The Discursive and Operational Foundations of the National Nanotechnology Initiative in the History of the National Science Foundation

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The National Science Foundation's (NSF) role in, and influence on, the National Nanotechnology Initiative (NNI) can best be understood through an examination of the NSF's history. Because of the NSF's weakened position at its founding in 1950 and obstacles faced throughout its history, the NSF developed a discursive strategy that focuses on making a causal link between support for basic science and societal benefits, and an operational strategy focused on growing its constituency through infrastructural support. The hallmarks of both of these strategies are present in the NNI.

Introduction

The website of the National Nanotechnology Initiative (NNI) prominently declares in a banner at the top of its homepage that it is "Leading to a Revolution in Technology and Industry" (www.nano.gov). The original banner of the NNI website, however, was less circumspect than its current iteration, declaring that the NNI was "Leading to the Next Industrial Revolution."[1] These simple catchphrases encapsulate a number of assumptions that the NNI is making about the link between scientific research, technological development, and potential societal benefits. The first is the discursive reliance upon the linear model of innovation that posits a causal link between investment in basic scientific research and

1. The previous iterations of the NNI website can be accessed at the Internet Archive (http://www.archive.org) dating back to 04/07/2000. "National Nanotechnology Initiative: Leading to the Next Industrial Revolution" is also the title of a White House press release from the Office of the Press Secretary that was issued on January 21, 2000. http://clinton4.nara.gov/WH/New/html/20000121_4.html

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positive societal and policy outcomes. The second is the strongly determinist claim that investment in nanotechnology will lead to wide ranging societal changes on the scale of the Industrial Revolution in the 18^{th} and 19^{th} centuries. The third assumption of these catchphrases is that the profound societal changes instigated by a nano revolution are ultimately positive. A short blurb also found at the top NNI homepage expands these claims further:

> The National Nanotechnology Initiative (NNI) provides a multi-agency framework to ensure U.S. leadership in nanotechnology that will be essential to improved human health, economic well being and national security. The NNI invests in fundamental research to further understanding of nanoscale phenomena and facilitates technology transfer.

While most of these assertions are standard tropes of U.S. science policy, a number of these statements are particularly associated with the National Science Foundation (NSF), a major financial and institutional player in the NNI. The NSF is the federal agency with the explicit mission to support the U.S. basic (fundamental) research enterprise, primarily at academic institutions. The claims in the blurb above echo both the rhetorical and operational strategies that have become hallmarks of the NSF since its founding in 1950.

The NSF's leadership role in the NNI[2] can be understood through the prism of the discursive, political, and material strategies that the Foundation has developed during its evolution from a bit player in the federal science system to an agency with a $5.9 billion budget that funds approximately 20% of all federally supported basic research at U.S. universities. The policies and practices of the NSF were indelibly shaped by the political and historical contours of the Cold War, which enabled the development of a discursive and operational strategy that links support for basic scientific research to national well-being. As the Cold War ended, this strategy shifted its focus more squarely on global economic competition, which had become a pressing concern by the mid-1970s. Additionally, the NSF developed a strategy of building its constituency through expanding its grant base, supporting academic facilities and the construction of research centers, and leading and working within multi-agency

2. The National Research Council's 2002 report *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative* singles out the NSF for it's leadership in a number of aspects the NNI, including the establishment of the Nanoscale Science, Engineering and Technology steering subcommittee (p. 1), interagency coordination (p. 19), and education, training, and societal outreach (p. 32). The report also declares "The success of the initiative to date is due in large part to the leadership of the NSF" (p. 19).

federal initiatives. These strategies helped ensure the perpetuation of the Foundation and the maintenance of Congressional appropriations throughout an era of changing political priorities.

At its founding in 1950 after a seven year political struggle over the shape that the agency would take, the NSF emerged as a "puny partner in the larger federal establishment" (Kevles 1987, p. 358) and developed, both consciously, and as a matter of circumstance, discursive and operational strategies that helped ensure its survival. Rhetorically, the NSF, like other federal agencies that support scientific research, has linked its investment pattern to the eventual enhancement of societal well-being and positive economic outcomes. The NSF, unlike the National Aeronautics and Space Administration (NASA) or the Department of Defense (DoD) for example, is not a mission agency of the federal government in the narrow sense that it is not charged with the exclusive responsibility to promote science in support of a defined goal, such as space flight or national defense. The mission of the NSF is to broadly promote the health of the national scientific enterprise, with a traditional emphasis on basic research, and, in the words of the NSF Act of 1950, "to advance the national health, prosperity, and welfare; to secure the national defense" (NSF Act 1950). While this mission allows the NSF wide latitude to support research across the disciplinary spectrum, it is also ties support for the scientific enterprise to such nebulous concepts as national health, prosperity, welfare, and defense. Since the NSF was created by an act of Congress, and is dependent upon Congress for budget appropriations, it must demonstrate fidelity to the goals laid out in its Act and show a causal link between support for science and the enhancement of national well-being. To accomplish this, the Foundation has utilized a discourse of scientific progress that relies upon variants of the linear model that links investment in basic scientific research to the generation of scientific knowledge, the application of that knowledge to directed research, the development of technology, and the diffusion of products to the market, where societal benefits accrue. As the political and social conditions in which science policy are embedded have changed over time, this strategy has been adapted to shifting national and geopolitical priorities, yet the premise that the investment in basic research contributes to positive outcomes has remained.

The NSF has expanded its constituent base by developing deep linkages with the academic scientific research community and by helping to build the scientific infrastructure of the nation. This was accomplished by growing its grant base, funding academic research facilities through material grants, supporting the construction of campus-based research centers, and leading and working within multi-agency federal initiatives. These actions not only contributed to the NSF's mission to support basic research, but also had the secondary effect of creating a constituency that could in turn support the Foundation. Furthermore, the NSF's experience leading and/or taking part in multi-agency science and technology (S&T) coalitions allowed the Foundation to build contacts within the constellation of federal agencies, and become a financial and operational partner with more powerful institutions. These partnerships range from leading the U.S. International Geophysical Year initiative in 1957–1958, through the management and eventual commercialization of the Internet in the late 1980s and early 1990s, and participation in the NNI. By the end of the 20th century the NSF officially recognized this multi-pronged approach to investment by emphasizing the strategic areas of Ideas, People, and Tools.[3] The Foundation has recognized that its mission to "to advance the national health, prosperity, and welfare; to secure the national defense" is best served by broadly supporting the nation's scientific infrastructure. This includes fostering the education and development of the scientific workforce, investments in equipment material resources, as well as grant-based financial support for scientific research.

In addition to developing an operational strategy, the NSF has, over the years, spent a great deal of time attempting to define itself both internally and externally, while paying close attention to the reception that their message has received from outside parties, including Congress and the scientific community. One enduring theme that has seemed to resonate for both the NSF and its audiences is the rhetoric of science as the new American frontier. The Foundation's embrace of frontier rhetoric to help explain its mission has been greatly influenced by Vannevar Bush's seminal 1945 report *Science—the Endless Frontier,* a document that proposed the formation of a National Research Foundation.[4] Although the NSF differed in several important ways from the organization that Bush argued for, many of the ideas and language contained in the report appeared in the National Science Foundation Act of 1950, and traces of Bush's language have permeated Foundation documents and reports for decades.[5] The NSF's use of

3. Minutes of the Opening Session, 354th Meeting of the National Science Board, July 28–29, 1999. See also NSF Strategic Plan for FY 2003–2008.

4. The NSF itself has reprinted *Science—the Endless Frontier* in 1960, 1980, and 1990 and hosts an online version of the report at its website www.nsf.gov. Additionally, the 1960 reprint featured an Introduction from NSF Director Alan Waterman, the 1980 reprint featured an Introduction from NSF Director Richard Atkinson, and the 1990 reprint featured a Foreword by NSF Director Erich Bloch.

5. Basic examples of this include a recent call for proposals titled "Physics at the Information Frontier," a September 24, 2007 press release titled "NSF and Department of

the frontier as a metaphor to explain the importance of scientific endeavor as socially, culturally, economically, and politically transformative also has roots in Frederick Jackson Turner's 1893 paper "The Significance of the Frontier in American History." Turner attributes the exceptionalism of U.S. national character and institutions to the peculiar conditions of the frontier, "the crucible" ([1893] 1956, p. 11) in which a uniquely American society was formed.

Turner argues that, "American history has been in a large degree the history of the colonization of the Great West. The existence of an area of free land, its continuous recession, and the advance of American settlement westward, explain American development" ([1893] 1956, p. 1). The intensification of westward expansion and frontier settlement was instrumental not only in the development of a uniquely American society, but also in the political unity of the nation. This cohesion was helped in large part, according to Turner, by the development of infrastructure. He writes,

> Thus civilization in America has followed the arteries made by geology, pouring an ever richer tide through them, until at last the slender paths of aboriginal intercourse have been broadened and interwoven into the complex mazes of modern commercial lines; the wilderness has been interpenetrated by lines of civilization growing ever more numerous. It is like the steady growth of a complex nervous system for the originally simple, inert continent. If one would understand why we are to-day one nation, rather than a collection of isolated states, he must study this economic and social consolidation of the country ([1893] 1956, p. 7).

Turner uses the metaphor of the human body to describe the North American continent, and the central nervous system to describe the complex network of transportation, economic, and social linkages across the nation. In his essay, the body is lifeless until settlers flow through the continent's natural arteries and "aboriginal" trails are broadened into a dense commercial network that acts upon the body as a central nervous system receiving and distributing impulses throughout the whole. Commerce and infrastructure act as the life force of the nation, guiding its development and actions. Infrastructure is an essential component of the frontier enterprise as it allows the raw resources discovered at the margins of settlement to be

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Homeland Security Partner to Drive Frontier Research in Nuclear Detection," and the chapter title "Nanotechnology: At the Frontiers of Engineering Research" of the NSF Engineering Directorate's 2004 brochure "Making Imagination Real," NSF 04-21. All of these documents were accessed at www.nsf.gov on 02/06/2008.

exploited in manner in which benefits accrue to society at large. This view of infrastructure is critical to understanding Turner's thesis as well the importance of the frontier metaphor to the NSF.

In *Science—the Endless Frontier* Bush enshrined both the promise and historical gravity of Turner's frontier thesis directly in the title of his report. This was certainly a calculated attempt to symbolically link his policy recommendations with the beneficial political, social, and economic developments associated with the settlement of the American frontier (Zachary [1997] 1999, p. 223). The term further evokes the historic bounty of plant, animal, and mineral resources present in the Western frontier. Bush uses Turner's language to transform science into an essential frontier for exploration, with new scientific knowledge as the essential raw resource to be discovered and utilized, and elevates the scientific community to the status of pioneers. Bush writes that,

> Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team, whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world ([1945] 1960, p. 11).

Despite Bush's acknowledgement that science must act as part of a team, and is but "one essential key" to national well-being, it is clear that science is the first among equals, and the field upon which all others depend for success. Bush, therefore, argues that the government's proper role regarding science is to open the scientific frontier to exploration by providing infrastructural and material support to scientific pioneers. He advocates government investment in science and the creation of a standalone National Research Foundation to facilitate support and coordinate policy.

Bush forcefully argues this point, leaving little doubt that he views the conquest of the scientific frontier as vital to the preservation and perpetuation of American power. He declares that the scientific enterprise is the legitimate successor to the physical frontiers of the American West as a site for fruitful exploration. He writes that,

> It has been basic United States policy that the Government should foster the opening of new frontiers. It opened the seas to clipper ships and furnished land for pioneers. Although these frontiers have more or less disappeared, the frontier of science remains. It is in keeping with the American tradition—one which has made the

> United States great—that new frontiers shall be made accessible to development by all American citizens. ([1945] 1960, p. 11)

For Bush, federal support for the scientific enterprise is a strategic necessity. He is explicit in this regard, and claims that science is essential to national well-being throughout *Science—the Endless Frontier.* He argues that without scientific progress employment numbers and the standard of living would deteriorate. In a statement that displays both a direct link to Turner's idea that the pioneer experience contributed to a unique form of American democracy as well as the direct influence of Second World War, he writes, "without scientific progress we could not have maintained our liberties against tyranny" ([1945] 1960, p. 11). The purity of science is presented a bulwark against the machinations of alien powers both past and present that would attempt to deprive the United States of its liberty.

However, it would be reckless to ascribe purely military overtones and motives to Bush and his treatise. Although the Second World War and the dawning of the atomic era contributed greatly to the tenor of the report, the purpose of *Science—the Endless Frontier* is to push for the creation of civilian-run science and research agency. Bush advocates the creation of an agency concerned with providing infrastructural support to the pioneers of pure science. He describes the void that the new agency would fill thus:

> We have no national policy for science. The Government has only begun to utilize science in the nation's welfare. There is no body within the Government charged with formulating or executing a national science policy. There are no standing committees of the Congress devoted to this important subject. Science has been in the wings. It should be brought to the center of the stage—for in it lies much of the hope for the future. ([1945] 1960, p. 12)

To remedy this, Bush argues for the creation of a comprehensive National Research Foundation. He claims that there are areas of research in the public interest—citing the military, agriculture, housing, public health, medical research, and research that requires massive capital investment—that would be inadequately funded in the absence of federal intervention. *Science—the Endless Frontier* is dedicated in part to making the case that (1) science is essential to national well-being, (2) adequately funding scientific research will lead to national well-being, (3) a lack of funding will negatively impact national welfare, and (4) a centralized federal agency is critical to this enterprise, since it will support research that would otherwise go unfunded. The basic premise of this argument has provided, and continues to provide, one of the central justifications given for government support for scientific research, the scientific community, and specifically the NSF.

Linearity

In his influential 1967 book, *The Politics of Pure Science,* science policy journalist Daniel Greenberg identified the NSF as the "bank" of the unofficial American Science Establishment ([1967] 1999, p. 4). This analogy has both literal and metaphorical components that echo throughout discussions of what exactly it is that the NSF does. The Foundation is a major funding organ of the federal government for scientific research, and distributes billions of dollars in research grants primarily to academic researchers across the United States. However, the bank metaphor can be extended to refer to the NSF a repository of scientific knowledge and research talent that the nation draws upon for scientific progress. The NSF itself has used this metaphor to promote its role in supporting the scientific enterprise. In a March 1987 report addressing the payoffs from the NSF's mission to support basic research, the Division of Policy Research and Analysis (PRA) stated,

> Like a standing army, its [the NSF's] task is to keep the Nation's scientific productive capacity at its maximum potential. The Foundation thus performs its mission like a bank or a reservoir. The banked or reserved item is the knowledge base produced by the research community, which is available for the country to draw upon. (PRA Report 1987, p. 4)

This metaphor is built upon the belief that basic research is the curious inquiry into the fundamental structure of nature and natural processes, rather than research directed toward the solution of a problem or set of problems. Because basic research is undirected it does not offer an immediate economic payoff. The justification for its support by the federal government is "that practical benefits accrue to society through . . . the creation of a reservoir of knowledge about the structure of nature" (Sarewitz 1996, p. 33).

The corollary to this metaphor is that through funding science, and especially basic science, the NSF sustains the capacity of the U.S. scientific community to be productive, and that productivity in turn contributes to beneficial scientific, economic, political, and social outcomes. At the heart of this thesis is a theoretical linear model that describes the relationship between scientific research and the economy. The model holds that basic research (undirected research into scientific phenomena) provides the foundation for applied research, which leads to the development of techniques and tools, and finally leads to the production and diffusion of innovation. While this model has been revised, updated, and repudiated many times over, its core tenet—that basic research eventually leads to innovation and positive societal outcomes—remains influential (Sarewitz 1996, p. 98; Godin 2006, pp. 639–667). The linear model, or some variation or kernel thereof, is often employed to justify government sponsorship of basic science, since it provides a framework for advocates of government support to argue that funding research is an investment in the future with a promised payoff. Godin (2006, pp. 659–60) attributes the longevity of this model to two factors: the simplicity of the model as a rhetorical device for science administrators and agencies to orient and justify their funding priorities, and the enduring presence of official statistics collected and organized into the three broad categories of basic research, applied research and development (R&D), and production and diffusion that allow conclusions about the relationship between them to be extrapolated. For Sarewitz (1996, p. 98) "the linear model forms the organizational basis of the post-World War II federal R&D system—institutionalized in agencies such as the National Science Foundation and National Institutes of Health—and its metaphorical power still influences the thinking and the rhetoric of both policy makers and natural scientists."

The problem, however, lies in the fact that the direct scientific, economic, political, and social benefits of basic research are difficult, if not impossible to identify (Greenberg [1967] 1999; 2001; Sarewitz 1996), because, in large part, the presence or absence of said results is endlessly contestable. It is certainly true that basic research has supplied a foundation for the development of technologies that achieved mass diffusion and have contributed to economic growth. However, the clean trajectory of the linear model insufficiently recognizes the symbiotic relationship between scientific research and technology, and between science, culture, politics, and economics (Sarewitz 1996, p. 97). In fact, science has become so discursively embedded in society, and vice versa, that any meaningful disengagement is so fraught as to be virtually impossible. What is at stake is not if government support for science will continue, but how much support will be available, which agencies will receive appropriations, and which fields and disciplines will be favored. It is not so much whether the river will flow, but where it will flow to. The rhetorical linking of scientific research to beneficial societal outcomes remains a mainstay of those who argue for continued and expanded governmental support for science and claim that their discipline, university, laboratory, or agency deserves a slice of the pie. Not only does the linear model provide the basis of the postwar U.S. scientific system, it provides a discursive framework in which the merits of individual scientific programs and problems are discussed.

In "Science, Money, and Politics: Political Triumph and Ethical Erosion," Greenberg argues that the success of the postwar U.S. science enterprise in generating political and fiscal support while ensuring autonomy gave rise to an "inventive bureaucracy that has eroded the right values of science and transformed it into a clever, well-financed claimant for money" (2001, p. 1). Greenberg claims that science would have fared well enough in the postwar high-tech U.S. without science evangelism, but persistent lobbying ensured even greater prosperity and the development of an inventive bureaucracy that enabled further expansion. He maintains that throughout the evolution of the postwar relationship between science and society, powerful institutions—the federal government, the military, and private industry—have found it beneficial to accommodate scientific autonomy, producing a nonpolitical enterprise embedded in the U.S. political system and supported by government largess (pp. 3–4). Greenberg argues that in order to protect and expand this support the politicians of science have developed durable and "self-serving myths and fables of science" that are used in efforts to secure and expand government support, including a cause-and-effect relationship between research and beneficial societal outcomes, and the imperilment of national well-being if science were to go unfunded (2001, p. 6–7). For the author, the most important aspect of the postwar development of a scientific enterprise very much concerned with expanding financial support is the detachment of science from serious societal and political scrutiny of its objectives, values and goals.

Political and institutional support for disciplines and projects can ebb and flow, in part, as the social and political contexts in which science is embedded change over time. The scientific enterprise as a whole endures however, as support across and among disciplines is constantly recalibrated to meet perceived political and social needs. Sarewitz (1996, pp. 1–15) illustrates this point in his discussion of the "end of the age of physics," attributing the disappearance of the political rationale for intense federal support for physics to the end of the Cold War. This encouraged the rise in political appeal of other disciplines in the 1990s, such as biomedical research, that offered potential solutions to more prevalent social problems (p. 3). However, the expanded role that the scientific enterprise enjoyed in the immediate postwar era has not diminished in the years since the end of the Cold War. The rationale for direct government support for S&T, and the mechanisms through which support was sought and distributed, did not disappear, but rather their messages and operations were adapted to the contours of evolving political and social conditions. Sarewitz argues that "government support for R&D must ultimately be justified by the creation of societal benefits" (p. 4), and it is therefore little wonder that in the absence of the Cold War that dominated 40 plus years of the postwar period, the scientific community has justified continued support for its programs by adapting, rhetorically and operationally, to meet the emergence of new perceived national needs.

The NSF is no exception to this phenomenon. It is embedded in a system that has evolved since the end of the Second World War that discursively links support for S&T to positive societal outcomes. The Foundation must demonstrate that its support for S&T tangibly contributes to national well-being, even though its mission to do so is broadly conceived and not easily defined. In order to maintain its Congressional appropriations and influence both within the federal government and with the scientific community, the Foundation has had to build its constituency through a discursive strategy that utilizes the basic tenets of the linear model and an operational strategy that contributes to the general strength of U.S. scientific infrastructure. Since it has been heavily invested in basic scientific research that does not immediately, or obviously, produce a quantifiable return on investment; the NSF has had to be creative in demonstrating its value to the U.S. scientific enterprise. The development of the NSF's discursive and operational strategies is not merely a product of happenstance, but rather both approaches arise out of the Foundation's history and early struggles to maintain relevance.

The National Science Foundation

As an independent federal agency created "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense . . ." (NSF Act 1950) the NSF is chiefly responsible for supporting the nation's basic research infrastructure and contributing to the vital national needs mentioned above. While most other federal agencies that are responsible for funding R&D are mission agencies (DoD, NASA, DoE, etc.) with defined research portfolios tailored to the specific mission of the agency, the NSF accounts for roughly 20 percent of all federally supported basic research conducted by America's colleges and universities. NSF funding is spread across disciplines, and is the major source of federal support for mathematics, computer science and the social sciences. The NSF is a critical player in the constellation of federal agencies that contribute to, and carry out, S&T policy initiatives of strategic national importance. Support for the U.S. university system, which provides the backbone for the nation's R&D infrastructure, highlights the Foundation's commitment to supporting the infrastructural underpinnings of U.S. science and the importance of a highly skilled workforce able to capitalize conduct research and drive innovation. Since the NSF is dependent on Congressional budget appropriations, and enmeshed in a constellation of federal agencies with both overlapping and conflicting interests, the Foundation is a political entity subject to stimuli and impulses of the political process.

The NSF was shaped by three major factors in its nascent history: the protracted political debate over its creation, its weakened position at its founding, and the cautious nature of Alan T. Waterman, the Foundation's first Director. The seven-year debate over what shape post-war U.S. science policy should take centered on questions of political oversight of the agency and control of S&T policy. In 1942 Senator Harley Kilgore, a New Deal populist, argued for a comprehensive agency in charge of formulating and coordinating federal research policy and funding both basic and applied research with some form of administrative representation from interested social parties (Kleinman 1995, p. 6). This proposal was not without opposition. In *Science—The Endless Frontier,* Bush, then head of the Office of Scientific Research and Development (OSRD), proposed an agency guided by a part-time board of eminent scientists and charged with supporting only basic research, leaving applied research to industry (Kevles, 1977; England, 1982; Kleinman, 1994). The controversy over the shape of the agency prompted four distinct attempts to pass legislation, accompanied by a shift in party power in the Senate and a Presidential veto, before President Truman finally signed the NSF Act on 5 May 1950. What emerged was a NSF with a board of eminent scientists appointed by the president, a director proposed by the board and appointed by the President, the mission to support *only* basic research and no role coordinating federal research policy—a hybrid model that incorporated most of Bush's vision for the agency with some of the oversight mechanisms favored by Kilgore. In essence, the NSF became an independent federal agency with the day-to-day power residing in the hands of the scientists and political oversight arising from the presidential appointment of the director and board and the reliance on Congress and the Bureau of Budget (BoB) for budget appropriations. This arrangement allowed the NSF the autonomy necessary to carry out its mission to support basic research relatively unimpeded by bureaucratic oversight, while simultaneously leaving it susceptible to sea changes in national S&T priorities.

However, during the years of political struggle required to pass the National Science Foundation Act, a number of newly established or reorganized federal agencies filled the void that the absence of a centralized science agency created (Kleinman 1995). These agencies included the Atomic Energy Commission (AEC), the Office of Naval Research (ONR), the Department of Defense (DoD), the Central Intelligence Agency (CIA), the National Security Council (NSC), as well as the considerably older agencies such as National Advisory Committee for Aeronautics (NACA), the Department of Agriculture (DOA), and a reorganized National Institutes of Health (NIH). Both the AEC and ONR were created by President Truman on August 1, 1946 (by the Atomic Energy Act and Act to Establish an Office of Naval Research in the Department of the Navy respectively) and immediately began providing financial support to academic researchers that the NSF, if it existed, would have conceivably supported. Kleinman attributes the delay in founding the NSF and the resulting fractured nature of U.S. science policy to "[t]he permeability of the state-which gave social interests easy access to congressional committees" and "opposition from newly established or strengthened science agencies with their own interests and patrons. When the NSF was finally established, the interests behind several independent science agencies were bolstered by their new institutionalized security, and they opposed a broad role for the National Science Foundation" (Kleinman 1995, p. 170). These new and reorganized agencies not only took on tasks that could conceivably have fallen under the purview of the NSF, but they also gained an advantage in the competition for attention, appropriations, resources, and qualified staff. The order in which these agencies were created also reflected the relative priority of U.S. policy areas in the postwar and early Cold War era: military, intelligence, and finally science, with an emphasis on research support for military technologies and atomic development and regulation. The NSF, at its inception, was just one small cog in the much larger federal system for science policy and support.

Don K. Price, Dean of the John F. Kennedy School of Government (1958–1977), consultant to the Executive Office of the President (1961–1972), and trustee of the Rand Corporation (1961–1971), delivered a withering assessment of the nascent NSF in a 1973 interview. Price stated that,

> [W]hen the Science Foundation was set up there had been some hope in the early days . . . that this was going to be much more nearly a monopoly on Government research . . . by the time the Science Foundation was really set up with about $3 million in appropriations, it was not the great new post-war overall research program doing military research for the War Department and so forth. It was just the smallest and youngest and weakest of the scientific research programs. (Price 1973)

While Price's assessment is fundamentally correct, he emphasizes only the delay in establishing the NSF, neglecting the person and personality of Alan T. Waterman, the first Director of the NSF, as a contributing factor for the perception that the Foundation was simply a "weak" federal player.

Prior to his appointment to the NSF, Waterman had spent a decade (OSRD 1941–46 and ONR 1946–51) working at the nexus of the scientific community and official Washington. Kleinman (1995, p. 157) describes Waterman as "the embodiment of the values of elites in the scientific community." In a 1972 interview, John Steelman, Chairman of the President's Scientific Research Board, 1946–1947, recalled that Truman favored Waterman over other names on the NSB list because he had "been mixed up in three or four organizations here in Washington, and we figured that the first director of the organization would have a better chance of surviving if he knew Washington and its peculiar ways" (Steelman 1972, p. 1). Steelman neglects to mention the tremendous influence that William T. Golden, special consultant to the BoB, exerted on Truman in choosing Waterman in part because of his stance that the work of the Foundation should be clearly delineated from that of the military (Golden, 1950), the support of Bush, and backing from Nobel Laureate, I. I. Rabi (Blanpied 1995, p. 24). Waterman believed in the discourse of "pure," autonomous basic research, and that the government should only support basic research that industry was unwilling or unable to support. He also maintained that applied research leading to the development of tools and processes, especially military applications, should be clearly demarcated from federally supported basic science. His ability to straddle the fine divide between political oversight of the scientific enterprise and belief that science was best served by protecting its autonomy may have ultimately been his greatest asset in the eyes of Truman. Waterman's nomination may have been based in part on the President's awareness that he would be unlikely to challenge the Executive Branch for an increased role in the coordination of U.S. science policy, or upset the tenuous balance between Congressional progressives and the laissez faire scientific elites.

Waterman was reluctant during the early years of the NSF to expand its role even when presented the opportunity to do so. In a 1973 interview, William D. Carey, of the BoB, recollected that the Eisenhower administration, especially several members of the cabinet, held "a very dim view of scientific research. And the relations between Government, particularly the administration, and the science community were very, very low" (Carey 1973, p. 1). In 1954 Carey proposed to the Director of the BoB, Joseph Dodge, that he draft an Executive Order that would grant the NSF policy coordination competence. Carey felt that Waterman was too passive in asserting the NSF's role stating that,

> Waterman didn't want to have policy function. Waterman wanted to be operational. He used to come to me and say 'Bill, when we

> get our budgets up to a high level which other agencies will respect then we'll be grown up and perhaps we can do some of this. But it would be suicidal for us to attempt it as a small semi-invisible National Science Foundation with no clout.' And to Waterman, whom I had a great respect for, clout was measured by size and scale of resources. (1973, p. 7)

Carey put Waterman's reluctance to accept a larger policy role into context, remarking that "[I]t was Waterman's attempt to be the mediator . . . He was on one hand trying to maintain a position of cooperation and support to the executive office of the President. He was also on the other hand trying to preserve the fragile relationship and sense of confidence with the external science community" (1973, p. 12). This last quote summarizes the pressure brought to bear on the early NSF to be responsive to both the President and Congress on one side and the scientific community on the other. This pressure was compounded by the necessity of the NSF to walk a narrow path in seeking out and claiming turf that would solidify its position in the federal apparatus, without stepping on the toes of the well-connected mission agencies or alienating its backers.

In the funding turbulence of the early 1950s, the NSF sought to expand its constituent base both inside of the federal government and the scientific community. It focused its attention on several infrastructural areas that were to become mainstays of Foundation policy over the years—grants to fund basic research, investment in scientific equipment and facilities, and the scientific workforce. The NSF would return time and again to the rhetoric of supporting national interest through the twin themes of basic research leading to economic and military security and the support for the nation's scientific infrastructure. For Waterman, the relevance of the NSF in policy matters rested in its scientific objectivity and he took every opportunity to distance himself and the Foundation from any formal role in the generation of science policy. While the strategy of focusing solely on scientific objectivity insulated the NSF from the hard-knuckled world of policy generation and coordination among competing agencies, the failure to grasp a policy function when the opportunity presented itself left the Foundation with very little real power beyond the management of its own affairs. The wisdom of this strategy would be tested in the aftermath of the Sputnik launch in 1957. Rather than taking the lead in formulating U.S. science policy, the NSF found itself instead having to respond to the political pressures being brought to bear of the agency from the highest levels of the government.

The context in which science U.S. policy operated changed radically in the wake of the Soviet launch of the Sputnik satellite in October 1957, and the NSF's reliance on the rhetoric of the scientific objectivity faced its greatest challenge. The U.S. government became concerned that the image of the United States as the leader in global scientific achievement had been degraded, and that global opinion would continue to plummet if the federal science funding agencies did not begin to consider the public relations impact of funded projects as part of a coordinated campaign of "political warfare" against the Soviet Union (Schwoch 2008). With its commitment to basic research and relatively insignificant stature in the federal government, the NSF needed to seek alternative avenues to prove its value to US science policy in the post-Sputnik climate. To remain relevant and responsive to both the Executive Branch and the scientific community, the NSF utilized government-wide increases in science funding to expand is constituent base through an operational focus on support for scientific infrastructure.

Building a Post-Sputnik Constituency

In 1960 the NSF initiated its Graduate Science Facilities Program to augment academic laboratory facilities and fund research equipment (Office of Legislative and Public Affairs (OLPA) 1987, p. 10). The NSF 1964 annual report states that,

> The shortage of laboratories not only restricts the number of people who can do research and who can be educated in the science, but also restricts the kind of research that can be done . . . An expansion of the science facilities requires large financial resources that are not generally available to the great majority of educational institutions. (quoted in OLPA 1987, pp. 10–11)

Over the ten-year history of the Facilities Program, $188 million was distributed to 182 institutions as funding shifted from awards for minor renovations and equipment repairs to grants for the construction of new and "multidisciplinary" structures with an estimated total value of $500 million to the affected institutions (p. 11).

During the 1960s the NSF initiated two other institutional support programs, Institutional Grants For Science (1961–74) and Science Development Grants (SDP) (1964–72), also known as the Centers of Excellence program. The Institutional Grants program was designed sustain and improve the scientific quality of academic institutions already granted NSF research awards, with 16% of funds being used for facilities, 30% on personnel, and 50% on equipment and supplies (OLPA, 1987, p. 14). Awards were based on a formula that took into account NSF and federal research support at institutions and were unrestricted in their application with the caveat that funds could not be applied to the costs of projects already supported by federal funds.

The Science Development Program, the "dominant new NSF program of the sixties," functioned on three principles: funding was institution rather than project based, the deliberate funding of second tier institutions and the exclusion of "top 20" schools, and an emphasis on the geographic distribution of funds (OLPA 1987, p. 16). Grants were intended to increase the selected institution's research and education activities over a five year period through the hiring of new faculty, graduate student support, and the construction of research facilities, and were awarded with the understanding that cost sharing would be negotiated with state governments, foundations, or other federal programs (1987, p. 17). By 1966 the program was subdivided into three programs to provide varying levels of support and to reach a wider number of institutions. The University Science Development (USD) program was intended to double the number of academic centers of excellence by providing three-year grants of $4 million with possible two-year supplements. The NSF required 31 institutions awarded USD grants to present evidence of an overall development plan, including extensive support for the sciences, and only chose institutions that they felt could achieve a broad level of excellence (1987, p. 18). The second tier of the SDP, the Departmental Science Development was developed to support selected departments with the potential for excellence at universities deemed too weak for the USD program. The third tier was comprised of Special Science Development Awards intended for departments with potential at universities with sub par support for science. Finally, a fourth subprogram was developed in 1967, the College Science Improvement program, to bolster undergraduate science education (1987, pp. 18–19).

It is worth noting that while the OLPA report quoted above designates the Science Development Program as the dominant *new* program of the 1960s, and it represented roughly 10% of NSF outlay at its height in 1968 (NSF 1969, pp. 253–255). However, traditional NSF programs still received the bulk of the funding. Grant-based research represented 33% of total NSF outlay during FY 1968, while education programs accounted for approximately 25% (1969, pp. 253–255). However, during the course of the 1960s infrastructure funding played an increasingly important role in Foundation plans. In addition to the SDP, the NSF was building new constituencies through funding the resource-intensive National Research Facilities, such as the Kitt Peak National Observatory and the National Center for Atmospheric Research. Funding for these facilities rose from roughly 1% of total outlay in FY 1960 (NSF 1961, p. 168) to 6% by FY 1970 (NSF 1971, p. 121).

Despite considerable success increasing the geographic distribution of grants and increasing facilities support at a number of universities, SDP fell victim to the pressures of tightening budgets in the late 1960s as overall federal R&D funding decreased and university enrollment plateaued (OLPA 1987, p. 20). By 1970, the NSF was subjected to Office of Management and Budget pressure to justify its SDP expenditures and phase out, eliminate, or merge facilities programs into the new Research Applied to National Needs Program due to three factors: the financial drain of the Vietnam War, the belief that an overabundance of scientific PhDs existed, and skepticism that the SDP could meet its goals (OLPA 1987, p. 22). Although the NSF encountered obstacles to its facilities' funding programs, its investments in infrastructural support paid dividends both rhetorically and materially. The Foundation was able to point to the geographic distribution of its support and partnerships with schools outside of the "top 20" as successful initiatives to strengthen U.S. science by enhancing the overall capacity of the scientific community to conduct research. Although these programs may have been eliminated or merged into other programs, the infrastructure that the Foundation had supported remained in place, allowing the NSF to continually point to the research produced and graduate students supported at these facilities as successful contributions to national well-being.

Computing: From Supercomputers to the Internet

The NSF's interest in computing provides an illustrative example of the agency operating to maximum advantage while staying inside of its comfort zone comprised of support for basic research, facilities and equipment, and the scientific workforce. Notes from a December 7, 1960 NSF senior staff meeting contained a significant passage about the Foundation's ongoing computing efforts, especially support for academic computing. The NSF's computer panel reported to the senior staff and made several major recommendations. The Foundation should continue and extend its practice of procuring research computers for major U.S. academic institutions. Second, that the NSF should subsidize the full time (of a time sharing mainframe operation) of research computers if necessary. Finally, the panel recommended that the Foundation should offer a one time matching funds initiative to aid in the procurement of training computers for up to 600 additional institutions outside of the pool of institutions already receiving computing support.

These suggestions highlight two important aspects of early NSF support for computing—the use of computers as research resources to augment research at academic science departments, and the Foundation's philosophy of building the strength of the nation's scientific workforce by broadly supporting science education. Additionally, by spreading its support for computing outside of the elite institutions that traditionally received funding and equipment from the federal government (especially the DoD which tended to concentrate research programs at a handful of large institutions), the NSF greatly expanded it constituent base and created contacts where none had previously existed. The importance of this cannot be underestimated, as the Foundation was able to consistently point to its support of researchers and facilities in under-represented states and regions as a bonus in Congressional dealings, especially when interacting with lawmakers serving those jurisdictions. One particular fruitful NSF strategy involved support for computer networking that facilitated geographically disbursed campus computing resources to be linked to one another in regional networks, and later to a national backbone that enabled a networking of networks. This strategy also allowed campus and regional networks to the access the powerful resources of the supercomputing centers that the NSF had begun to fund by the mid 1980s, Finally, investment in networking allowed the NSF to link its broad array of infrastructural investments in computing and distribute the potential benefits of its overall investment strategy to its many constituents.

Having learned the lesson at the end of the 1960s and throughout the 1970s that support for scientific infrastructure continued to pay dividends long after funding priorities shifted, the NSF utilized the renewed emphasis on basic science and engineering under Reagan (Bloch 1986, p. 595) to propose and execute a massive infrastructural campaign centered around supercomputing and computer networking. On November 16, 1983, Edward Knapp, Director of the NSF (1982–84), testified about supercomputers to the House Committee on Science and Technology, focusing on the "limited supercomputer access by academic scientists and the effect this has had on research and training at colleges and universities" (Knapp Testimony 1983, p. 1). After recounting the benefits of the computerized revolution in scientific research during the 1950s and 1960s, Knapp quickly shifted to describing the decline of federal support for academic computing during the 1970s, concluding that U.S. academic facilities had been unable to "keep up with whirlwind development" in computing technology, especially supercomputers. Knapp highlighted material science, applied mathematics, physics, economics, and civil engineering as areas that he considered especially reliant upon supercomputers that would fall behind should supercomputing access remain inadequate. He continued his testimony by claiming that advances in critical areas such as solid-state electronic technology and DNA sequencing would be detrimentally affected by a lack of funding.

Knapp concluded his testimony by informing the panel that the NSF had recognized the problem, had convened a panel, issued a report, organized an internal working group to tackle the problem, and was actively cooperating with other federal agencies, gathering more information, organizing workshops and meetings, and planning measures to help improve short-term academic access to supercomputers (Knapp Testimony 1983, pp. 4–6). Additionally, the NSF Director announced the Foundation's intention to "develop advanced computational resources locally at universities" (Knapp Testimony 1983, p. 8), foreshadowing the NSF Supercomputer Centers Program that in 1986 established the Cornell Theory Center, the National Center for Supercomputing Applications (at the University of Illinois Urbana/Champaign), the Pittsburgh Supercomputing Center (at Carnegie Mellon University and the University of Pittsburgh), and the San Diego Supercomputer Center (at the University of California, San Diego).

In essence, Knapp was priming the pump, using all of the classic Washington appropriations catchphrases to lay the groundwork for the Foundation's plans a robust supercomputing project. However, Knapp's testimony also exposed more wrinkles of the NSF's overall computing strategy. He stated that,

> Our long-term objectives include not only providing large-scale computer resources for research and training of a new generation of computational scientists and engineers, but improving remote access to advanced computing facilities for the scientific and engineering community. We will do this by extending and developing appropriate communications systems and networks between supercomputer centers and users. (Knapp Testimony 1983, pp. 7–8)

Knapp's testimony displays the multi-pronged argument that would characterize subsequent NSF computing strategy and many future large-scale research initiatives, namely the simultaneous development of resources, research, and the development of the science and engineering workforce.

By 1985, NSF program managers were contemplating how to increase access to the four recently approved supercomputer centers for a geographically diverse group of NSF-supported researchers. The NSF initiated the NSFNET project, which went online in 1986, and utilized ARPANET research and the resources of the NSF-funded CSNET, initiated in 1981 to provide networking to computer science departments. NSFNET linked the four supercomputer centers with a high-speed backbone and connected regional CSNET sub-networks to this new infrastructure by utilizing many protocols previously developed by ARPANET researchers.

However, because the NSFNET linked a number of separately developed networks to a central backbone, computer scientists and technicians at the supported networks were forced to adapt to the demands of the hierarchical architecture of the NSFNET. These researchers developed the next generation of internetworking protocols to enable communication between computers across a complex system of information and communication technologies to enable the NSF goal of non-discriminatory access to all researchers able to connect to the network.

One of the most successful outcomes of both the NSF supercomputing and NSFNET programs was a project that was only possible through the existence of both. Building upon the explosion of personal computing in the 1980s and the development and launch of the World Wide Web graphical user interface by Tim Berners-Lee and colleagues at CERN, the European Organization for Nuclear Research, researchers at the National Center for Supercomputing Applications at the University of Illinois Urbana/Champaign developed Mosaic in 1993, "the first freely available Web browser to allow Web pages to include both graphics and text" (NSF, A Brief History of NSF and the Internet). Mosaic built upon research conducted at the NSF Supercomputing Centers in the storage, archiving, and retrieval of information from across the NSFNET, as well as advances in web server technology. The concept of the computer network is a powerful metaphor for the NSF's funding and development strategy for large-scale science and engineering initiatives from the 1980s onward. The network itself serves not only as infrastructure that enables interconnection between disparate resources and research locations, but also as a site for the generation of new knowledge as an object of research itself. In this regard, the NSF's successful experience with supercomputing, computer networking, and the commercialization of the Internet has served as a template for its involvement in the National Nanotechnology Initiative. The NSF's supercomputing and networking initiatives both involved interaction with multiple government agencies, the funding of research proposals, facilities, equipment, personnel, and the education of graduate students, and a long-term commitment to projects and centers distributed throughout the nation. The value of the infrastructural strategy to the NSF is clearly displayed through the positive developments that arose from its funding of supercomputing resources and computer networking. Not only did it enable the NSF to physically and virtually spread resources among its constituencies, it also allowed the NSF to take credit for research conducted at facilities that it funded. Although the NSF did not fund many of the discoveries and developments that enabled its success, its contributions allowed for the development and subsequent privatization of one of the most impressive information and communications infrastructure projects in history—a feat that the Foundation has utilized to demonstrate its important contributions to national well-being and to press for continued financial support.

The Nano Age?

As the United States emerged from the Cold War as the sole global superpower, it was forced to adjust to a world in which the relationship between the central and peripheral issues that had defined the previous four-plus decades of Cold War policy underwent realignment. The challenges posed by the Soviet Union did not disappear with its breakup, as the nuclear disarmament of former Soviet Republics and the endurance of the missile defense debate demonstrate. Rather, binary opposition to the Soviet Union became more peripheral as formerly ancillary issues assumed greater prominence. In the absence of the Soviet threat to the United States as a motivating factor, S&T policy began to shift its focus to emerging challenges, namely national competitiveness in a globalizing world. The claim that the end of the Cold War changed everything is inaccurate hyperbole. However, the claim that the end of the Cold War brought significant realignment of policy issues has merit. These realignments are particularly visible in the rhetorical and discursive formations articulated by the NSF in the aftermath of the Cold War. The trope of epic change brought on by the end of the Cold War was pervasive in many spheres of public discourse. This was a moment famously described by Francis Fukuyama as "The End of History" (1992), and one characterized in the United States by President George H. W. Bush's evocation of the rhetoric of a "new world order." A LexisNexis search for the phrase "end of the Cold War" between January 1, 1989 and January 1, 1993 returns 647 articles in *The New York Times* and 581 articles in *The Washington Post* alone. The phrase was also used in 86 separate instances of Congressional testimony during the same period.[6] These numbers serve as an indication that the political changes occurring in the late 1980s and early 1990s had a pronounced effect on the public discourse, and that the evocation of the phrase "end of the cold war" was a common phenomenon.

One interesting discursive strategy positioned the end of the Cold War as a trope of absence. The elimination of the Soviet Union as the overarching justification for many policy decisions created a vacuum that a discourse of innovation and international competitiveness partially filled. This shift is strongly hinted at in the following passage from the NSF's *Science and Engineering Indicators: 1993,*

6. LexisNexis Academic search 02/06/2008. LexisNexis Congressional Publications search on 02/06/2008.

> The Berlin Wall came down on September 11, 1989 [sic][7], and two years later in December 1991-Communism in the former Soviet Union was replaced with dawning democracy. With these two events, the debate surrounding U.S. S&T policy in the nineties was irreversibly redefined. *The policy focus has since begun to shift from military technological superiority toward federal initiatives designed to help recapture global commercial primacy* (emphasis added). These changes in national policy objectives are mirrored by changes in the functional focus of federal R& D support, as indicated in federal spending documents (NSB 1993, 101–102).

The *Indicators 1993* report singles out the need for the U.S. to address increasing globalization and calls on policymakers to seize the opportunity to confront the challenges of increased interaction with other advanced economies. The report notes the realignment of the post Cold War S&T world into regional R&D blocks, singling out the United States, Europe and the Pacific Rim as areas of rapid development and heavy investment. The challenge that the report presents for the United States is to find the balance between the promise of expanding international markets for its products and the threat of increased competition from global actors.

The international challenges that motivate the strategy of global commercial primacy did not simply arise at the end of the Cold War, but have been a feature of increasing commercial globalization since at least the mid-1970s. In a 1986 article in *Science* entitled "Basic Research and Economic Health: The Coming Challenge," Erich Bloch, then director of the NSF (1984–1990), wrote that "the United States faces an international economic challenge that can best be met with renewed emphasis on the basic science and engineering that underlies new technology" (p. 595). The challenges facing the United States in 1986—record deficits, vigorous competition in the high technology sector from the Pacific Rim, the outsourcing of technology production to nations with cheaper labor—are reminiscent of the challenges facing the United States in 2008. The perception that the Pacific Rim poses a direct threat to U.S. commercial primacy has its foundation in Japan's technological ascendancy in the 1970s and 1980s in the automotive and electronics sectors, and the convergence of global economies by the mid 1970s. With an economically unified Europe and burgeoning technology and manufacturing sectors in China and India added to the mix, the United States finds itself beset on all sides by the uncertainties of a globalized world.

7. The fall of the Berlin Wall is mistakenly dated September 11, 1989 (09/11/1989) rather than the correct date of November 9, 1989 (11/09/1989).

At its most basic level, the primary motivation for government support for basic research remains the linear model. While it is convenient for quickly and simply explaining (or justifying) government expenditures on basic research, the linear model fails to adequately explain the complex relationship between science and technology. One alternative model advanced by the NSF in its *1996 Science and Engineering Indicators* is the chain-link model that describes feedback loops and the bi-directional interaction between basic and applied research (NSB 1996, pp. 4–10). In this model the role of government agencies is expanded from simply providing funding strictly for basic scientific research to include applied research and technology development. In the chain-link model, government supports the R&D *process,* through research grants as well as education and facilities funding, promoting links between academic institutions and private industry and the establishment of centers-of-excellence. The chain link model is an interesting rhetorical tool, utilizing as technology development and innovation as its core precept and shifting emphasis from support for autonomous basic research to support for the "process" of scientific R&D. This shift enabled the NSF to claim fidelity to its original mission, but also included the understanding that the scope of the Foundation's programs had expanded to include foci at various points of the R&D process.

The "NSF Strategic Plan FY 2003–2008" provides a vision statement for the NSF that describes its role at the forefront of the U.S. Government's science and engineering initiatives, and underscores the belief that advances in science and engineering are central to the health and economy of the nation. The statement reads, "NSF investments—in people, in their ideas, and in the tools they use—will catalyze the strong progress in science and engineering needed to establish world leadership and secure the Nation's security, prosperity, and well-being" (NSF Strategic Plan, p. 9). The themes of world leadership, national security, and economic prosperity run throughout NSF documents and leave the reader little doubt that the NSF continues to view its vision, mission, and objectives as synonymous with those of the United States as a whole.

National Nanotechnology Initiative

Nanotechnology is broadly conceived of as the key to unleashing rapid and wholesale industrial change. To this end, nanotechnology is the focus of an intense and massive combined federal campaign that has achieved significant buy-in from all of the major governmental S&T agencies, Congress, and the military with very little public debate. Nanotechnology research, development, and education are being positioned as the cornerstones of a governmental initiative to propel U.S. science beyond the next research frontier and solidify U.S. technological and economic dominance over the burgeoning field. To further these goals, President Clinton announced the NNI at the California Institute of Technology in January 2000, establishing the federal coordinating mechanism for NSE R&D during FY 2001.

Currently there is a tremendous groundswell of support at all levels of the U.S. government to foster nanoscale science and engineering (NSE) R&D. No fewer than four Congressional Bills have been passed in the last half-decade, with the express purpose of officially endorsing and underwriting nanotechnology research. Numerous other bills, such as the NSF Authorization Act, which is regularly renewed by Congress, explicitly appropriate funds to support or initiate nanotechnology research. The Office of Science and Technology Policy (OSTP) and OMB have identified NSE as providing the next generation of breakthrough technologies. Accordingly, the NNI has been established with significant buy-in from the NSF, DoD, DoE, NIH, NASA, National Institute of Standards and Technology (NIST), Department of Justice, and to a lesser extent the Departments of State, Transportation, Treasury, and Agriculture. The centrality of the NSF in this consortium cannot be stressed strongly enough. A 2002 National Research Council report titled *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative* states that,

> The success of the initiative to date is due in large part to the leadership of the NSF. Under this leadership, the NNI has organized the major research-sponsoring agencies into a coordinated body, the NSET [Nanoscale Science, Engineering and Technology subcommittee], with regular meetings and information sharing. It has also attracted participation by other federal agencies that do not focus on research but that could advance their own missions by the applications anticipated from nanoscale science and technology. (2002, p. 19)

Additionally, the NSF has provided the NNI between one-quarter and one-third of its operating budget per year between 2001–2007, and is projected to contribute roughly 26% of all funds in both FY 2008 and FY 2009[8].

The history of federal support for NSE stretches back at least two decades and encompasses nanoscale programs and projects at several agencies. Notably the DoD supported the Ultra Submicron Electronics Re-

8. Detailed funding figures can be found at http://www.nano.gov/html/about/funding.html

search (USER) program in the early 1980s, the ONR Accelerated Research Initiative on interfacial nanostructures in the mid 1980s, and the DARPA Ultra Electronics and Ultra Photonics (ULTRA) program that focused on ultra fast and ultra dense electronic devices and chips in the early 1990s (Department of Defense 2005, p. 4). In 1990, Mihail "Mike" Roco, currently the Senior Advisor for Nanotechnology at the NSF and former Chair of U.S. National Science and Technology Council's (NSTC) Subcommittee on Nanoscale Science, Engineering and Technology (NSET), proposed, and received funding for, nanoparticle synthesis and processing as a new programmatic topic at the NSF (Roco 2007, p. 9). In addition to these programs, both the DoD and NSF provided individual grant-based funding for nanoscale research across disciplines. One of the earliest infrastructural initiatives supporting nanoscale research was the NSF-funded National Nanofabrication Users Network (NNUN), started in 1994 to provide support to a network of nanofabrication facilities at Cornell, Stanford, Howard, Pennsylvania State, and the University of California, Santa Barbara. The NNUN provided physical and virtual access to nanofabrication resources located at member facilities for academic, industrial, and government researchers, as well as graduate and undergraduate students.

By 1996, staff members at several federal agencies concerned with NSE, including Roco, began meeting to discuss their projects and examine avenues for cooperation, and in September 1998 when the group was officially recognized as the Interagency Working Group on Nanotechnology (IWGN) under the auspices of OSTP. Roco describes the impetus behind the establishment of the informal and then the formal working group as identifying "nanotechnology as a 'dormant' S&E opportunity, but with an 'immense' potential" (Roco 2007, p. 9). Roco characterizes the challenges of the 1990s as "the search for the relevance of nanotechnology" and "[c]reating a chorus to support nanotechnology" (2007, p. 9). To do so, he organized a meeting with researchers and government experts in November 1996 to begin the process of "setting a vision" for nanotechnology, including the preparation of supporting material and an initial report on ten areas of promising nanoscale research (2007, p. 10). Once the IWGN was officially established in 1998, it sponsored workshops and studies to define the field, produced two major reports in 1999, *Nanostructure Science and Technology: a Worldwide Study* and *Nanotechnology Research Directions* (National Research Council 2002, p. 11), and completed a draft plan for the NNI, which Roco successfully pitched to the OSTP in March 1999 (Roco 2007, p. 11). Once the NNI had been presented, the IWGN shifted its emphasis to the discursive arena, as the group set about "establishing a clear definition of nanotechnology and communicating the vision," with special emphasis on Congress and the Administration where "nanotechnology was not known" (2007, p. 11). The Clinton administration elevated nanotechnology to the status of a federal initiative, including the NNI in its 2001 budget proposal to Congress. Once the NNI was established, the IWGN was disbanded and replaced with the NSTC NSET subcommittee, which is responsible for coordinating the federal government's NSE initiatives and programs.

The NSF's influence on the NNI stems from several factors: the role of Mike Roco, the fact that the NSF had been involved in supporting NSE initiatives since the early 1990s, and its willingness to act as the initiative's coordinating agency. Roco has been described as the "United States' leading nanobooster" (Berube 2006, p. 87), and in his capacity as the Senior Advisor for Nanotechnology at the NSF he has been able to drive the Foundation's approach to nano initiatives and programs. He commonly utilizes the rhetoric of the linear model, and warns that these benefits will be missed if NSE is not adequately supported (Roco 2001; 2002; 2007). Berube describes this rhetoric as "hyperbolic" and claims that Roco "seems to revel in fear appeals and nationalistic rhetorical flourishes" (2006, p. 88). While this may be an overstatement, it is certainly true that Roco honors the timeworn tradition of linking increased funding to the Foundation's mission "to advance the national health, prosperity, and welfare; to secure the national defense," as enshrined in the NSF Act of 1950. Roco's influence is not easily uncoupled from the NSF's NSE initiatives, as he has been at the forefront of almost all of them since 1990. The history of NSF support for nanotechnology put it in a perfect position to assume a leadership role in the NNI once it was proposed in 1999. Not only was Roco a driving force behind the development of the IWGN, and later the NSET subcommittee, but the NSF was able to assert itself because it could point to demonstrable success funding a number of pre-NNI nano programs such as Nanoscale Modeling and Simulation, Exploratory Research on Biosystems at the Nanoscale, and Synthesis, Processing, and Utilization of Functional Nanostructures, as well as supporting the multi-institutional NNUN. Finally, according to Berube, the NSF "sold itself as the organization that could handle the massive interagency coordination to make the NNI a success" (2006, p. 98), based on its track record during the 1990s of administering grants and the programs mentioned above, its support for researchers and students across the nation, and the creation of a NSE theme area at the Foundation.

Having established itself as an institutional, as well as financial, player in the NNI the NSF utilized its operational philosophy of supporting Ideas, People, and Tools to expand its NSE support by funding an increasing number of geographically distributed centers, programs, and grants.

The Foundation currently supports 39 centers that conduct nanoscale research, either in whole or in part. Of the centers, 15 are dedicated Nanoscale Science and Engineering Centers (NSEC) and four are nano-specific Materials Research Science and Engineering Centers (MRSEC). Additionally, the NSF has maximized it reach by funding six Nanoscale Science and Engineering Networks that provide infrastructural and collaborative support to researchers and centers distributed across institutions in a manner reminiscent of the supercomputing centers of the 1980s. Two of these networks in particular, the National Nanotechnology Infrastructure Network (NNIN) and the Network For Computational Nanotechnology (NCN), are excellent examples of this.

The NNIN was founded in March 2003, replacing the NNUN, and has expanded to support 13 major nanotechnology user facilities at universities across the nation. A NNIN 2008 brochure describes the network thus:

> Central to the operation of NNIN is the commitment to provide open access to advanced technology for the entire nanotechnology community. With the rapid growth and unlimited potential of nanotechnology, it is critical that the nation provide appropriate accessible research resources. Through NNIN everyone can have access to state-of-the-art nanotechnology resources. This is in stark contrast to most academic and industrial laboratories that are closed to all but their owners. (NNIN 2008, p. 9)

The NNIN allows users access to specific technologies at individual or multiple sites inside of the network to accomplish research goals otherwise impossible at the researcher's home institutions. By concentrating funding at the 13 member institutions but making the resources available to the community at large, the NSF has been able to expand its constituency by providing infrastructural support to as broad a user base as possible. While the NNIN provides physical access to research infrastructure, the NCN, a network of six universities, provides virtual access to advanced simulation technologies through its nanoHUB.org website. According to the nanoHUB website the NCN

> is an NSF-supported 'research and infrastructure' network with a shared vision for the role that innovative cyberinfrastructure can play in research, education, and outreach. We are deploying a major resource for the community (the nanoHUB science gateway) and developing open-source technology that others can use.

The nanoHUB offers distributed users the ability to run simulation tools remotely, providing networked access to online resources to being developed at the NCN partner institutions. By limiting funding to a handful of centers and tasking the NCN with creating resource that are widely available to users, the NSF is able to create a virtual infrastructure to complement its investment in material resources and, once again, expand its constituent base. Much like the NSF investment in computer networking and the NSFNET backbone in the 1980s and early 1990s, the NCN acts as both a site for the generation of new knowledge as an object of research itself. It enables the exploration of the nano frontier through simulation tools on the virtual frontier.

Although the NNI is touted as providing the foundation for wholesale societal change, Roco and William Bainbridge of the NSF argue in their 2002 NSF and Department of Commerce-sponsored report, *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science,* that no single area of technological advancement will deliver the breakthroughs that the NNI anticipates. Only a combination of advances in interrelated fields, as well as investment in research, researchers, and research facilities—the Ideas, People, and Tools model—will produce the predicted revolution in technology and industry. Roco and Bainbridge argue that,

> Developments in systems approaches, mathematics, and computation in conjunction with NBIC [nanotechnology, biotechnology, information technology and cognitive science] allows us for the first time to understand the natural world, human society, and scientific research as *closely coupled complex, hierarchical systems.* At this moment in the evolution of technical achievement, *improvement of human performance through integration of technologies* becomes possible. (2002, p. ix)

The report claims that NBIC convergence will not only improve human performance, but will also radically restructure academic and industrial science and engineering by provoking a shift to interdisciplinarity and the dissolution of disciplinary boundaries (2002, p. vii). The report positions NBIC convergence as creating a holistic system of systems, and claims that "converging technologies could achieve a tremendous improvement in human abilities, societal outcomes, the nation's productivity, and the quality of life" (2002, p. ix). By coupling research advances to benefits across the complex hierarchy of human society—the individual, group, academy, society, and nation—the NBIC report privileges a vision of the "next revolution" that utilizes the rhetoric of interoperability across a network of systems. This approach also displays the NSF hallmarks of emphasis on infrastructural development and frontier rhetoric. The interoperation of nanoscale advances across disciplines not only requires capital investment in the facilities and tools necessary for R&D, but also the creation of information, coordination, and social networks among nanoscale researchers.

The profound societal and economic changes that have occurred through the introduction of the Internet, first in military and academic communications, and subsequently in economic and interpersonal communications, serve, for better or worse, as a model of potential NBIC convergence. The basis for NBIC is "material unity at the nanoscale and on technology integration from that scale" (Roco and Bainbridge 2002, p. ix), and the stated goal of NBIC is the eventual enhancement of human performance, beginning with the manipulation of the nanoscale to enable the integration of organic and inorganic structures and the production of transforming tools. The report claims that, "The building blocks of matter that are fundamental to all sciences originate at the nanoscale. Revolutionary advances at the interfaces between previously separate fields of science and technology are ready to create key *transforming tools* for NBIC technologies" (2002, p. ix). The report argues that by combining these advances with research into complex, hierarchical systems the manipulation of human life becomes a possibility, as does the ability to more directly influence societal outcomes. Understanding the natural world, human society, and scientific knowledge as interoperable components of the same system allows for the application of science and engineering to the human condition with the express purpose of altering, enhancing, and/or controlling the human body and human cognition. The application of NBIC technologies to societal outcomes represents step toward the integration of individuals and human populations into an infrastructural matrix of technologies and social institutions designed to enhance the social, political, and economic well-being of the nation, and mitigate risk in an increasingly complex world.

Nano Rhetoric

The NSF has been successful in establishing itself as a major player in the NNI, developing an impressive array of physical and virtual infrastructure to support the initiative. However, it has done so by shrewdly playing an excellent game of Washington semantics. James Murday, Head of the Chemistry Division of the Naval Research Lab and former Executive Secretary of the NSET subcommittee, has remarked that the IWGN discussed whether to use nano*science* or nano*technology* when deciding on a name for the NNI. He said that the group decided to use nanotechnology because asking for "science" funding would get them nowhere in Congress (Murday 2005). Using the rhetoric of technology and economic growth to get the NNI off the ground corresponds with a general shift in U.S. funding discourse following the end of the Cold War that privileges technology development over basic research. Interestingly, according to Roco "nanotechnology" was chosen over any name that included "science" because the IWGN wanted to demonstrate "the relevance to society" (2007, p. 13). Kleinman claims that a discourse of technology policy "clearly displaced" the postwar emphasis on basic science in policy debates, becoming firmly entrenched in Washington with the election of Bill Clinton in 1992" (1995, p. 192), and both Murday and Roco's version of events adhere to this argument.

Kleinman singles out the 1993 Clinton administration's technology policy report, "Technology for America's Economic Growth, A New Direction to Build Economic Strength," as a clearly articulated example of the new technology rhetoric taking hold in the early 1990s. The report places technological development at the fulcrum point of U.S. competitiveness and economic growth, and calls for changes to the basic operating assumptions of postwar research policy in which defense technology is "serendipitously" transferred to the private sector. The report advocates an active federal policy "helping private firms develop and profit from innovations" (Clinton and Gore, quoted in Kleinman 1995, p. 192). In the Clinton model, basic research is not scrapped, or even marginalized, but rather acts as the basis for technological development. However, it is no longer *sine qua non* of U.S. competitiveness policy. The importance of support for basic research is not diminished; rather it serves as a necessary precursor to technological development. Basic scientific research both drives the development of technology and is driven by technological developments that enable the further exploration of the *"endless frontier."* Therefore, basic scientific research and technological development are symbiotically combined in a "chain link" model that acknowledges bidirectional feedback and allows both to coexist as a precursor, as well as result, of one another. The NSF's emphasis on infrastructure makes a great deal of sense in the context of this model. It is able to claim fidelity to its mission to broadly support basic scientific research by funding the facilities, tools, talent, and research networks that make the generation of new scientific knowledge possible.

In addition to justifying its NSE operations by predicting future positive outcomes and hitching its wagon to the discourse of technological progress, the NSF has also used frontier rhetoric to paint the nanoscale as the next vista of discovery. Perhaps the best example of this is the 1999 brochure *Nanotechnology—Shaping the World Atom by Atom.* The brochure was issued by the NSTC IWGN group chaired by Roco, and was used as part of the campaign to sell the NNI. The cover image displays a nanoterrain fading into a horizon depicting outer space with a distant Earth, Moon, and comet arrayed against a starry background, linking NSE research to the exploration of outer space. Nordmann (2004, p. 48–54) argues that the image serves to "remind us of the conquest of outer space that will now be matched by a conquest of inner space." While the space race of the 1960s was a product of Cold War competition between the U.S. and Soviet Union, "the current rush to claim and inhabit inner space was conceived as an economic arms race especially against Japan" (2004, p. 49). The report states, "Whoever becomes most knowledgeable and skilled on these nanoscopic scales will probably find themselves well positioned in the ever more technologically-based and globalized economy of the 21^{st} century" (IWGN 1999, p. 2). These arguments display the hallmarks of standard NSF justifications for its programs, as well as Roco's more "hyperbolic" rhetoric and appeals to national interest. NSE is explicitly positioned as the successor to the technical and public diplomacy successes of the space program, and implicitly linked to the economic successes of past large-scale programs, such as the Internet.

In addition to the visual rhetoric of space exploration, the brochure hammers home the position that funding NSE will lead to positive societal outcomes through the strategic use of "expert" breakout quotes. One pertinent example states that,

> Nanotechnology has given us the tools . . . to play with the ultimate toy box of nature—atoms and molecules. Everything is made from it . . . The possibilities to create new things appear limitless.—Horst Stormer, Lucent Technologies and Columbia University, Physics Nobel Prize Winner (1999, p. 2)

The Stormer quote represents one of the more interesting arguments for federal support of NSE. He describes the nanoscale as "ultimate toy box of nature" and maintains that society will profit from exploiting the limitless potential contained therein. This is reminiscent of Roco and Bainbridge's description of the nanoscale containing the "building blocks of matter." Both quotes present a vision of the nanoscale as a frontier in which the knowledge and ability to reinvent society, from-the-bottom-up, can be discovered. While the Bush report argues that science is a new frontier for American endeavor and a "proper concern of government," the vision presented in the Roco and Bainbridge and IWGN reports paints NSE with the brush of Turner's frontier thesis. The nano frontier will act as the crucible in which society can be rebuilt and reinvented by scientists and engineers deliberately restacking nanoscale building blocks of matter. For a proposition so fundamentally radical, both quotes interestingly use language—"building blocks" and "toy box"—associated with the quaint pursuits of youth. It is difficult to tell whether this is a conscious effort to assuage fears about unintended consequences or simply reflective of the authors' unconscious faith in progress arising from discoveries on the nano frontier.

It is worth noting the discourse of a nano frontier is itself problematic. The exploration of the outer space is a fundamentally different proposition than the exploration of inner space. Both outer space and inner space represent frontiers of scientific knowledge, however the former is expansive and extends to the furthest reaches of the universe, while the latter turns ever inward in finite space. Like the Manhattan Project, the nano frontier is one of endless contraction and collapse, albeit without the associated mushroom cloud of nuclear fission. While both inner and outer space frontiers of intellectual and physical exploration, only the nanoscale requires direct manipulation to unlock its secrets. The revolutionary breakthroughs promised by the NNI will only come about through conscious intervention at the nanoscale and the deliberate reordering of the building blocks of matter. Therefore, like Turner's Western frontier, the nanoscale does not reward exploration so much as colonization.

Coupled with promises of economic benefit and societal well-being, the rhetoric of endless frontiers and limitless potential forms a powerful political argument for federal support for NSE, typical of postwar rhetoric of U.S. science policy. Despite criticisms (Greenberg [1967] 1999; 2001; Sarewitz 1996) of this rhetorical strategy, the major tropes remain basically unchanged. The IWGN report bluntly asserts that, "nanotechnology stands out as a likely launch pad to a new technological era because it focuses on perhaps the final engineering scales people have to master" (1999, p. 4). Perhaps the key to understanding the persistence of this rhetoric, not only in the promotion of the NNI and NSE but throughout the history of the NSF, is contained in a passage of Greenberg's ([1967] 1999, p. 33) *The Politics of Pure Science:*

> Largely in response to the predicament of being neither self-explanatory nor self-supporting, basic research has had an incentive, for purposes of survival and growth to claim certainty when, at most it could establish only probability; it has incentive to ascribe to itself clear-cut economic significance, when, in fact, neither scientists nor economists have anything but a dim understanding of the role that science plays in economic development.

Complex scientific research must rely, by necessity, on the good will of the politicians that control the purse strings and the society in which it is embedded. Since few politicians and members of society will ever understand the scientific principles behind NSE, or most NSF-sponsored research for that matter, its proponents must press for support in terms that are readily understandable. It is little wonder then that "nanoscale science and engineering" is renamed "nanotechnology," that difficult to explain scientific research is recast as unambiguous and positive technological development, and that worries over potentially negative unintended consequences are ameliorated by claims that nanotechnology will radically transform society by enabling human control over the building blocks of matter. Nanotechnology is sold to key constituencies as the key to making human destiny manifest.

Conclusion

This paper argues that the National Science Foundation's role in, and influence on the operational and discursive strategies employed by the National Nanotechnology Initiative can best be understood through an examination of the NSF's history. Because of the Foundation's weakened starting position at its founding in 1950, the cautious nature of its first director, and its broad mission "to advance the national health, prosperity, and welfare; to secure the national defense" through support for basic science, it has been forced to develop strategies that ensure its continued survival among larger, older, and more powerful agencies competing for Congressional appropriations. These strategies have evolved over time as the NSF has encountered obstacles and celebrated triumphs to become a part of its institutional history. This strategy has two components—one discursive and one operational. The discursive component consists of a two-pronged approach that, on one hand, situates the basic research that the Foundation supports in the frontier rhetoric of Frederick Jackson Turner and Vannevar Bush, while on the other, promotes the societal, economic, political, and security benefits of basic research by utilizing a linear model of innovation. The NSF's operational strategy has evolved over time to emphasize infrastructural support for the nation's scientific endeavors through investment in research, the scientific workforce, and the tools and facilities that enable high-quality research. The Foundation has recently referred to these target areas as Ideas, People, and Tools. By focusing on infrastructural improvements at academic institutions, such as computing facilities, the NSF is able to support all three areas simultaneously. Through support for distributed computing and computer networking the Foundation's infrastructural strategy became virtual, allowing it to concentrate physical resources at a handful of institutions while enabling geographically disbursed users access to high quality resources.

The NNI has exhibited many of the same characteristics of the NSF's discursive and operational strategies. This should come as little surprise, as the NSF is a major financial and political player in the NNI, provides much of its coordination, and its Senior Advisor for Nanotechnology, Mike Roco, has been perhaps the single most influential individual in federal nano circles for the better part of two decades. The NNI exhibits both an adherence to the discursive strategy of linking federal investment in upstream basic research to positive downstream outcomes, as well as a propensity to engage in frontier rhetoric to explain how research conducted at the nanoscale will "lead to a revolution in technology and industry." Furthermore, the NNI, through the auspices of the NSF, has placed a great deal of emphasis on the infrastructural underpinnings of the anticipated nano revolution, providing support for the three target areas of Ideas, People, and Tools, as well as the establishment of research and virtual simulation networks modeled upon earlier Foundation successes with networked computing. An analysis of NSF history and the Foundation's motivations for supporting nanoscale science and engineering are a useful tool for understanding the founding of the NNI and discursive and operational strategies of that it employs. This paper is an attempt to tell part of that story.

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