Science out of the Shadows:
PUBLIC NANOTECHNOLOGY AND SOCIAL WELFARE

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BEHIND THE FINANCIAL CRISIS OF 2007–10 LAY AN ECONOMIC CRISIS, and behind the economic crisis lay a development crisis. Despite the apparent success of the United States at ruling the roost in information technology, biotech, and related areas of science-based industry, discussions of long-term economic power in the first decade of the 2000s generally called U.S. economic leadership into question. Some editorialists called the decade the "Big Zero" because of the lack of majority wage and wealth gains for the first time since the 1930s.[1] Ongoing hardships for the American poor, including hunger, the end of the expansion of the middle-class, and the reduction in social

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[1] Paul Krugman, "The Big Zero," *New York Times,* December 28, 2009, http://www.nytimes.com/2009/12/28/opinion/28krugman.html.

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mobility, are now widely recognized phenomena.[2] For stocks, if one counts dividend income, the 2000s were actually worse than the Great Depression decade of the 1930s.[3]

THE ATTACK ON EGALITARIAN SOURCES OF VALUE

How did we get here, despite so much good labor, research and development (R&D), and financial activity? Much of the answer involves a shift in economic theory, or economic culture more specifically, and can be summarized as the decline of equality. Equality and its tandem notion of the "general welfare" have, to simplify, been largely discredited in the United States by two conceptual moves endlessly retold in American politics. The first is the sidelining of the labor theory of value. Under the "Fordist" industrial system, political and business leaders pressed hard to enhance the productivity of the "American workforce," seen as a differentiated ensemble whose high general productivity was crucial to U.S. success. This view justified a strong welfare state that invested in health, education, training, nutrition, and the other inputs of economic success that the market never distributed with sufficient breadth. This welfare perspective was also important to the workplace. By the early 1970s, good "human relations" between labor and management were established as part of the high-productivity mix. The blockbuster early-1980s management book *In Search of Excellence* reflected this trend, along with the ascendancy of a Japanese labor model that stressed cooperation and integration, by tying the best financial results to a liberal, humane management theory that put the nurturing of labor at the center of management practice.[4]

Ten years later, during the transition from the Reagan to the Clinton years, all this had changed. As just one example, a best-selling story about the rise of Netscape in the 1990s gave the starring roles to technology, finance, and ineffable entrepreneurial spirit, bit parts to the brilliantly trained software engineers, who were mostly from India, Taiwan, and other places outside the United States and who had developed the technology, and no part at all to the underlying research by crucial figures such as Tim Berners-Lee, who initially invented the addressing system and other core components of the Web's basic architecture.[5] Nontechnical labor in high-tech firms was equally invisible. Endogenous growth theory, later used to explain and advance the dot-com miracle, accelerated the quiet replacement in the United States of labor with technology as the primary input of economic growth.[6]

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[2] For an accessible overview of wage stagnation and declining social mobility, see Isabel Sawhill and John E. Morton, "Economic Mobility: Is the American Dream Alive and Well?" (Washington, DC: Pew Charitable Trusts, 2008).

[3] Nikolaj Gammeltoft, "U.S. Stocks Drop as Crisis Causes S&P 500's First Decade Loss," *Bloomberg News,* January 1, 2010, http://www.bloomberg.com/apps/news?pid=newsarchive&sid=azRby9JhxPH0dyn/content/article/2009/12/31/AR2009123103250.html.

[4] Thomas J. Peters and Robert H. Waterman, *In Search of Excellence: Lessons from America's Best-Run Companies* (New York: Harpers, 1982). For an overview of the changing dynamics between conservative and liberal management theory, see my "Corporate Culture Wars," in *Corporate Futures: The Diffusion of the Culturally Sensitive Corporate Form*, ed. George Marcus (Chicago: University of Chicago Press, 1998), 23–62.

[5] Michael Lewis, *The New New Thing: A Silicon Valley Story* (New York: Norton, 1999).

[6] This replacement was made most influentially in "new growth theory," an important extension of neoclassical economics in the 1980s. Often associated with papers by Gene M. Grossman and Elhanan Helpman in 1989, by Philippe Aghion and Peter Howitt in 1990, and by Paul Romer in 1990, this theory made technological change "endogenous," or internal, to economic markets and susceptible to policy modification. For an illustrative popularization of the idea, see Joseph Cortright, "New Growth Theory, Technology and Learning: A User's Guide," *Reviews of Economic Development Literature and Practice,* no. 4 (Washington, DC: U.S. Economic Development Administration, 2001),

As production and higher productivity were increasingly seen as coming not from general, socially well-distributed labor—from social labor as such—but from knowledge that was primarily "STEM" (science, technology, engineering, and mathematics) knowledge via STEM's highly specialized elites, a second move worked in harmony with this first one. Egalitarian social relations were cast as an economically regressive practice that discouraged the productive elite by confiscating the value they created and redistributing it to people who produced far less. Equality was no longer an expression of creative energies that arose from everywhere in society but was seen as redistribution from the more productive to the less productive. Now even progressive politicians argue for social policy on a terrain formed by a conservative version of neoclassical market economics. The inequality boom in wealth and income—as well as between the private and the public sector—logically reflects antiegalitarian growth theory. By this I mean growth theory that sees the value-creating power of labor as radically unequal as one moves from one sector to another and from the "best" employees in one sector to the rest. This theory is supported by an informal but pervasive "Pareto principle" in the distribution of wealth as in everything else: 80 percent of the wealth is naturally owned by 20 percent of the people, and (at least) 80 percent of economic value is produced by the labor of 20 percent (or less) of the people. This idea circulates as a kind of cultural folklore or intuition or common sense, particularly in high-tech communities. The intuition says that value does not come from everyone working as well as they can with the best possible universal education and training but comes from the "vital few" of STEM domains, finance, and business law because the few make the best use of general resources and should therefore have special access to and control over them.

THE LIMITS OF ELITE-CENTERED PRODUCTION

But an interesting anomaly has cropped up in recent years. Despite a theory of disproportionate value creation that fit well with the existing American industrial system, the decade of the 2000s saw a growing sense that the "engine of the American economy"—the research enterprise—was starting to sputter.[7] Though the United States had long dominated overall research output as well as "high-impact" research, its lead seemed to be eroding.[8] The National Academy of Sciences, not known for exaggeration, sponsored a widely referenced report called "Rising above the Gathering Storm," which expressed over five hundred pages of concern about the country's "future prosperity."[9] It made sensible recommendations for improving K–12 education, research funding, and the innovation environment, among other things. Two years later, a follow-up meeting reaffirmed the recommendations but also found mediocre progress at best:

> "A number of significant events have taken place since the *Gathering Storm* report was released," said Norman Augustine, who chaired the committee that wrote the report. Unfor-

http://www.eda.gov/ImageCache/EDAPublic/documents/pdfdocs/1g3lr_5f7_5fcortright_2epdf/v1/1g3lr_5f7_5fcortright.pdf (accessed January 22, 2010). My interest here is in the way this theory enabled the eclipse of labor, which became a minor input unless hugely multiplied by technology and finance.

[7] For a brief overview, see Karin Fischer, "America Falling: Longtime Dominance in Education Erodes," *Chronicle of Higher Education,* October 5, 2009, http://chronicle.com/article/America-Falling-Longtime/48683/?sid=at&utm_source=at&utm_medium=en.

[8] See James D. Adams, "Is the U.S. Losing Its Preeminence in Higher Education?" (working paper 15233, National Bureau of Economic Research, August 2009), http://www.nber.org/papers/w15233.

[9] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, "Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future," http://www.nap.edu/catalog/11463.html.

> tunately, he added, most of those positive events have occurred in other countries. Governments around the world are boosting their support of science and engineering research, invigorating precollege science and math education, and investing in institutions of higher education. Meanwhile, the United States has made little progress in strengthening its education, research, and innovation systems. "It would be a cruel outcome if the *Gathering Storm* report were to motivate others to become more competitive while we did little," said Augustine.[10]

For most of the past decade, it has been easy enough to pin R&D troubles on the antiscience, antiresearch Bush administration. But the neglect of what I will call the "development infrastructure" went far beyond the Bush administration proper. The country's educational pipeline continued to crumble. Among the approximately thirty countries tracked by the Organization for Economic Cooperation and Development, the United States is now fourteenth in college participation, sixteenth in degree completion, and twenty-first in high school graduation rates.[11] In California, an extreme but ominous case, the self-proclaimed world capital of the knowledge economy has seen the educational level of its general population fall faster than at any other point in the modern history of wealthy countries, as far as I can determine. To take just two measures:

- California ranks forty-ninth in the share of its population aged twenty-five and over who have at least a high school degree. Between 1977 and 1983 California had ranked first among the fifteen largest states on this measure.
- In 2004, 30.4 percent of California nineteen-year-olds were enrolled in college. This was down from 43.4 percent in 1996. In 2004, California ranked forty-sixth among the states in the share of its nineteen-year-olds who were enrolled in college, down from seventeenth in 1996.[12]

These are precipitous declines.

Major factors in these startling drops are flat or falling overall federal investment in research[13] and flat or falling public investment in higher education.[14] The claim that there is a general causal relation between strong and steady R&D investment and economic growth is now

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[10] National Academy of Sciences et al., "Rising above the Gathering Storm: Two Years Later" (2009), http://www.nap.edu/catalog/12537.html. For a survey of the kind of data that underwrites pessimistic views like Augustine's, see John Aubrey Douglass, "Higher Education Budgets and the Global Recession: Tracking Varied National Responses and Their Consequences," Center for Studies in Higher Education Research and Occasional Paper Series, CSHE.4.10 (February 2010), http://cshe.berkeley.edu/publications/docs/ROPS.Douglass.HEGlobalRecession.2.24.10.pdf (accessed February 24, 2010).

[11] John A. Douglass, "Wrong Trajectory" (speech to the California Alumni Association, May/June 2008), http://alumni.berkeley.edu/california/200805/freespeech.asp (accessed January 17, 2009).

[12] Tom Mortenson, "California at the Edge of a Cliff," *California Faculty Association*, 2009, 2.

[13] For the pattern before the arrival of the Obama administration, see, e.g., American Association for the Advancement of Science, "Federal Research Funding Flat in 2009 as Federal Budget Stalls" (September 30, 2008), http://www.aaas.org/spp/rd/upd908.htm (accessed January 22, 2010).

[14] For the California case tied to the statistics in the previous paragraph, see Christopher Newfield et al., "Current Budget Trends and the Future of the University of California" (University of California Academic Senate, University Committee on Planning and Budget, May 2006), http://www.universityofcalifornia.edu/senate/reports/AC.Futures.Rpt.0107.pdf (accessed January 22, 2010).

generally uncontroversial, though details and ratios are of course disputed.[15] I will take this causal relation as axiomatic—it is in fact only partially correct—and turn to another aspect of the issue, which is the decline in investment itself. What has allowed the decline in investment in the knowledge infrastructure in an economy like that of the United States, which depends on it? And what factors might allow for the reversal of this decline? I am interested in the conditions of possibility of the neglect of a developmental infrastructure, which is in large part a cultural issue, one that involves public feelings about technical knowledge and science overall. I am also interested in how the country might shift away from this neglect, particularly during an Obama administration that promised opportunities for rebuilding an advanced social infrastructure. I offer a case study in nanotechnology policy and will argue that science would fare better with the public were it able to offer a "general welfare" vision of science's purpose.

OBAMA SCIENCE IN THE REPUBLICAN DESERT

I first review the suggestion that the Obama administration has already turned the page on Bush era neglect of public investment. This was, for example, the message of an address given by the head of the American Association for the Advancement of Science (AAAS) at an event sponsored by the European Research Commission in Brussels in October 2009. As evidence of an important shift, Alan I. Leshner, the CEO of the AAAS, cited Obama's inaugural address: "we will restore science to its rightful place, and wield technology's wonders." He then showed statistics to indicate that U.S. support for R&D is bouncing back.[16] On another occasion, White House science adviser John P. Holdren summarized the administration's priorities as an intensification of a preexisting emphasis on science and technology's impact on the economy, a desire to improve STEM education, and a focus on alternative energy.[17] But there are no hints of a change on more fundamental issues, such as reducing the scope of intellectual property rights, which some have argued will increase innovation and adoption. Judging from the elements they select for special mention, these and other science leaders have welcomed Obama policy because it restores a pre-Bush trajectory, not because it offers a fresh departure or a new vision of public science.[18] It has not yet sponsored "moon shot"–style projects in an obvious area like renewable energy, as did the Kennedy administration with the creation of NASA and the definition of the space program's timetable and goals.

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[15] For an example of the current consensus, see the papers about innovation in a range of domains in Rebecca Henderson and Richard G. Newell, eds., *Accelerating Energy Innovation: Lessons from Multiple Sectors,* http://www.nber.org/~confer/2009/EIf09/program.html (accessed January 22, 2010), particularly Henderson's summary.

[16] Alan I. Leshner, "Europe and the United States—a Crucial Moment for Science Cooperation" (Joint Research Centre Annual Lecture, October 28, 2009), http://www.aaas.org/news/releases/2009/media/1106ec_leshner_lecture_presentation.pdf (accessed January 24, 2010).

[17] John P. Holdren, "Science in the White House," *Science* 324, no. 5927 (May 1, 2009): 567, http://www.sciencemag.org.proxy.library.ucsb.edu:2048/cgi/content/full/324/5927/567.

[18] For examples of intelligent continuity with established, Clinton era science policy, see *Richard Bendis* and *Ethan Byler*, "Creating a National Innovation Framework," *Science Progress,* April 22, 2009, http://www.scienceprogress.org/2009/04/creating-a-national-innovation-framework/(accessed January 24, 2010); Brian Kahin, "Beyond the Box Innovation Policy in an Innovation-Driven Economy," *Science Progress,* July 13, 2009, http://www.scienceprogress.org/2009/07/beyond-the-box/(accessed January 24, 2010); Rebecca Henderson, introduction and summary to *Accelerating Energy Innovation: Lessons from Multiple Sectors* (Cambridge, MA: MIT Press, forthcoming), http://www.nber.org/~confer/2009/EIf09/summary.pdf (accessed November 3, 2009).

Nor will the Obama administration offer developmental liftoff unless it undertakes a major cultural shift. Although it is manifestly more supportive of science research than was its predecessor, it has yet to produce evidence of will or means to change the basic paradigm in which publicly funded science is forced to exist. This paradigm rests on the idea that public action is generally inefficient, destructive of entrepreneurial drive, or geared to bolster society's losers, or all three at once. Over the past thirty years, it has enabled a large part of the electorate to forget the previous vision of New Deal/Great Society public services as just and effective investments in the entire citizenry and to replace it with a view of public services as remedial programs for those unable to succeed in the competitive and dynamic market economy. For example, bus service in Los Angeles is in practice largely provided for those who lack a car rather than for more efficient transport for a population of many millions of people that minimizes environmental damage and the massive wasting of time in traffic. Within the existing paradigm, the majority who can afford a car have little reason to vote for tax-supported public transport. Public services are seen as stop-loss functions rather than as creators of social value, and therefore, a large portion of the American public and particularly of its leaders appear to believe that public services are, by default, a drain, not a gain.[19] Public action coordinated by government, because it is regarded as addressing deficiencies rather than adding value, is seen *not* as part of the nation's *innovation* system but as a safety net, keeping things from getting worse, not helping things get better.

This paradigm, and the overall culture that accepts it, have put educational and research policy in an awkward position. Education and research are seen by majorities as important to their children's future.[20] At the same time, they are largely funded by the public and are in fact public services, which places them closer to those things that patch a hole or teach young people how to read and write, and farther from things like CMOS processor architecture that are thought to lead to a better world. The overall polling and interview evidence suggests that the public is indeed ambivalent about research and education.[21] And this ambivalence is an enabling factor in the reality of education and research funding in recent years, where the pattern is to cut them early and deeply in a squeeze, with the partial exception of health research.

These deep American misgivings about *public development* are an important limit on the country's ability to fund research and education. The underlying conservative paradigm holds that the value of public research and education spending can be accurately expressed by the value created for the private sector, and that the social value of innovation can be measured in relation to measurable returns to individual firms. The logical conclusion is that public expenditures should be limited to those that by and large seem useful to particular industries or even to their most important firms. Without effecting a larger cultural shift away from this paradigm, Obama policy will be limited to assisting private development in the early stages of both educational training and technology R&D when "market failure" is all but inevitable. Without such a shift, Obama policy will not be able to assign government a role in leading, defining, and shaping development. Obama centrism does not see government as *creative*, as itself the generator of

[19] Christopher Newfield, *Unmaking the Public University: The Forty-Year Assault on the Middle Class* (Cambridge, MA: Harvard University Press, 2008).

[20] For a recent example, see Public Policy Institute of California, "Californians and Higher Education" (November 2009), http://www.ppic.org/content/pubs/survey/S_1109MBS.pdf (accessed January 22, 2010).

[21] As an example of ambivalence about nanotechnological research, see Nick Pidgeon, Barbara Harthorn, Karl Bryant, and Tee Rogers-Hayden, "Deliberating the Risks of Nanotechnologies for Energy and Health Applications in the United States and United Kingdom," *Nature Nanotechnology* 4 (2009): 95–98, http://www.nature.com/nnano/journal/v4/n2/abs/nnano.2008.362.html.

new value independently of its support for the private sector. Cass Sunstein, alluding to the Milton Friedman–dominated Chicago School of conservative economics, once called Obama a "University of Chicago Democrat."[22] My translation of this accurate description is that the Obama default is to favor government as supporter of the private sector but not government as creator of the social relations that enable and also comprehend a robust, self-determining public infrastructure. In reality, it is well known that social "spillovers" of research and education—the social value of inventions, well-educated workers, and the like—greatly exceed the value that any one firm can appropriate to itself.[23] But in the absence of a new focus on science's public value, education and R&D will be funded to a much smaller extent than their public value would justify, and this is because within our existing framework private returns will remain the main measure of the value of public investment.

The fundamental policy question is this: do our societies want to scale public funding for research, development, and education to the incredible *size* of the public problems they address? If we are serious about decarbonizing the energy economy, do we not need a moon shot–scale effort? Sheer scale suggests that the answer is yes, since we do not really want too little, too late to be our answer to climate change, global hunger, or anything else. But there is no obvious way that current science policy can get us from here to there. My hypothesis is that the only way to bridge the gap is to explain the enormous *social* benefits that follow from major social investment in R&D and in education. I say this based in part on long experience with and observation of American society, but also based on research that shows, for example, lower R&D rates in regions where voters think the R&D will largely benefit someone else.[24] High rates of R&D—like other kinds of social investment—will find public support mostly, if not only, when they offer the possibility of increasing general public benefits. These narratives will have to be so good that they eclipse the stories of personal wealth and indirect national prosperity that currently have a lock on popular tales of progress. This means telling new stories of public benefits in a way that will create a new set of cultural attitudes toward developmental infrastructure. Proper funding of the developmental infrastructure of the United States will depend on building a new common sense about its public value and function. We will need to articulate how this infrastructure works—how research, development, and education work and what they do. We will need to describe the people in it, narrate their strengths and weaknesses, their hopes and fears, describe their effort in all the complexity of their struggles—in short, tell the full social story of the development of technology, a story that includes the social agents and dilemmas in the plot.

I will suggest how this storytelling might work by analyzing current narratives about a part of the developmental infrastructure that is in general favorably viewed—that for nanotechnology.

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[22] David Leonhardt, "Obamanomics," *New York Times Magazine,* August 20, 2008, http://www.nytimes.com/2008/08/24/magazine/24Obamanomics-t.html (accessed January 22, 2010).

[23] See, e.g., Suzanne Scotchmer, *Innovation and Incentives* (Cambridge, MA: MIT Press, 2004), 269: "for investments in R&D, unlike ordinary capital, the social value of a marginal investment is not equal to the private value."

[24] See, e.g., Brian Wright and Tiffany Shih, "Agricultural Innovation," in *Accelerating Energy Innovation*, http://www.nber.org/~confer/2009/EIf09/wright.pdf (accessed December 28, 2009).

THE NATIONAL NANOTECHNOLOGY INITIATIVE

There is no 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.[25] Although the federal government funds only about 28 percent of all R&D, about 70 percent of all R&D is classified as "D"—that is, product development organized by corporations.[26] Around 60 percent of *basic* research in the United States is funded by the federal government.[27] 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 account for 60 percent of the federal R&D budget.[28] The two 60 percents do not refer to the same research, but we can say that much "basic" research is mission research rather than focused on addressing either fundamental scientific questions or articulated social needs. Rather than being the servant of market forces, as the Left often accuses and the Right demands, the federal government is a leader in setting the agendas of basic research in continuous collaboration with the relevant scientific communities and in keeping with its own agency goals. My questions are as follows. Are federal agencies focused on creating and sustaining networked partnerships that include science's various publics in the network? As an important example, did the National Nanotechnology Initiative advance this cause?

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 codiscovery of the fullerene molecule and was popularizing such soon-to-be-defining "nano" characteristics as self-assembly and such nanophenomena as molecular electronics.[29]

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 that "efficient conversion of energy, materials, and other resources into products of high performance will be a strategic necessity in the next cen-

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[25] Special thanks to John Munro of the Department of History at the University of California, Santa Barbara, for providing excellent research assistance for this section and the next. Thanks as well to the UCSB Faculty Senate Council on Research.

[26] See National Science Foundation, *Science and Engineering Indicators 2008*, chap. 4, http://www.nsf.gov/statistics/seind08/c4/c4h.htm.

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

[28] David C. Mowery, "What Does Economic Theory Tell Us about Mission-Oriented R&D?" in *The New Economics of Technology Policy*, ed. D. Foray (Northampton, MA: Edward Elgar, forthcoming); National Science Foundation, *Science and Engineering Indicators 2008*, chap. 4.

[29] On publication growth, see Ira Bennett and Daniel Sarewitz, "Too Little, Too Late? Research Policies on the Societal Implications of Nanotechnology in the United States" (Phoenix: 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.

tury."[30] 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."[31]

The National Nanotechnology Initiative (NNI) was indeed drafted, passed, announced by President Bill Clinton at the California Institute of Technology in January 2000, and put into effect later that year.[32] An important step in its passage was the communication to policymakers of nanotechnology's broader social impacts. Some of these were presented when the House of Representatives Committee on Science heard testimony about the value of nanotechnology, including Smalley's claim that nanoscience was "about to enter a golden new era."[33] The committee's report, "Unlocking Our Future," has a long section on "science for society," which sings the praises of publicly funded science with practical benefits.[34] In 2002, NNI leaders issued a five-hundred-page report on nanotechnology's impact on "human performance" that included an eloquent call for large government funding for nanotechnology with high social benefits from none other than the former Republican Speaker of the House and "small government" activist Newt Gingrich.[35] Discussions of nanotechnology's social benefits were essential to garnering political support. The apparent 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 to nor present for the genesis of the NNI. Societal impacts were generally reduced to economic impacts, and the leading rationale for the NNI was economic competition with other countries.[36] The agenda-

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

[31] Interagency Working Group on Nanoscience, Engineering, and Technology, *Nanotechnology Research Directions: IWGN Workshop Report* (1999), 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.

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

[33] House of Representatives Committee on Science, 105th Congress. My understanding of the NNI's origins has benefited from the excellent history of the NNI written by my Center for Nanotechnology in Society colleague W. Patrick McCray, "Will Small Be Beautiful? Making Policies for Our Nanotech Future," *History and Technology* 21, no. 2 (2005): 177–203. Smalley citation from McCray.

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

[35] Mihail C. Roco and William Sims Bainbridge, eds., *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science* (Arlington, VA: National Science Foundation, 2002), 36-55, http://www.wtec.org/ConvergingTechnologies/1/NBIC_report.pdf.

[36] McCray, "Will Small Be Beautiful?" 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

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 who 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."[37] The public appeared, not as an active character in official discussions, but as a recipient: as an audience to be persuaded, as students to be educated, as reactors to risk events to be managed, and as passive 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 nonexistent in the conference report, and always improvable if not largely replaceable by computer networks and other forms of associative technology.[38]

One particularly interesting example occurs when the report expresses a desire to use nanotechnology "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, the report continues, "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." I quote part of its description at length in an attempt to convey 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

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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, *Converging Technologies,* 39).

[37] Bennett and Sarewitz, "Too Little, Too Late?"

[38] In Roco and Bainbridge, *Converging Technologies,* see, e.g., "Theme B Summary," 97–101,"Theme D Summary," 275–77; and Sherry Terkle, "Sociable Technologies: Enhancing Human Performance When the Computer Is Not a Tool but a Companion," 150–58.

> in different ways by different participants. Improving group interactions via brain-to-brain and brain-machine-brain interactions will also be explored.[39]

The authors seem unaware of the Orwellian structure of this idea, of its hive-mind overtones, or of its potential for domestic surveillance. 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 a unit's performance through each member's controlled coordination with all others, thus underwriting Earth's 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, with the exception of enabling new levels of group sex, and all nonmilitary and nonsexual understanding continues in Scalzi's correct assessment to depend on sociocultural 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 its asociality. Society is remote, weak, and receptive rather than present, involved, active, and intrinsic both to problems and to their solutions. 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; nor do these projects offer technological expertise in applying nanotechnology to those social needs. Though such articulations are often incomplete and in process, that does not explain why the reports leave these social conditions abstract, remote, and underdescribed; the people who compose those conditions are not present.

THE STATE OF NANOSCIENTIFIC OUTREACH

What about a fallback position? This would be less than public participation and deliberation and instead a kind of communication in which governmental agencies can establish the conditions of equitable private-public partnerships by at least acknowledging and presenting the results of public funding to various publics. This would mean conveying the impact of the presence of—if not the public voice and will behind—public money. The public pays for a lot of research, and its contribution could be acknowledged, 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. We looked for accounts that linked public inputs 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:

1. NNI funding
2. A federal agency (e.g., National Science Foundation)
3. Funding and Requests for Proposals
4. Funded research
5. Disclosures of inventions and publications

[39] Ibid., 276.

6. Patents
7. Licenses
8. Development and products

This list is of course far more linear than development ever is. Another, equally fundamental problem is that once the money arrives at (a), the public contribution, in spite of statutory reporting requirements, largely disappears.[40] Our most recent confirmation of this problem involved the company Nanosolar, which applies nanoscale scientific innovation to improving the efficiency of photovoltaic cells. Nanosolar was cited by the White House's Office of Science and Technology Policy as having received a great deal of NNI funding that it put to good inventive use.[41] Nanosolar was indeed, as of January 2010, the assignee on twenty-one patents at the U.S. Patent and Trademark Office and had applied for an additional forty-four. None of these patents cited a government interest as having had a part in their development.[42]

Bearing in mind these known issues with the innovation structure and the data, we used this sequence as 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 Advanced Research Projects Agency (DARPA). The Department of Defense receives about a third of NNI's annual funding,[43] and DARPA, widely credited with creating the "ARPANET" that led to the Internet, is a leading government agency in taking on high-risk projects that might be total losses or might, on the other hand, lead to something like the post-1960s revolution in information technology.[44]

In fact, no public documentation of DARPA nanoscale progress exists. What one finds after systematically searching 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.[45]

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[40] The "linear model" of R&D has been soundly critiqued within science and technology studies and by 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).

[41] Statement of Ambassador Richard M. Russell, associate director and deputy director for Technology, Office of Science and Technology Policy, Executive Office of the President, before the Subcommittee on Science, Technology, and Innovation, Committee on Commerce, Science, and Transportation, U.S. Senate, April 24, 2008, http://commerce.senate.gov/public/_files/RussellNanoFINAL.pdf (accessed January 15, 2010).

[42] Search conducted and analyzed by Jerry Macala and Christopher Newfield, January 15, 2010. Requirements that federal agencies report on technologies developed with the use of government funds are part of the Stevenson-Wydler Act of 1982, follow-on legislation to the Bayh-Dole Act; *Utilization of Federal Technology, U.S. Code,* Title 15, chap. 63, sec. 3710, http://www.law.cornell.edu/uscode/15/usc_sec_15_00003710----000-.html (accessed January 19, 2010). Thanks to Gerald Barnett of the University of Washington for this reference.

[43] National Nanotechnology Initiative: FY 2009 Budget and Highlights, http://www.nano.gov/NNI_FY09_budget_summary.pdf.

[44] Among the many works on this topic, see, e.g., Glenn R. Fong, "ARPA Does Windows: The Defense Underpinning of the PC Revolution," *Business and Politics* 3, no. 3 (2001): 213–37 (criticizing orthodox market-based explanations of technological and economic progress); and Shane Greenstein, "Nurturing the Accumulation of Innovations: Lessons from the Internet," in Henderson and Newell, op. cit., note 15.

[45] Our primary grouping was

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

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."[46] Nonspecialists 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 enabled massive improvements in hard-disk storage that in turn transformed the PC industry in the late 1990s and resulted in a Nobel Prize in 2007.[47]

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 highlight 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 to 2003, there is some overlap in topics related to this idea but no sequencing, identified trend, or systematic mutual referencing. The level of nonspecificity 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.[48]

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

[46] DoD FY 2001 Budget Estimates, February 2000, 14.

[47] W. Patrick McCray, "From Lab to iPod: A Story of Discovery and Commercialization in the Post–Cold War Era," *Technology and Culture* 50, no. 1 (2009): 58–81.

[48] DoD FY 2000/2001 Budget Estimates, February 1999, p. 16, under "FY 1999 Accomplishments": "Nanoscale/Biomolecular Materials. ($1.350 Million)."

DoD FY 2001 Budget Estimates, February 2000, p. 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, p. 19, under "FY 2000 Accomplishments":

Nanoscale/Biomolecular Materials. ($9.233 Million)

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.[49] The reports do not link

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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, p. 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.

[49] For example, here are the descriptions for one program for three consecutive years:

DoD FY 2004/2005 Budget Estimates, February 2003, p. 30, 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.

DoD FY 2005 Budget Estimates, February 2004, p. 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.

funded laboratory activity to the formal reporting. The text conveys a lack of interest in convincing the reader that public financing is being used for clearly articulated or imaginative 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.[50] But no cluster of goals, patterns, systematic developments, or public objec-

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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.

DoD FY 2006/2007 Budget Estimates, February 2005, p. 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 nanoscale 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.

[50] My synthetic list of previous accomplishments DoD FY 2009 Budget Estimates, February 2008) reads as follows:

The development of nanochannel glass recording devices is mentioned under "Nanostructure in Biology" (13).

In a section on electronic sciences, nanoaperture 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- micro- and mesoscales 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 (206–7).

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

Reconfigurable Structures demonstrated more than a hundred cycles of dry nanoadhesion to glass at approximately 30 psi (normal) (213).

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

tives appears. There is no way for a nonspecialist—and probably not for a specialist outside the subdiscipline in question—to understand the interconnection among the projects.

Even more fundamentally, there is no acknowledgment of the contribution 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? I am not saying that nanotechnology-enabled "personalized energy" applications[51] should already be on the market, and yet nearly ten years after the NNI began, there is no way of determining the *specific* impact of the NNI on ongoing research and emerging platforms or possible public impacts in the future.

We can imagine how government reporting might create coherent development narratives about advanced nanotechnology. Since products have not yet emerged, the endings have yet to be written. But a basic plot framework could already be in place: public officials who scanned research results for large and important development patterns spent years persuading policymakers to fund programs, allocated public money with both blindness and insight, and supported research that failed and research that succeeded; meanwhile, scientists, technicians, and others persisted against the odds and produced important interim results with future potentials that are clearly specified. In the most interesting cases these narratives could read like serialized novels.

Such narratives are not yet being attempted. Nanotechnology analysts tend to use standardized forms of output metrics (publication and patent counts) and 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.[52] Sometimes international comparisons are made, and such comparisons have clear policy uses in encouraging politicians to improve funding in areas in which the United States may be losing ground to rivals.[53] Statistical growth curves convey a clear impression of progress and

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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 complementary metal-oxide-semiconductor (CMOS) processes (323).

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

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

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

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

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

[51] Daniel G. Nocera, "Personalized Solar Energy," *Inorganic Chemistry* (2009), 48, 10001-10017.

[52] 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* 9 (2007): 529–42. "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).

[53] 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, no. 6 (2008): 981–86.

acceleration, and nearly all areas of nanoscale research have seen major increases in activity in the United States and elsewhere over the past two decades.

But publications and patents do not literally equal development, production, and use. Statistics are an imperfect and in some cases a misleading measure of social impacts and development.[54] 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.[55] The construction of patent claims often expresses business strategies toward 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 reflects activity and has a *symbolic* value: it operates successfully as a *sign* of funded activity—actually, as a displaced 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 in a literal way reflect or directly express the stages of that development or suggest, before its realization, where development will lead, or what society will get out of it.

The gap between a signifier and its "signified," or a sign and what it denotes, can be addressed only through acts of interpretation, or what I am discussing here as narrative analysis.[56] This type of analysis inserts research signs, such as patent trends, into their institutional context, one fully populated with scientists, managers, technical staff, graduate students, agency bureaucrats, politicians, journalists, social movements—representatives of the actual world in which research occurs every day. Such narrative analysis (or reconstruction) has not yet been attempted in the measurement literature. Our research suggests the difficulty the general public and policymakers alike would have in reviewing these measurements and then interpreting their way to a relation between public funding and social benefits. The NNI's reporting is structured to symbolize accomplishment, but the symbols are mistakenly read as literal measures of science progress. These symbols are stylized pseudonarratives that appear to work for a presumed audience of research managers, funding-agency personnel, aides to elected officials, and laboratory staff who need to understand funding trends. But they do not work at all as either genesis narratives, science stories, or funding dramas and thus do not bring science and social aims together.

The limitations of this well-developed, high-quality initiative, the NNI, suggest the elements required by a narrative that truly conveys the *social* value of social investment in technology. First, the NNI or its equivalent, such as an energy or climate moon shot, will need to articulate society's direct *participation* in the initiative, both "upstream" and "downstream." Sec-

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[54] Benoît Godin, "Making Science, Technology, and Innovation Policy" (paper presented at the Polish Academy of Sciences, Committee for Science, Warsaw, Poland, December 2, 2008), *RICEC* 1, no. 1 (2009), http://ricec.info/images/stories/articlerevue/b_godin_3iricec_042009.pdf (accessed February 11, 2010).

[55] See, e.g., Mark Lemley, "Patenting Nanotechnology," *Stanford Law Review* 58 (November 2005): 601; David C. Mowery et al., "Pioneering Inventors or Thicket-Builders: Which U.S. Firms Use Continuations in Patenting?" *Management Science* 55 (July 2009): 1214–26; Newfield, *Unmaking the Public University*, chap. 12; and Suzanne Scotchmer, *Innovation and Incentives* (Boston: MIT Press, 2004).

[56] See Ferdinand de Saussure, *Writings in General Linguistics* (1916; Oxford: Oxford University Press, 2006); Richard Rorty, *Philosophy and the Mirror of Nature* (Princeton, NJ: Princeton University Press, 1979).

ond, the initiative will need narratives of agony, ecstasy, failure, and progress—real stories of human labor that can be appreciated and that will allow the wider society to see scientific R&D as important to a clearly defined set of impacts on the public welfare. These stories would galvanize both public support for funding and, regarding the purposes to which research would best be put, the public imagination. It would move beyond the moon shot narrative of the 1960s, which was largely controlled by Washington's political and military system, and draw on "lead users" and grassroots dreamers in ways that would give nanotechnology a public presence and social focus that it currently lacks.

SCIENCE AND PUBLIC WELFARE

I am writing this piece as the Obama administration begins its second year. Although little that has happened in the first year suggests that Obama will break any molds, there are resources in his own political tradition that he could draw on should he so choose. He was propelled into the White House in the first place by his own true stories about people's struggles to overcome obstacles through a combination of invention and perseverance. Such dramas have similar structures whether you look for them in art, politics, science, or civil society. Innovative practices rebuild cities, redesign schools, reimagine materials for charge transport in photovoltaic cells, and replace failed political regimes with better ones. Without accurate, detailed, inspiring stories of the drama of discovery and development, no new level of investment in either will take place. Without new stories about the role of public infrastructure in supporting economic development, government activity will continue to be regarded as tampering with the market. This remains true even as the "market" no longer seems like an honest economic broker to most Americans, and even as many look to government to not only control abuses but redevelop those large parts of both the economy and the society that have fallen into disrepair. The valuable work of science agencies is a major victim of this silence about the full extent of the innovation system, particularly in its complex public dimensions. Another major victim is the developmental role played by various publics themselves, which for ideological and political reasons is hidden from those publics.

The most impressive feature of the Obama presidential campaign was its ability to scale up a community-organizing approach to national politics—to foster a community-organizing appreciation of the intelligence of ordinary people and of their right and their ability to coauthor national rules. This campaign vision rejected the idea that the country's publics are outside looking in, whether the inside in question is health care, foreign affairs, financial governance, or innovation policy. This vision was far more prominent during the Obama campaign than it has been during the Obama administration, but it did imply the principle that has been important to my discussion here: an *egalitarian* partnership among government, industry, and multiple publics. It is equality that allows collaboration to be open and rapid and to take place among the full complement of actors and insights, including those that appear from the policy center to be beyond the pale.

Policymakers are more interested than ever in public engagement, and they have some standard mechanisms that aim at creating partnerships between the public and the government. Government agencies try to communicate with society through procedures such as "public comment," which can include conducting hearings and accepting invitations to meet with citizens groups, community organizers, activists, and various nongovernmental agencies. 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.[57] These mechanisms are less common on technical subjects, in which most of the public lacks the background to participate equitably, or even to feel interested in the first place.

A more effective mode through which science agencies could reconnect with the public is by telling the kinds of stories I referred to above—stories of the winding road "from bench to bedside." This would mean telling the actual tale of scientific development that the government makes possible. In such a story, obstacles, conflicts, crises, and overcoming would not be buried under thick coats of varnish. These stories would also include society itself, meaning, in the world of the laboratory, the graduate students, staff, technicians, and private and public funders who populate this world. In the narrative the social actors would not be subordinated to but would be *equal partners with* the university laboratories, government research centers, and corporations that manufacture and sell the eventual products.

Such stories 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 that scientific community—the very things that link science to every other kind of work all over the world. Better stories would feature the consistent energy, the everyday teamwork, the ups-and-downs of efforts at communication, the discoveries large and small, the gradual transfer of these discoveries into a development process, and the eventual arrival of the good or service into society at large.[58]

To be effective, these stories must exist together inside a larger process of social self-governance, in which aims and means are collaboratively established and managed. Self-governance would define large social aims for federal programs—such as defining the benefits of nanotechnological research in the case of the NNI. It would be *egalitarian* in that it would grant agency to people at every step of the process in their various contributions to the common effort. The narratives would necessarily be narratives of general welfare, ones that describe the collectively created processes of scientific advancement and that will ultimately be both more just and more effective than our current narratives, which have artificially and incorrectly diminished agency to the nexus of business managers, faculty entrepreneurs, and laboratory heads. In short, the irony of the current moment is that science will need to see itself as part of society's overall welfare portfolio before it can access the new level of resources its most important projects require. A

57 See, e.g., Pidgeon et al., "Deliberating the Risks of Nanotechnologies."

58 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 science popularizer Carl Sagan (Bainbridge and Roco, *Converging Technologies,* 37).