under “Program Accomplishments/ Planned Programs”:

  - Nanoscale/Bio-molecular and Metamaterials

    - FY 2002 5.028

FY 2003 12.881
FY 2004 8.907
FY 2005 5.051

- The research in this thrust area exploits advances in nanoscale and bio-molecular materials, including computationally based materials science, in order to develop unique microstructures and properties of materials. This includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale (Metamaterials) level.

- Program Plans:

  - Develop theoretical understanding and modeling tools for predicting novel metamaterial structures that exhibit superior microwave and magnetic properties for DoD electric drive and propulsion, power electronics, antenna, and radar applications.

  - Develop algorithmic approaches for predicting properties and structure of nano-scale and meta-materials using first principles/quantum mechanical methods with higher accuracy and reduced computational complexity.

Couple the algorithmic approaches to methods that extract parameters for simulation of materials at larger spatial scales while conducting experiments to verify/validate the predicted properties at all spatial scales.

Explore the mechanisms of phonon engineering for enhancing transport properties in organics.

Develop advanced image detector materials to instantly and simultaneously detect one structural (computed tomography) and two functional (position emission tomography and single photon emission tomography) images of medical and life science interest.

B. DoD FY 2005 Budget Estimates, February 2004:
http://www.darpa.mil/Docs/DoDFY2005BdgtEstFeb04.pdf

- From page 21, under “Program Accomplishments/ Planned Programs”:

- Nanoscale/Bio-molecular and Metamaterials
  - FY 2003 7.912

FY 2004 8.486
FY 2005 14.051

  - The research in this thrust area exploits advances in nanoscale and bio-molecular materials, including computationally based materials science, in order to develop unique microstructures and properties of materials. This includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale (Metamaterials) level.
  - Program Plans:
    - Develop theoretical understanding and modeling tools for predicting novel metamaterial structures that exhibit superior microwave and magnetic properties for DoD electric drive and propulsion, power electronics, antenna, and radar applications.

Develop algorithmic approaches for predicting properties and structure of nano-scale and meta-materials using first principles/quantum mechanical methods with higher accuracy and reduced computational complexity.

Couple the algorithmic approaches to methods that extract parameters for simulation of materials at larger spatial scales while conducting experiments to verify/validate the predicted properties at all spatial scales.

Explore fundamental behavior of nanostructured materials that display quantum and/or non-equilibrium behavior.

Exploit an understanding of properties that are dominated by surface behavior to develop materials with increased thermal conductivity, biocidal properties, and phonon capture.

- *This time, last year's vague description of accomplishments has merely been reasserted verbatim*.

C. DoD FY 2006/2007 Budget Estimates, February 2005: http://www.darpa.mil/Docs/DescriptiveSummaryFebruary2005.pdf

- From page 34, under "Program Accomplishments/Planned Programs":
  - Nanoscale/Bio-molecular and Metamaterials
    - FY 2004 7.845

FY 2005 14.051
FY 2006 11.450

  - The research in this thrust area exploits advances in nanoscale and bio-molecular materials, including computationally based materials science, in order to develop unique microstructures and properties of materials. This includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale (Metamaterials) level.

- Program Plans:

  - Develop theoretical understanding and modeling tools for predicting novel metamaterial structures that exhibit superior microwave and magnetic properties for DoD electric drive and propulsion, power electronics, antenna, and radar applications.

Develop algorithmic approaches for predicting properties and structure of nano-scale and meta-materials using first principles/quantum mechanical methods with higher accuracy and reduced computational complexity.

Couple the algorithmic approaches to methods that extract parameters for simulation of materials at larger spatial scales while conducting experiments to verify/validate the predicted properties at all spatial scales.

Explore fundamental behavior of nanostructured materials that display quantum and/or non-equilibrium behavior.

D. DoD FY 2007 Budget Estimates, February 2006: http://www.darpa.mil/Docs/FY07_Final.pdf

- From page 36, under “Program Accomplishments/Planned Programs”:

  - Nanoscale/Biomolecular and MetaMaterials

    - FY 2005 14.826

FY 2006 11.000

- FY 2007 15.450

- The research in this thrust area exploits advances in nanoscale and bio-molecular materials, including computationally based materials science, in order to develop unique microstructures and properties of materials. This includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale (Metamaterials) level.

- Program Plans:

  - Develop algorithmic approaches for predicting properties and structure of nano-scale and meta-materials using first principles/quantum mechanical methods with higher accuracy and reduced computational complexity.

Couple the algorithmic approaches to methods that extract parameters for simulation of materials at larger spatial scales while conducting experiments to verify/validate the predicted properties at all spatial scales.

Explore and exploit the underlying dualities between discrete and continuous computational methods to dramatically improve DoD computational abilities.

Apply ideas from non-Euclidean geometry to obtain fast optimization methods for certain problems in robotics, including pursuitevasion, optimal path-planning, and reconfiguration.

Explore fundamental behavior of nanostructured materials that display quantum and/or non-equilibrium behavior.

E. DoD FY 2008/2009 Budget Estimates, February 2007: http://www.darpa.mil/Docs/FY08_budg_est.pdf

- From page 32, under "Program Accomplishments/ Planned Programs":
  - Nanoscale/Biomolecular and MetaMaterials
    - FY 2006 11.000

FY 2007 12.000
FY 2008 15.057
FY 2009 17.500

- The research in this thrust area exploits advances in nanoscale and bio-molecular materials, including computationally based materials science, in order to develop unique microstructures and properties of materials. This includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale (Metamaterials) level.
- Program Plans:
  - Develop algorithmic approaches for predicting properties and structure of nano-scale and meta-materials using first principles/quantum mechanical methods with higher accuracy and reduced computational complexity.

Couple the algorithmic approaches to methods that extract parameters for simulation of materials at larger spatial scales while conducting experiments to verify/validate the predicted properties at all spatial scales.

Explore and exploit the underlying dualities between discrete and continuous computational methods to dramatically improve DoD computational abilities.

Develop theoretical advances to characterize the propagation of random effects through differential equation models of electromagnetic material systems to allow interpolation, extrapolation, and hybridization of solutions to known systems to closely related "perturbed" systems.

F. DoD FY 2009 Budget Estimates, February 2008: http://www.darpa.mil/Docs/DARPAPB09February2008.pdf

- From page 38, under "Program Accomplishments/Planned Programs":
    - Nanoscale/Biomolecular and MetaMaterials
        - FY 2007 12.029

FY 2008 16.500
FY 2009 17.500

- The research in this thrust area exploits advances in nanoscale and bio-molecular materials, including computationally based materials science, in order to develop unique microstructures and material properties. This includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale (Metamaterials).
- Program Plans:
    - FY 2007 Accomplishments
        - Developed a cluster expansion method for materials properties that achieved 10^6 reduction in the number of calculations
        - Developed a substantiation for quantum monte carlo calculations linear in the number of particles

Developed a new method for predicting material properties based upon linear combinations of atomic potentials
Demonstrated a laser driven, 1 billion electron volt electron beam
Designed composite nano-material structures and demonstrated processing capabilities for achieving improved optical and mechanical properties over existing infrared windows
Developed and applied new theory for multiple input multiple array radar systems that lead to 10x improvement in missed target detection while providing 10x reduction in search volume

25 Our synthetic list reads as follows:

- The development of nanochannel glass recording devices is mentioned under "Nanostructure in Biology" on page 13.

In a section on electronic sciences, nano-aperture vertical cavity surface emitting lasers are mentioned (27).

The next page mentions fabrication technologies for nanometer scaled transistors

The Advanced Materials Research Institute records the development and demonstration of sensors made from metal oxide nanoparticles and nanowires (43)

Unconventional therapeutics demonstrated that engineered organic nanoparticles elicit an immune response (109)

A later section on materials processing and manufacturing mentions the establishment of digital representation of microstructure across the nano- mirco- and meso- scales to effectively and quantitatively describe structures and features of interest, as well as the demonstration of carbon nanotube filaments from electrospun precursor polymer fibers, and composite fibers incorporating carbon nanotubes in graphite derived via commercially scalable fiber production methodologies (206-207).

Multifunctional Materials and Structures mentions having demonstrated an ability to control period nano features in alumina for warm forming of polymers (209).

Reconfigurable Structures demonstrated >100 cycles of dry nanoadhesion to glass at approximately 30 psi (normal) (213).

Functional Materials and Devices demonstrated nano-material architectures that are calculated to significantly improve the energy product of magnets, power density of batteries, and figure of merit for high temperature thermoelectric. They also demonstrated two optimized nano-phase mixed oxides for anodes in lithium ion batteries (216).

Cognitively Augmented Design for Quantum Technology investigated the exploitation of new fields of nanophotonics and plasmonics in which metal nanostructures converted electromagnetic radiation into charge density waves (281).

The National Security Foundry Initiative pursued research concepts for shrinking semiconductor devices to the nanoscale and explored applications to integrated Microsystems (295).

RAD Hard by Design developed a standard cell Application-specific Integrated Circuit (AISC) library in commercial 90 nanometer (nm) complementary metal-oxide-semiconductor (CMOS) processes (323).

Nano-Electro-Mechanical-Computers (NEMS) developed nanomechanical switch-based logic in semiconductors, metals, and insulators (351).

Laser-Photoacoustic Spectroscopy (L-PAS) developed tuned lasers with a range of ± 40 nanometers (nm) (363).

Deep Ultraviolet Avalanche Photodetectors (DUVAP) demonstrated Geiger mode operation at 280 nanometers (373).

Ultra-Low Power Electronics for Special Purpose Computers developed nanoscale now power electronics for defense applications (385).

Persistent Ocean Surveillance demonstrated feasibility of using nanofluidic technology with moving magnets in a linear generator to harvest wave energy (453).

26 For a high-quality version of this argument, see Daning Hu, Hsinchun Chen, Zan Huang, and Mihail C. Roco, "Longitudinal study on patent citations to academic research articles in nanotechnology (1976–2004)," *Journal of Nanoparticle Research* (2007) 9:529–542. "The number of patents and article citations in patent documents has

increased faster in this interval for the [Nanoscale Science and Engineering] area as

compared to all areas together . . . The number of academic article citations per journal and year for the top 10 most cited journals has increased about 50

times in the interval (2000–2004) as compared to the interval (1976–1989)" (541).

27 For a straightforward example, see Jan Youtie, Philip Shapira, and Alan L. Porter, "Nanotechnology

publications and citations by leading countries and blocs," *Journal of Nanoparticle Research,* 10:6 (August 2008): 981-986.

28 See, for example, Mark Lemley, "Patenting Nanotechnology," 58 *Stanford Law Review* 601, David C. Mowery, et al. "Pioneering Inventors or Thicket-Builders: Which U.S. Firms use Continuations in Patenting?" *Management Science*, Christopher Newfield, *Unmaking the Public University: the 40 Year Assault on the Middle Class* (Cambridge: Harvard University Press, 2008), chapter 12, and Suzanne Scotchmer, *Innovation and Incentives* (Boston: MIT Press, 2004).

29 See for example Pidgeon, N, Harthorn, B., Bryant, K, Rogers-Hayden, T. 2009. Deliberating the risks of nanotechnologies for energy and health applications in the United States and United Kingdom. Nature Nanotechnology 4:95-98. http://www.nature.com/nnano/journal/v4/n2/abs/nnano.2008.362.html

30 When Newt Gingrich said, "When you lay out the potential positive improvements for the nation, for the individual, for the society, you then have to communicate that in relatively vivid language," his examples of vivid language were [science fiction] authors Isaac Asimov and Arthur C. Clarke, and the SF-like science popularizer Carl Sagan (Bainbridge and Roco, p. 37).