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Speaking of Science: The Role of the National Science Foundation in the Development of United States Information Infrastructure

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ABSTRACT

Speaking of Science: The Role of the National Science Foundation in the Development of United States Information Infrastructure

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This dissertation argues that the National Science Foundation's role in, and influence on, the development of large scale scientific and technological systems, most notably improvements to U.S. information infrastructure, can best be understood through an examination of the NSF's institutional history. Because of the Foundation's weakened starting position at its founding in 1950, the cautious nature of its first director, Alan T. Waterman, 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 a strategy that ensures its continued survival among larger, older, and more powerful agencies competing for congressional appropriations. This strategy has two components: a discursive approach that situates Foundation support for basic research to the frontier rhetoric of Frederick Jackson Turner and Vannevar Bush and promotes the societal, economic, political, and security benefits of basic research utilizing a linear model of innovation. The NSF's operational strategy emphasizes the development of information and communications infrastructure, information management, virtual simulation, and at the most fundamental level, the generation of new scientific knowledge. This dissertation examines the influence of external and internal feedback upon the NSF. In response to

these stimuli, the NSF has repeatedly utilized the frontier imagery of Frederick Jackson Turner and Vannevar Bush to justify its operations. This rhetoric has shaped the NSF's historic support for the virtual frontiers of science – satellites, information management and control systems, supercomputing, the NSFNET backbone, and the Network for Computational Nanotechnology. The NSF not only supports the opening of frontiers through building and supporting infrastructure, but also through grants to researchers and the training of scientific pioneers. By providing support at critical and overlapping stages and junctures of the frontier enterprise, the NSF simultaneously fulfills its mission and creates lasting infrastructural traces that establish sovereignty over space and enables the generation of fundamental knowledge that undergirds, at least rhetorically, the linear model of innovation that shapes post-war science and technology policy in the United States.

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Chapter One: 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 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 18th and 19th 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

[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

> 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 discursive, political, and material strategies the Foundation developed during its evolution from a bit player in the federal science system to an agency with a $6.06 billion budget (FY 2008) that funds approximately 20% of all federally supported basic

[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 (1), interagency coordination (19), and education, training, and societal outreach (32). The report also declares "The success of the initiative to date is due in large part to the leadership of the NSF" (19).

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 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, 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: 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. The NSF was created by an act of Congress, and is dependent upon Congress for budget appropriations. It therefore 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 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 acknowledged 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 and material resources, as well as grant-based financial support for scientific research.

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[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.

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 engagement 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 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

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[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 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.

History." Turner attributes the exceptionalism of U.S. national character and institutions to the peculiar conditions of the frontier, “the crucible” ([1893] 1956, 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, 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:

> 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, 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 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 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, 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 endless frontier for exploration, with new scientific knowledge as the essential raw resource to be discovered and utilized, and casts the scientific community in 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, 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 stand-alone 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:

> 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, 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, 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, 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, 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 1987, 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 necessarily 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, 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, 98; Godin 2006, 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, 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, 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 spotlights the symbiotic relationship between scientific research and technology, and between science, culture, politics, and economics (Sarewitz 1996, 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 what channel it will cut, and therefore 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, 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 (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, 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, 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 (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 science and technology, 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" (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 science and technology to positive societal outcomes. The Foundation must demonstrate that its support for science and technology 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.

This dissertation seeks to highlight the important role not only that science and technology policy plays in the development of large-scale technological systems, but also to identify the role of institutional history in shaping the trajectory of science and technology policy, and therefore technological innovation. The focus of the dissertation is limited to the National Science Foundation rather than the entire federal science and technology funding and policy apparatus for reasons both practical and intellectual. The National Science Foundation is truly a unique, and often misunderstood, federal agency. Its mission, discussed elsewhere in this dissertation in detail, is to broadly support scientific research, and promote national well-being and security through this support – providing it wide latitude to operate, but an equally large and nebulous mandate to fulfill. Because science itself is a field, or array of fields, with fuzzy borders, and concepts such as national well-being and security are difficult to quantify, the direct role that the NSF plays in supporting and securing these things is challenging to describe. At its founding, the NSF was charged with accomplishing these goals primarily through support for basic science, or science for the sake of inquiry into the fundamental tenets of nature, rather than science directed or applied to a specific outcome. While basic science is worthy of support, and provides a foundation for applied research, engineering, and innovation, its direct contribution to the tools and techniques that in part drive economic prosperity and national security is often difficult to quantify. Without basic research into physics we would not have quantum mechanics, but how and why each fundamental discovery in the field of physics contributed to quantum mechanics is more difficult to ascertain. Taking this one step further, without an understanding of quantum principles you would not have scanning tunnel microscopy, a powerful method for viewing surfaces at the atomic level developed by Binnig and Rohrer at IBM Zürich in 1981, or the scanning tunnel microscope that is instrumental in nanoscale science and engineering. Where do you start counting contributions? Why this is important when examining the NSF is the fact that the NSF is embedded in a political system that is responsive to internal and external feedback, and is dependent upon the President for budget recommendations and Congress for final appropriations. Congress does not financially support basic science with taxpayer funds as an exercise in altruism; it does so because it expects a return on investment in ways that are compatible with the national interest – another nebulous concept (and if local constituencies benefit, so much the better). What complicates the issue is that the NSF distributes the vast majority of its annual budget to third parties in the form of research grants, institutional and infrastructural funding, and educational support. The Foundation itself directly produces very little, and its operational overhead comprises only a fraction of its overall budget. Its value, therefore, resides in the judicious disbursal of funds to individuals, projects, centers, networks, and institutions that do produce tangible results. The NSF must justify its appropriations in each budget cycle by demonstrating that the funds that it distributes to third parties produces tangible results that enhance national well-being and national security. Yet, since it overwhelmingly supports basic research, which is non-directed, it must rely upon a linear economic model that attributes upstream investment in basic research to the type of downstream technological innovations that secure prosperity and security in order to justify its operations to Congress and the Executive Branch. The NSF claims that through its research grants, it supports the generation of the ideas that undergird American innovation. Since the NSF itself does not directly produce scientific research, it must also justify its expenditures on facilities, infrastructure, and education as producing something tangible that contributes to its mission. It does so by claiming that these investments produce the people and tools that comprise the metaphorical laboratory and its staff in which American research and innovation takes place.

This dissertation 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 dissertation is an attempt to tell part of that story.

Roadmap

This dissertation is divided into nine chapters, including this introduction, that argue that the National Science Foundation's role in, and influence on, the development of large scale scientific and technological systems, most notably improvements to U.S. information infrastructure, can best be understood through an examination of the NSF's institutional history. The next 8 chapters are devoted to exploring the historical, rhetorical, political, and theoretical contexts in which the NSF operates.

Chapter Two discusses the historical origins of the constellation of major players involved in the generation and execution of U.S. science and technology policy. This chapter traces the origins of the linear model of innovation that provides the central justification for federal investment in basic scientific research – the central operational mandate of the NSF. The chapter then turns its attention to critiques of the linear model and unpacks the assumption that downstream investment in basic scientific research inevitably leads to innovation, development, and the accrual of societal benefits. The chapter also examines the rhetoric employed by actors in science and technology policy network to justify the investment of federal funds in their enterprise. The agenda-setting influence of the federal science and technology policy complex on scientific research is examined through the lens of the strategic challenges faced by the Unites States, most notably the Cold War and the immediate post-Cold War period, and their effect on policy generation. The chapter then examines the impact of the shift from the Cold War emphasis on military supremacy to post-Cold War attention to economic competition and globalization on the NSF and US science and technology policy.

Chapter Three begins to address in detail the importance of rhetoric to the NSF through an examination of Frederick Jackson Turner's 1893 address to the American Historical Association, "The Significance of the Frontier in American History," which attributed the uniqueness of US national character to the peculiar conditions of continental expansion of the United States. Turner's argues that American history is the exploration and colonization of an ever-receding frontier and the westward advancement of a unique American culture. Turner's arguments and imagery are subsequently adopted by the NSF, via Vannevar Bush, to recast basic scientific research as both a frontier enterprise and as fundamentally American. The chapter moves from a close reading of Turner's essay to an examination of the influence of contemporary 19th century thought, including evolutionary human geography, upon Turner. The influence of Turner's "frontier thesis" on foreign policy is examined in the context of expansionism during the early decades of the 20th century and the perceived need for the United States to continually seek and occupy new frontiers after the disappearance of the physical frontier of the American West. Finally, Frederick Jackson Turner's 1910 address to the American Historical Association entitled "Social Forces in American History," in which he revisits the theme of the disappearing frontier and the profound changes underway in the first decade of the twentieth century, is examined. Turner argues that American history since 1893 represented efforts to find substitutes to replace the natural frontier as a safeguard for American democracy.

Chapter Four continues to address the importance of rhetoric to the NSF through a close reading of Vannevar Bush's seminal 1945 report *Science – the Endless Frontier*, which linked his science policy recommendations with the beneficial political, social, and economic developments associated with the American frontier expounded upon by Turner. By describing science as an "endless frontier" Bush directly proposes a substitute to Turner's natural frontier. In his report, Bush strongly advocates the creation of a federally funded national research agency to broadly support basic scientific research, arguing that the presence of such an agency would directly serve national interest and enhance societal well-being. Bush argues that federal support for science is a proper concern for the Government and acts as a safeguard for democracy. He draws on the example of scientific contributions to the successful conclusion of World War II to illustrate his argument. In *Science – the Endless Frontier* Bush utilizes the basic framework of the linear model to argue that failure to continuously progress on the scientific frontier could lead to stagnation and significant damage to the nation.

In Chapter Five attention is turned to the institutional history of the NSF. The chapter argues that the NSF is a political entity subject to stimuli and impulses of the political process since it is both dependent on congressional budget appropriations and enmeshed in a constellation of federal agencies with both overlapping and conflicting interests. The chapter details the three major factors that shaped the Foundation in its early history utilizing primary source documents and oral histories: 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 chapter addresses early NSF forays into satellite research conducted under the auspices of the 1957-1958 International Geophysical Year, the realization that demonstrable scientific and technological successes were of particular import for Cold War public diplomacy, and the fact that science and technology policy was becoming increasingly inseparable from the psychological proxy-conflicts of the Cold War. These realizations inspired the NSF to develop an operational strategy of providing infrastructural support to the academic scientific community and expanding its constituent base through the broad geographic distribution of resources. The chapter concludes with a cautionary example of applied social science research at the NSF from the late 1960s through mid-1970s in the form of the Research Applied to Nation Needs program, which owed both its rise and subsequent decline to changes in political climate.

The NSF's computing and information management activities between 1950 and 1970 are the subjects of Chapter Six. Early support for computing was focused on infrastructural support for campus computing to aid scientific research. By the mid-1950s the NSF recognized high-speed computing as an answer to the problem of "increasing complexity" faced by many scientists and engineers. The NSF addressed the complexity problem not only through support for advanced computer modeling and simulation, but also through initiatives in information management designed to control the flow of scientific knowledge. The chapter then demonstrates how the Cold War concept of information overload – that not only the generation of knowledge, but also its efficient management is influential to the exercise of power – has influenced the NSF's computing activities from the mid-1950s through the present.

Chapter Seven provides an analysis of large-scale computing projects and networking under the auspices of the NSF. Dealing with the 1970s through 1990s, the chapter expands upon the concepts of infrastructure, information management, and complexity addressed in previous chapters, and examines emerging concerns over the speed of technological change taking place during this era. The importance of NSF investment in, and networking of, regional supercomputing centers is discussed, as is the impact of these developments upon the establishment of NSFNET and the NSF's high-speed backbone. The influence of the NSF upon the development and eventual commercialization of the Internet is discussed in detail, as is the important role that

Erich Bloch, Director of the NSF, and Gordon Bell, Assistant Director of the Computing Directorate, played in this process. Finally, the chapter argues that the unique characteristics of the Foundation that had evolved over time both in response to internal as well as external pressure helped shape the Foundation's management of the successful convergence of multiple, separately funded and administered, technology initiatives to create a large-scale technological system.

The NSF's pivotal role in the National Nanotechnology Initiative (NNI) and the post-Cold War generation of science and technology policy is discussed in Chapter Eight. The chapter traces the emerging contours of the science and technology policy shift in emphasis from military to commercial supremacy and from science to technology in the 1990s, and how the NNI reflects these changes. The influence of the NSF and its Senior Advisor for Nanotechnology, Mihail Roco, on the founding and operation of the NNI is discussed in detail, as is the role of the Foundation at the center of a constellation of federal agencies involved in the promotion and support of nanoscale science and engineering in the US. The chapter examines how the promotion of convergence between nanotechnology, biology, information technology, and cognitive science reflects the evolution of the NSF as an institution, and the influence of the Foundation on the rhetoric used to promote the NNI.

Finally, in the Conclusion, the NSF's involvement in nanoscale science and engineering and the NNI is examined through the prism of Paul Virilio's concepts of *limit-performances and techno-science*, through which he postulates that modern science has been corrupted. The chapter revisits criticisms of US science and technology policy and the linear model and argues that the NSF and the US science establishment are rhetorically preoccupied with claiming fidelity to the concepts scientific truth and demonstrating its importance to the accrual of societal benefits. Virilio's criticism that science has erroneously become enamored with the *acceleration of reality* and the *aesthetics of scientific disappearance* is challenged by the fact that many of the tools associated with nanoscale science and engineering, from the scanning tunnel microscope to advanced computer simulation environments, are precisely what make the nanoscale appear. The chapter argues that the NSF's infrastructural support for scientific research and technological development represents an effort to settle the frontiers of science. The idea of infrastructure extending sovereignty over both physical and virtual space is examined in the context of Bruno Latour's discussion of networks and Paul Edwards' concept of *discursive infrastructure*, concluding that the history of the NSF and its operational reality are inscribed in the techno-scientific networks that it has supported.

Chapter Two: The Federal Science and Technology Policy Complex

This National Nanotechnology Initiative and the NSF's involvement in the promotion of nanotechnology represents a broad and long-term federal commitment to achieving a symbolic, as well as technological, victory in the race to develop this emerging technology. Nanotechnology is a strategic endeavor to achieve the "next industrial revolution" and simultaneously address the uncertainty of economic globalization and asymmetrical threats to US interests. Rosenau's (1997) model of the complex adaptive systems subject to multiple feedback streams and internal and external stimuli is a useful lens through which to examine the emerging contours of the post-Cold War world and the evolution of US science and technology policy. Following the end of the Cold War, US science and technology policy shifted its primary focus from "military technological supremacy" to "global commercial primacy" (NSF, 1993) to confront the commercial "threat" posed by Pacific Rim and European economies. The NNI is a critical component of a US science and technology policy designed to maintain a competitive advantage in an increasingly globalized world no longer defined by the bipolarity of the Cold War. The NSF plays a critical role in this strategy not only by supporting basic nanotechnology research, but also through the funding of university-based research centers and the creation of a highly skilled S&E workforce designed to sustain the nanotechnology "revolution." This dissertation argues that

NSF’s focus on education and curriculum development positions the S&E workforce squarely on the frontline of US efforts to win the “race to the bottom” and achieve “global commercial primacy.”

Origins

Blanpied and Hollander (1986, 75-76) locate the origin of the secular Western tradition of viewing scientific progress as leading to social progress in work of English philosopher Francis Bacon (1561-1626) and Sarewitz (1996, 100-101) views this tradition as an outgrowth of Bacon's work as well as that of French philosopher and mathematician René Descartes (1596-1650). Both philosophers' work is embedded in a Christian tradition that ascribed to humanity dominion over nature, and both viewed science as a means for understanding and ultimately controlling nature and furthering God's work by advancing order and progress on earth. By following the theological thrust to exert control over nature, humanity could employ science to both material and spiritual benefit, and individual scientists could exercise influence and shape social discourse. All of these authors draw a direct line from the Baconian/Cartesian model of scientific progress to Vannevar Bush's vision of secular science in his 1945 treatise *Science – the Endless Frontier*. Blanpied and Hollander (1986, 76) see echoes of Bacon not only in the idea that science leads to social progress, but also in Bacon's contention that scientific progress required a systematic program undertaken by self-selected groups, who would be granted autonomy by society, to pursue research into the mysteries of nature. The argument for peacetime government support for science put forth by Bush linked continued scientific progress to social progress and the enhancement of human welfare. Additionally, his plan for a national research foundation explicitly called for granting the agency the utmost autonomy in choosing its own director, establishing priorities, and distributing funds.

For Sarewitz (1996, 101-103), Bush's invocation of the political and cultural myth of the creation of the United States in *Science – the Endless Frontier* replaces the Christian call to serve God by assuming dominion over nature. The metaphor of the endless scientific frontier mirrors the historical myth of the American frontier, an area of the unknown that demands exploration and colonization, and whose exploitation leads to enhanced economic, social, and political prosperity. In *Science – the Endless Frontier* Bush wrote:

> It has been basic United States policy that 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 for development by all American citizens. (1945, Ch. 1.2)

Through his use of the clipper ship analogy, Bush also implies that communication and transportation are linked to the pursuit of scientific research and are similarly worthy. The connection between science, communication, and transportation is particularly interesting as it highlight the importance of infrastructure and information to the process of scientific discovery. However, as Sarewitz correctly notes, Bush's metaphor fails to recognize that the "taming" of the American frontier was accompanied by genocide, slavery, and the destruction of nature. Nevertheless, it still casts a long shadow over current discourses about science and progress, as it offers up the frontier of science as an area of untapped and limitless potential. Bush goes on to state that,

> Since health, well-being, and security are proper concerns of Government, scientific progress is, and must be, of vital interest to Government. Without scientific progress the national health would deteriorate; without scientific progress we could not hope for improvement in our standard of living or for an increased number of jobs for our citizens; and without scientific progress we could not have maintained our liberties against tyranny. (1945, Ch. 1.2)

Bush's report includes several glaring oversights, including the potential negative effects of scientific activity, how the subjective values of scientists affect research trajectories, and the need for broad based social support for research priorities (Blanpied and Hollander 1986, 77). While the phrasing and choice of metaphors may have changed in the intervening years since Bush's report was published, and areas of oversight have been acknowledged, the basic flavors of his argument continue to influence the underlying assumptions of US science policy. Namely, that scientific research into the secrets of the endless frontier will inexorably lead to social progress and well-being, and that this research should be generously supported by the government to ensure maximum benefit.

As most authors who turn a critical eye to the relationship between the federal government, science, universities, and industry acknowledge, this relationship has borne fruit and has given rise to spectacular successes. However, the underlying assumptions and rhetoric at the nexus of politics, power, money, and science that have sustained support for the scientific system should be subjected to critical scrutiny. As Sarewitz (1996, 4) observes,

> Modern society is obviously dependent in many ways on science and technology, and the federal government has helped to create the world's most advanced system of research and development in response to this dependence. But the R&D system is therefore a political entity, itself dependent upon government decision-making processes and public

> approval for its own well-being. In this context of dependence, and in light of the growing complexity and magnitude of challenges to humanity's long-term welfare, the assertion of causality between progress in the laboratory and progress in society may therefore be viewed as an unproven – although extremely powerful – political argument invoked by researchers and research advocates to sustain public support. Upon such arguments the research system is built.

For Sarewitz (1996) the assertion of causality is based in what he terms the myths of scientific progress. The myth of infinite benefit will be highlighted in this study. The myth of infinite benefit holds that if scientific research and technology development improve social wellbeing, then the more that is invested into R&D the better the quality of life will be (19). This myth is propelled by linking success in the past to infinite future returns. Sarewitz notes that if this causal link were to be incontrovertibly true, then the massive R&D expenditures of the US in the five plus decades since the end of the Second World War should ensure that the US would rank at, or very near, the top of all indicators that measure social wellbeing. This however, is not necessarily the case when indicators that measure wages, leisure time, concentration of wealth, or unemployment are taken into account (20-23). The US has fared extremely well since the end of the Second World War, but the infinite benefits that Bush's *Science – the Endless Frontier* predicted emerging simply as a matter of course from increased federal support for science have not materialized. Sarewitz notes that the US, which spends a much higher portion of its civilian R&D budget on health research than most other industrialized nations, still lags behind these other nations in many health indicators (21). There is insufficient empirical evidence to support the more-more proposition at the heart of causal link between funding and outcomes.

An interesting aspect that emerges from the myth of infinite benefit is that it conceals the political reality that an expanding research system creates a growing constituency that in turn produces a greater demand for federal support (23). The presence of funding helps create a constituency as well as competition for funds, and increases the demand for more government support. This demand can then be used rhetorically, both by the scientific community as well as by federal funding agencies, to argue for expanded support for the scientific enterprise, lest critical research that would contribute to national wellbeing go unfunded. Sarewitz argues that, "the population dynamics of the R&D system stimulates an ever-increasing demand for government support – growth that can be rationalized by the myth of infinite benefit" (24). Demand for federal support drives arguments to increase science funding using the rhetoric of infinite benefit to justify increased expenditures as a prerequisite for positive societal outcomes, and to warn that the failure to fund the scientific enterprise will lead to diminished wellbeing.

The central claim of Daniel Greenberg's "Science, Money, and Politics: Political Triumph and Ethical Erosion" (2001) is that the success of the postwar US 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" (1). Greenberg argues that science would have fared well enough in the postwar high-tech US without science evangelism, but persistent lobbying ensured even greater prosperity and the development of the 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 US political system and supported by government largess (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, 6-7). For Greenberg, 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.

Government Spending and Academic/Scientific Agenda Setting

The intense governmental and military interest in nanotechnology, the creation of the National Nanotechnology Initiative, and the emphasis on NBIC convergence detailed in the NDF/DoC report "Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science" has a number of historical antecedents in the history of US science. Public/private research and development partnerships permeate the history of technological advancement in the United States throughout the 20th century, becoming the norm for much of the large scale scientific endeavors that have taken place in the nation since the conclusion of the Second World War. During the Cold War in particular, government and military funding of US science and research institutions had a significant impact on the shape, scope, and direction of technological change. It is safe to state that during the Cold War period government and military funding was instrumental in guiding the national science and technology agenda, resulting in the creation, promotion, and promulgation of specific sets of knowledge and skills that consistently adhered to the aims of US strategic interest. Cold War science became intrinsically linked to the interests of their funding agencies leading to the creation of what President Eisenhower referred to as the "military-industrial complex" in his final major speech as the chief executive of the nation (Eisenhower, 1960).

The extraordinary power of this funding and agenda setting network of government and military agencies, universities, private industry, scientific researchers was apparent to Eisenhower by 1960. In his speech he warned of allowing the developments of the military-industrial complex to compromise our liberties by subordinating all other societal needs to those of national security.

> "The total influence – economic, political, and even spiritual – is felt in every city, every State house, every office of the Federal government. We recognize the imperative need for this development. Yet we must not fail to comprehend its grave implications. Our toil, resources and livelihood are all involved; so is the very structure of our society. In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex. The potential for the disastrous rise of misplaced power exists and will persist. "(Eisenhower, 1960)

Eisenhower advocated for the American public to become, in his words, "an alert and knowledgeable citizenry," and to act a counterbalance to prevent the military-industrial complex from wielding unchecked power and endangering the peace and prosperity of the nation. In examining the influence of the network of governmental and military agencies promoting research and development initiatives to usher in a nanotechnology revolution, it is important to heed Eisenhower's warnings and to strive toward becoming an alert and knowledgeable about nanotechnology research and funding.

A vital component of understanding current nanotechnology endeavors is the examination of the historical role of the US government and military in setting a national science research and development agenda. While acknowledging the influence of military funding of engineering and physics during the Second World War and to a lesser extent during the First World War and the Interwar, the history of American science during the Cold War provides the best template for understanding the current National Nanotechnology Initiative in general and NBIC convergence specifically. However, the Second World War casts a long shadow over the post war era and the massive mobilization of all sectors of the US economy, including science and engineering, to meet the demands of the war set the stage for the institutionalization of the relationship between governmental/military funding and science during the Cold War.

It is during the Cold War that many of the non-military governmental agencies that currently play a crucial role in NNI and NBIC convergence were founded, or first became active in the funding of science and technology. The National Science Foundation, the crucial agency in the nanotechnology matrix, was founded by Congress in 1950 by the National Science Foundation Act, and tasked "To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense." The National Science Foundation Act also created a policy steering apparatus for the NSF called the National Science Board consisting of twenty-four presidentially appointed members and a Director as the chief executive (Mazuzan, 1994). Additionally, other key players in the National Nanotechnology Initiative came into being or gained prominence during the early years of the Cold War. The National Institutes of Health, the umbrella organization that coordinates US health research, was formally reorganized in 1948 to administer over the myriad health administrations that had existed in the United States since the late 19th century (Harden). The National Aeronautics and Space Administration (NASA), was founded on October 1, 1958 in direct response to increasing Cold War tensions and the aftermath of the Sputnik space launch by the Soviet Union, and followed Department of Defense and Department of the Navy rocketry programs in the 1940s and 1950s (Garber & Launius, 2002).

Despite the origins of the NSF, NIH, and NASA in the late 1940s and 1950s, no sector of the government shaped and formed national science and technology policy, research, and development in the first two and a half decades of the Cold War more profoundly than the Department of Defense. The most ready example of the influence of the military on the national science agenda during this period is the fact that the US Department of Defense was "the single biggest patron of American science" in the decade immediately following the conclusion of the Second World War, and contributed roughly 80 percent of all federal funds for scientific research and development throughout the 1950s (Leslie, 1993, 1). However, over the course of Cold War the overt military influence on American science became less pronounced, as an intertwined network of government agencies, the military, the intelligence community, private industry, academics, and academies became institutionalized, variously described as the military-industrial complex, the military-industrial-academic complex (Leslie, 1993), the military-industrial-university complex (Hughes, 1998), and the military-industrial-media-entertainment network (Der Derian, 2001). No matter what one calls this network of public and private entities, it had, and continues to have, a profound influence on the scientific agenda of the United States.

The various names attributed to this complex point to one of the more interesting aspects of its existence: its intricacies, myriad interconnections, and lack of centralized command and control. This should in no way discount its existence or influence, or lead to the perception that this network exists by mere happenstance. Rather it highlights the highly intricate, and at times fluid, nature of the relationship between the science research and development of a funding apparatus and a cadre of clients. Central to the functioning of this network is the establishment of scientific priorities and the subsequent distribution of funding for the execution of those priorities. The interplay between the formation of a scientific agenda that promotes national interest and national security and the funding of research that adheres to these interests directly shapes current and future technological change; change that has had and will continue to have a profound impact upon the United States and the world.

In order to understand the impact that the current emphasis on NNI and NBIC convergence may have on the practice of science in the United States and what potential societal effects may come of this emphasis one needs to examine the profound effect that governmental/military funding has had on technological change, the academy, and society in the Cold War, and post Cold War era. The influence, funding, and agenda setting of the government/military agencies has lead directly to the creation of a number of revolutionary technologies and technological practices in the roughly 60 years since the conclusion of the Second World War. A primary example is the development of the Internet, which is the culmination of multiple, and often previously unrelated, technological advances in numerous engineering and computing fields, most of which were directly or indirectly funded by various government and military agencies with the purpose of advancing national interest and national security. Combining advances in such disparate fields as solid state engineering, software development, and telecommunications infrastructure, the Internet is an extremely successful example of the convergence of multiple, separately funded and administered technology initiatives to create a complete technological system (Abbate, 1999).

The lessons learned from the creation of complex systems technologies and systems management techniques during the Second World War and Cold War (Hughes, 1998; Hughes and Hughes, 2000) have had a tremendous impact on the development of newer technologies, like the Internet, and continue to influence current approaches to managing technological change. The systems view of technology is extremely pronounced in the current vision of NBIC convergence, which aims to create and develop new technologies and technological systems by combining scientific advances in nanotechnology, biotechnology, information technology, and cognitive science.

Not all of the lessons from the funding of scientific development during the Cold War however, provide a template for the successful management of technological change. The influence of government/military funding has had a major impact on the shaping of what is and what is not "valid," often leaving an indelible imprint on the researchers, research facilities and universities tasked with producing scientific advances as well as training and educating future researchers. The effect that the intersection of national interest and university research funding can have is captured in Christopher Simpson's *Science of Coercion: Communication Research & Psychological Warfare 1945-1960*, which documents the impact of military funding of psychological warfare research on the creation and codification of the discipline of Communications Research. The connections between the military, major researchers (most of who had formed friendships and alliances in the military during WW II), and major research institutions produced a body of research and published literature that came to define what is known as the dominant paradigm of Communication Research. This paradigm however, was shaped though its necessary application to psychological warfare initiatives, and subsequently became the received knowledge for the next generation of researchers. As Leslie reminds us in *The Cold War and American Science*, a valid question to consider while examining what research gets funded, is what science and which researchers are ignored, invalidated, or overlooked by those who influence and shape the national scientific agenda. It is critical to ask "What possibilities for growth and scientific achievement are we missing out on by privileging one technology or one process over another, and what possible effects may we encounter, both positive and negative, by choosing one path over another?"

Many Damn Things Simultaneously

James Rosenau's (1997) article "Many Damn Things Simultaneously: Complexity Theory and World Affairs" characterizes of the post-Cold War era as an "emergent epoch of multiple contradictions" fraught with "uncertainty" and also serves as an apt description of the state of US science and technology policy during the 1990s. During the Cold War the relative stability of the US-Soviet rivalry allowed a comfortable science and technology coalition of federal agencies, the military, industry, and universities to develop in support of US strategic interests. Even during the 1970s and 1980s, as economic competition with the Pacific Rim and Europe intensified, Cold War objectives dominated strategic thinking and planning. With the collapse of communism in Eastern Europe and the Soviet Union, the binary opposition of the Cold War was replaced with asymmetry, as international actors began to reevaluate their strategic alignment and priorities.

Uncertainty the over the dawning of a “new world order” at the start of the 1990s was augmented by the contradictions of increasing globalization. Global economic integration provided actors with broad access to world markets while simultaneously increasing economic competition and exposing ethnic, national, and regional differences that had been papered over during the Cold War. Complexity theory can be used to make sense of simultaneous global integration and fragmentation and develop a model of the world as a complex adaptive system. Rosenau (1997) writes that,

> Such a system is distinguished by a set of interrelated parts, each one of which is potentially capable of being an autonomous agent that, through acting autonomously, can impact on the others and all of which either engage in patterned behavior as they sustain day-to-day routines or break with the routines when new challenges require new responses and new patterns. The capacity of the agents to break with routines and thus initiate unfamiliar feedback processes is what makes the system complex.

This model is also useful for understanding complex policy making organs and the relationship of individual actors inside of the system. It is important to recognize that breaks in routine, both expected and unexpected, initiate feedback that can in turn have a profound influence over future outcomes. Rosenau warns against viewing complexity theory as a means for predicting policy outcomes, however it is useful for understanding the interactive process of policy formation. Policy is not a product of a simple linear model of cause-and-effect, but the outcome of a complex process subject to multiple streams of feedback originating both externally and internally.

The NSF, Scientific Research and Technology Development

In an article entitled "Basic Research and Economic Health: The Coming Challenge" NSF Director Erich Bloch (1986) identifies four distinct phases of federal science and technology policy since the conclusion of the Second World War that corresponds with shifts in NSF policy. The first phase lasts from the end of the war until 1957, and is characterized by heavy R&D support through the mission agencies. In this era the nascent NSF supported broad basic science for its intrinsic value and its involvement in multi-agency projects was limited to coordinating federal participation in the International Geophysical Year (IGY) from July 1957 through December 1959 (England 1982). The NSF's participation in the IGY saw its emergence as a permanent federal agency and produced a lasting Foundation presence in Antarctica and a continued commitment to international, cooperative science. The IGY also produced the first bitter lesson as the Foundation engaged in budget battles and bureaucratic turf wars with the Department of Defense. The Soviet launch of Sputnik on October 4, 1957 ushered in the second phase of federal science and technology policy characterized by a massive increase in R&D funding especially at the university level. The importance of the NSF in the federal R&D funding apparatus rose along with the pressures of competition with the Soviet Union and the desire to produce scientific and technological achievements that enhanced the global image of the United States.

By the middle of the turbulent 1960s, the widespread perception that social and infrastructural conditions in the US were deteriorating compelled Congress to push the NSF to shift its focus away from basic research and toward applied social science that "produced results." After 1968, the massive funding increases of the previous ten years leveled off and federal focus shifted from to the pressing domestic issues facing the nation. congressional demands for "relevance" (Bloch, 1986) and "results" (Larsen, 1992)[6] prompted the creation of a social sciences division at the NSF through a presidential amendment to the NSF Act of 1950, emphasizing applied research that addressed social issues such as crime, housing, and energy. During this phase the NSF created and funded the Interdisciplinary Research Relevant to Problems of Our Society

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[6] For a detailed history of social sciences at the National Science Foundation see Otto Larsen's comprehensive 1992 work, "Milestones and Millstones: Social Science at the National Science Foundation, 1945-1991."

(IRRPOS) (1968-1970) and Research Applied to National Needs (RANN) (1970-1977) programs to address the pressure to demonstrate "relevance" and produce "results."

The fourth phase that Bloch highlights begins in 1980 with a renewed emphasis on support for basic science and engineering research and is characterized by the Reagan Administration's (1981-1989) focus on defense related R&D and related increases in science and technology support. This era in the NSF's history is marked by the abolition of RANN in 1977, the establishment of an Engineering Directorate in 1981, and the establishment of major university research centers, most notably supercomputing centers in 1985 at Carnegie Mellon University, Cornell University, University of Illinois, Princeton University, and UC-San Diego. The experience with large scale applied research in the early to mid- 1970s, and the subsequent shift back toward basic research in the late 1970s provided the NSF with a solid institutional foundation from with to approach the development and oversight of NSFNET.

Bloch's model ends in the mid-1980s during the defense related build-up of the Reagan years. Bloch's model can be extended to incorporate the major geo-political shifts of the past twenty years. A fifth era of science and technology policy coincides with the end of the Cold War starting with the fall of the Berlin Wall in late 1989 and the collapse of communism in the Soviet Union in 1991 and runs through 2001. This era characterized by the shift in US science and technology policy from supporting global military supremacy to achieving global commercial primacy (NSB, 1993) mentioned above. The post-Cold War environment is one of multiple contradictions associated with increasing globalization and a reordering of international priorities. It is in this era that the NSF successfully managed the commercialization of the Internet, a feat that in many ways came to define the "go-go" 1990s, the "new economy," and the "information age." Finally, Bloch's timeline can be extended to include an emerging sixth era that begins with the bursting of the Internet bubble in financial markets and arrives fully with the terrorist attacks on New York and Washington, DC on September 11, 2001.

Economic Challenges of Globalization

The international challenges that motivate the strategy of global commercial primacy did not simply arise with the ending of the Cold War, but have been a central 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 National Science Foundation (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 (Bloch, 595)." Two decades later the idea that the US faces an intense foreign economic competition, and that vigorous support for basic research and engineering in the pursuit of new technology is the remedy persists. 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 very reminiscent of several challenges facing the United States in 2008. The perception that the Pacific Rim economies pose a direct threat to US 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, as new dangers emerge in the endless frontier of science.

Rise of Japan

The origins of Japan's rise to technological juggernaut and the convergence of global economies can be traced back to the US post WWII reconstruction policies for Europe and Japan. In the 25 years following WWII the global economy witnessed the rapid convergence of real per capita GDP and productivity levels among the United States, its Western European allies, and former enemies Germany, Italy, and Japan – a group referred to as the "convergence club" (Ostry 1997). The damage inflicted on Western Europe, Germany, and Japan during the war coupled with the United States' massive wartime industrialization efforts produced a massive GDP and productivity gap between the United States and any other industrialized nation. By the early 1970s this gap began to narrow as the GDP and productivity levels for the France, Japan, Italy, Germany, and the UK began to converge with those in the US. Post-war reconstruction played an obvious role in the rehabilitation of these devastated economies. However, rebuilding is only part of the story. More importantly, Ostry argues that the implementation of specific U.S. post-war policies can be seen as the catalyst and driver of economic convergence between these industrialized economies (Ostry 1997, 2).

U.S. technological superiority, which manifested itself in the decades following the Second World War, had its roots in the government and industrial investment in wartime R&D (many sources), and the good fortune to escape the conflict with all of its manufacturing and industrial infrastructure intact. In the decades immediately following war the Department of Defense provided the majority of industrial and university R&D funding (many sources), a holdover from WWII and a reflection of the US engagement of the Soviet Union during the Cold War. The early years of convergence between these economies consisted mainly of a process of "technological catch-up" that was built around domestic and international policy initiatives that promoted investment and trade between the partner economies with the US acting as the "master architect and builder" of this policy framework (Ostry 1997, 12).

The Marshall Plan, the US-sponsored program dedicated to rebuilding the infrastructure of post-war Europe, provides the most obvious historical example of this policy approach – the combination of technology transfer, direct investment, and the promotion of liberal trade policy in affected nations. The Marshall Plan is generously viewed as a benign exercise in democracy promotion and cynically as a shrewd public relations ploy designed to combat Soviet influence in Europe. The truth lies somewhere in between, as the promotion of liberal democracies and diplomatic strategy are not mutually exclusive. Ostry highlights a fortunate confluence of historical events that pushed various US foreign policy camps into agreement to quickly launch the Marshall Plan in 1947, leading to a major U.S. economic and public relations coup. Compounding the positive effect of the Marshall Plan on European public opinion for the United States was the Soviet refusal to participate in any formalized, multilateral plan to rebuild the post-War European economy (Ostry 1997, 14).

While much of the Marshall Plan's success can be viewed as primarily symbolic, perhaps its most lasting impact upon post-war Europe was the creation of a new environment for the formulation of economic policy that allowed for more deregulation and market-oriented policies than may have been possible in Western Europe had economic recovery simply been left domestic governments without the financial assurances promised in the plan (De Long and Eichengreen 1991, 3). The Marshall Plan enabled Western European governments to pursue "mixed economies" based on market principals rather than central planning and is described as a "large and highly successful structural adjustment program" by De Long and Eichengreen (1991, 5). The structural adjustment of Western European economies along more market-oriented lines not only helped spur economic recovery but also promoted subsequent convergence within Western European, and later with Japan and the United States.

Ostry (1997, 16-17) examines both the speed and political compromises behind the implementation of the Marshall Plan, concluding that post-war US unilateralism allowed for the rapid development and implementation of the plan. The fact that a dominant US was able to enter into negations with a decimated and war-weary Europe allowed for conditions to be negotiated that would find wide acceptance not only in the U.S. Congress, but also in the powerful business community. Additionally, Ostry highlights the slowdown in post-war rebuilding by 1947 as an additional factor in the rapid implementation of the plan, citing US fears that economic stagnation could lead to support for Western European communist parties (1997, 17). The Marshall Plan is therefore as much a product of economic aid as it is influenced by the political logic of the nascent Cold War.

The starting position in post-war Japan could not have been more different than Western Europe. As the U.S. assumed political control through the figure of General Douglas MacArthur as proconsul, it made clear that it would not be responsible for the economic recovery of Japan, as its destruction was a result of its own behavior (Ostry 1997, 35). Additionally, US proposals for post-war Japan included plans for reparation payments to Asian nations that Japan had invaded, as well as the creation of a domestic economic structure that would not be capable of competing with or surpassing its neighbors (Ostry 1997, 36). However, as the unfolding reality of the Cold War in Asia and the Pacific Rim made clear to US policy makers, Japan provided the US with a useful ally against the Soviet, Chinese, and North Korean communist threats. The Korean War is one milestone in the US turnaround in attitude toward Japan as the demand for supplies for the US military campaign on the Korean peninsula fueled industrial production in Japan. Japan shifted from vanquished foe to the center of US military power in the Pacific and the central player in US-sponsored resistance to communism in East Asia. This shift helped cement an emphasis on manufacturing and technology in the Japanese economy that would become the topic of much debate in the United States by the 1980s as economic and technological competition with Japan became a cause of great consternation.

As Japan assumed a central role in US geopolitical strategy in Asia at the start of the 1950s US policy makers scrapped many of their demands for the liberalization of the Japanese economy, leaving large sectors of the Japanese bureaucracy essentially unreformed. Because Japanese industrial output was essential for the US military campaign on the Korean peninsula, the imposition of liberal reforms, like those instituted in Europe under the Marshall Plan, fell by the wayside. Technology transfer became one of the most important early factors in Japanese reconstruction efforts to meet demands for increased output. However, Japan restricted most foreign direct investment and limited Japanese investment abroad, instead preferring to license technology primarily from the United States (Ostry 1997, 44). While these policies allowed Japan to quickly recover its industrial capacity and "catch-up" with other technologically advanced nations it led to charges of trade protectionism (Ostry 1997, 48), reverse engineering US technology, and techno-nationalism (Corning, 3).

Both the structural adjustment associated with the Marshall Plan in Europe and the abandonment of economic liberalization in Japan as a goal were policy decisions that would produce long-range political consequences for US science and technology policy in the decades following the conclusion of WWII. As the US focused its attention on communism and direct and proxy confrontation with the Soviet Union in the four plus decades that followed WWII, the consequences of the post-war recovery plans for both Western Europe and Japan would begin to produce the contours of the Cold War economic system that emerged in the 1970s and the post-Cold War economic system that has profoundly influenced the scope and direction of US science and technology policy since the collapse of the Soviet Union.

Increasingly, government agencies must balance the economic and security needs of the nation with the pressures and opportunities of a globalized economy, globalized science workforce, and globalized risks and contingencies. While some have declared that globalization has the potential to erode the relevance of the nation-state (Wolf 2001; Reis 2004; Sutter 2006), interaction between government, industry, academy, and workforce in national networks will continue to play an important role in any large-scale R&D endeavor and effect the performance of the actors in these networks. One of the primary functions of government in these networks is to provide financial support, state-of-the-art infrastructure, and education of the science and engineering workforce. The S&E workforce is a critical component of any NSI, as human capital is necessary to create and sustain scientific innovation. A superior S&E workforce enhances national competitiveness as it helps attract "inflows of capital, technology, and scientific expertise" (Kaounides 1999, 73). However, trans-national corporations that cut across multiple national systems of innovation that benefit from cross-border economic, labor, and information flows are playing an increasingly important role in national innovation networks. National governments are therefore faced with the challenge of balancing the contradictory impulses of fostering a competitive national system of innovation in which trans-national corporations play a central role, and the fear that the cross-border flows integral to the success of trans-national corporations will simultaneously undermine national interest.

Techno-Globalization / Techno-Nationalism

US responses to these economic challenges have traditionally ranged from calls for protectionist trade policies to the promotion of international market liberalization. In a May 1987 article in *The Atlantic Monthly* entitled "The rise of techno-nationalism" Robert Reich examined the tensions between two modes of national technology policy known as techno-globalism and techno-nationalism (Simon, 1997; Yamada, 2001; Corning, 2004). The techno-globalist perspective favors state-supported infrastructure that aids advances in basic science, while private sector firms provide technical innovation and are responsible product development. The liberalization of the world technology market and the elimination of international trade barriers to facilitate the diffusion of products and knowledge in order to maximize private firm contribution to the national economy are central to this policy (Keller and Samuels, 2003). Techno-nationalism, on the other hand, seeks to insulate the national technology sector from competition through limiting direct foreign investment and the imposition of tariffs and barriers to inhibit foreign technology from penetrating the domestic market. Techno-nationalism grants the state "substantial control over the generation of knowledge and the standards by which design and manufacture are undertaken (Keller and Samuels, 2003: 7)."

Noting a rise in proposals for the implementation of US techno-nationalist policies in the 1980s in response to increased competition from Japan, Reich examines what he sees as the paradox of the techno-nationalist policy in the United States. He notes three difficulties in its application to US technology policy: the difficulty "confining new knowledge within national borders," the difficulty implementing techno-nationalist policy inside of a techno-globalist US framework, and the fact that the exclusion of foreign researchers and investment is not in the best interest of the nation. The first and second point illustrate what Reich refers to as the "absurdity" of imposing protectionist policies on universities and corporations that are built on the premise of openness and autonomy from state control. It is in the elucidation of the third point that Reich begins to make the central argument of the piece, and the argument that informs this dissertation. He argues that the US should be concerned with the ability of its workforce to learn and master advanced techniques that will provide the critical skills needed to transform breakthrough discoveries into commercial products faster than our competitors. Exposure to emerging technologies and innovation, regardless of national origin, is critical for developing a globally competitive workforce. It is this ability to exploit the competitive advantage of a highly skilled and educated workforce that Reich defines as the basis for any nation's technological prowess and the key to military security and commercial competitiveness.

Reich's earlier comments dovetail with the sentiments expressed in Erich Bloch's article in *Science*. Bloch writes that, "Success in the global market means creating and applying new knowledge – which is to say new technology – faster than one's competitors. This is the fundamental law in this competitive world" (Bloch 1986, 595). It is not surprising that the first issue addressed in Bloch's article under the heading "The Health of the Science and Engineering Base" is *education* and contains the warning that "as the world becomes more and more technologically oriented, no country will be able to keep up without an adequate number of technically trained people (Bloch, 1986: 596)." Bloch proposes "a major shift of resources toward the nation's universities" and advocates policies that seek to strengthen the "synergy between the academic, industrial, and federal pillars of the nation's technology sector" (Bloch 1986, 598). He stresses the importance of creating and supporting multidisciplinary research centers housed at US universities that would draw on government funding and industry participation and focus on training students through hands-on involvement in cutting edge research. These students in turn will become the next generation of technical professionals and educators, contributing to the expansion of the skilled workforce through participation and teaching. Bloch also highlights the advantages that the host institution can expect through participation in a government-academy-industry alliance, namely access to funding, professional expertise, and commercial opportunity.

The NSF approach addresses what Kaounides (1999) describes as the three major multidisciplinary science-based revolutions underway at the turn of the millennium: material science and engineering, biosciences and biotechnology, and in information technology and content convergence. Indeed, these three revolutions are the foundation upon which the current NBIC convergence initiative – that is the addition and application of nanoscience to these three revolutions – is based. At this moment, however, a NBIC convergence is not a forgone conclusion, but rather a potential revolution on the horizon. In order to achieve the long range goals of NBIC convergence there are a number of actions that must take place at various spots in the government-industry-academic R&D nexus, or what can be described as a national system of innovation (NSI). At this initial stage of NBIC convergence national government plays an important role as both a catalyst and support mechanism for innovation through direct support for R&D and policy development. In an era of increasing globalization, Kaounides reserves an important role for national government in supporting "multidisciplinary basic research in local centers of excellence, in education and training programs, in the creation of world-class national S&T infrastructure… and in the diffusion and application of new research information and knowledge to domestic and local networks of industries, including services" (Kaounides 1999, 55). This description of government's role in fostering revolutionary R&D could easily have originated in any NSF description of their central mission, focusing on multidisciplinary basic research, education, infrastructure, and industry cooperation.

The techno-globalist position is not without its detractors. Tonelson (1995) warns against techno-globalist policy by writing that "as long as major asymmetries exist and as long as Americans care about the results of their interactions with other systems, activist government policies will be needed from time to time to ensure that US businesses and workers can compete effectively." This quote not only highlights the differences between the techno-globalist and techno-nationalist perspectives but points toward the fundamental tension in protecting national interest in a world filled with asymmetries, unpredictability, and opportunity. Yamada (2002) reconciles these tensions by claiming that the world is in fact glocalizing, or simultaneously globalizing and localizing. The technology sector is subject to these contradictory forces as transnational technology concerns operate across national systems of innovation and encounter techno-nationalist policies. Yamada proposes that national governments facing glocalization turn toward neo-techno-nationalist policies, a hybrid of techno-nationalism and techno-globalism that seeks to leverage the advantages of globalization to enrich the national system of innovation. This means carefully attracting the best foreign talent and direct investment in an attempt to gain competitive advantage, while protecting the native workforce and national system of innovation. During an era of techno-glocalization, when "many damn things" occur simultaneously, Rosenau's (1997) model of the complex, adaptive system responsive to multiple feedback loops and both internal and external stimuli is most applicable to the generation of national S&T policy.

Increasingly, government agencies must balance the economic and security needs of the nation with the pressures and opportunities of a globalized economy, globalized science workforce, and globalized risks and contingencies. Interaction between government, industry, academy, and workforce in national networks will certainly continue to play an important role in any large-scale R&D endeavor and effect the performance of the actors in these networks. The primary function of government in these networks is to provide financial support, underwrite state-of-the-art infrastructure, and educate the science and engineering workforce. A superior S&E workforce creates and sustains scientific innovation and enhances national competitiveness as it helps attract “inflows of capital, technology, and scientific expertise (Kaounides 1999, 73).” However, trans-national corporations that operate in multiple national systems of innovation and benefit from cross-border economic, human, and information flows are playing an increasingly central role in technology innovation. National governments are therefore faced with the challenge of balancing the contradictory impulses of fostering a competitive national system of innovation in which trans-national corporations play a central role, and the fear that the cross-border flows integral to the success of these corporations will simultaneously undermine national S&T policy objectives and strengthen the hand of international competitors by distributing local knowledge and competencies across national borders.

The Role of the NSF

The National Science Foundation's influence on the course of scientific discovery in the United States is heavily tied to its role as a major funding source for research and development. The National Science Foundation Authorization Act of December 2002 (Public Law 107-368) establishes congressional appropriations to the Foundation for Fiscal Years 2003-2007 and demonstrates congressional confidence in the NSF's role as a principle stakeholder in the generation of US science policy. For FY 2003 the NSF was appropriated over 5.5 billion dollars, the vast majority of which is earmarked for direct investment in science and engineering research, development, facilities and education. Funding levels for FY 2004-2007 increased annually, reaching 6.4, 7.4, 8.5, and 9.8 billion dollars respectively (Public Law 107-368, Sect. 5). While the NSF itself does not directly carry out research (except polar research which is not dealt with in this chapter), it does invest in "the best new ideas generated by scientists and engineers working at the forefront of discovery" (NSF 2003, 23), who submit grant proposals to the Foundation for competitive review. The funding of outside researchers rather than establishing in-house research and development capabilities is a strategic decision on the part of the NSF to ensure a diversity of scientific discovery. The funding of outside research also enables the Foundation to more directly affect a broad spectrum of science researchers and institutions, which in turn helps sustain the national scope of the US science policy.

Central to the NSF's mission to support basic research is the premise that basic research is a fundamental component of national prosperity and well-being. This is highlighted in a 1984 NSF internal memo explaining why basic research support, especially at universities, is in the national interest and should be funded by the government. The memo states that:

> • Basic research is the foundation of technological development – for defense and the economy.
>
> • The benefits of basic research are so long-term and diffuse that the private sector will not adequately support it in the broad national interest.
>
> • Science leadership leads to national prestige.
>
> • Universities are the major source of new ideas through basic research across all disciplines, and through basic research, universities are the source of future scientific and engineering manpower. (NSF 1984)

This four-point schema highlights the basic operating assumptions of the NSF and is important for understanding it fundamental approach to participation in and management of long-term visionary projects. Its approach envisions basic research as central to technological development that enhances national defense and economic vitality, and enhances international prestige through science leadership. The American university system is central for this environment as it incubates innovation and strengthens the competitiveness of the science and engineering workforce. The NSF's funding commitments to science and research at major academies provides the Foundation with an enormous amount of influence on determining the course of scientific discovery and production in the United States, as well as an incredible ability to mold the national agenda for science education and training.

In a March 1987 report addressing to 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 1987, 4).

That fact that an internal NSF report uses both military and economic imagery to describe its role and mission is extremely interesting, as at the scientific R&D in the 1980s was driven by two major influences; military competition with the Soviet Union and the global trade threat posed by the rise of East Asian economies, most notably at that time the threat of Japan.

The PRA report utilizes several interesting examples to demonstrate that NSF investment in basic research had "resulted in value added to the Nation's economy in excess of the money invested" including semiconductors, fiber optics, machine vision, and recombinant DNA (PRA 1987, 5-6). In these examples we can see not only several sectors of the budding information biotechnology revolutions of the 1980s but also components of NBIC convergence. The PRA Report does not that claim the success of these sectors was solely a result of NSF support, and acknowledges that funding from various federal, academic, and industrial sources also played an instrumental role. However, the choice of these sectors to illustrate the value of the NSF to the economic well-being of the nation, demonstrates an understanding at the Foundation in the late 1980s of the importance of the commercialization of technologies to the outside perception of the NSF mission. Furthermore, these four technologies represent two of massive economic successes of the 1990s, computer and communications networks and bio and genetic technologies. The first three sectors listed are all information and communication technologies, with semiconductors holding a special place in the history of U.S. computing research, development, and commercialization and fiber optics being responsible for massive bandwidth and speed increases in communications networks.

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 2003, 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.

In order to achieve success in promoting the well-being of the United States through science and engineering, the NSF has codified the three distinct strategic goals mentioned above into operational principles: People, Ideas, and Tools. Mirroring the tripartite emphasis of the vision statement, the NSF aims to create "a world-class science and engineering workforce; new knowledge across the frontiers of science and engineering; and the tools to get the job done efficiently and effectively (NSF 2003, 9)." At the organizational level, each of these categories should be treated as distinct areas of NSF capital, as well as intellectual, investment. To complement this vision a fourth category, Organizational Achievement, has been added to ensure the smooth management of the other three by the NSF apparatus. This division is consistent with the NSF's commitment to long term strategic development of science and engineering by simultaneously investing in research, researchers, and the research apparatus, which is specifically designed to maximize the return on the initial investment by producing the next wave of breakthrough technology that will positively impact the national and global economy, as well as establish the United States at the forefront of technological change, and the preeminence of the US-based scientific workforce for years to come.

The "National Science Foundation Strategic Plan FY 2003-2008" identifies five major areas that hold great potential for "accelerating S&E [science and engineering] progress, advancing the frontiers of knowledge, and addressing national interests (NSF 2003, 23)." The NSF currently recognizes Biocomplexity in the Environment, Human and Social Dynamics, Information Technology Research, Mathematical Sciences, Nanoscale Science and Engineering, and Workforce for the 21st Century as its priority areas, which receive intense and sustained funding support form the NSF. Foundation support for priority areas is meant to act as a catalyst for accelerated change and discovery in those areas in order to recognize favorable outcomes that establish US based science and engineering professionals the leaders of technological change, provide for sustained growth and research, and are beneficial to US national security and economic interests.

The NSF, however, does not act alone in this capacity, but is rather part of a complex network of government agencies, universities, private industry, and the military that help determine and fund scientific and engineering research and development of strategic importance to the United States. Nevertheless, the NSF is a critical node in this network and is an important stakeholder in many interagency science initiatives. The NSF has seen its influence expand during the 1990s and the early years of the new millennium due in no small part to its brief yet highly successful stewardship of the Internet from ARPANET through NSFNET to the commercially available global communications medium that we recognize today. The United States Government, eager to replicate the tremendous technological and economic success of the Internet, is looking forward to the next paradigm-shifting scientific/technological innovation as a strategic investment in the future. Under the auspices of the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB), several interagency science and technology initiatives have been identified as potential areas for radical discovery and development including the National Nanotechnology Initiative (NNI), in which the NSF is a key player.

Nanotechnology is currently enjoying great favor as *the* revolutionary technology *sine qua non*, and has enjoyed a massive funding boom since the turn of the century. OTSP has recently issued a press release that highlights an almost 50 percent increase in funding over NNI's 2001 budget to a little under one billion dollars during FY 2005 as proposed in President Bush's 2005 Budget (OSTP 2005). With this increase in funds secured, the NNI identified an ambitious set of eleven priority areas for funding during FY 2006:

> (1) advance the knowledge frontiers of nanoscale phenomena and processes to an extend that systematic control over matter at the nanoscale could be achieved; (2) research to enable design of hierarchically structured materials and efficient nanomanufacturing from the molecular scale; (3) increased research focus on active nanostructures and complex nanosystems; (4) nano-biosystems and medicine; (5) silicon nanoelectronics and beyond; (6) development of instrumentation, metrology and standards; (7) environmental, health and safety issues, including development of instrumentation for environmental and toxicity studies; (8) the education and training of the new generation or workers for the future industries; (9) addressing ethical and other social issues raised by the development of nanotechnology; (10) establish and operate major scientific user facilities with advanced instrumentation; and (11) partnerships to enhance industrial participation in the nanotechnology revolution (Roco 2006).

These eleven points offer an excellent overview of the types of initiatives that the NNI consortium is considering, however it also masks much of the specific ongoing and planned nanotechnology initiatives through its general language.

The generality of this language is telling; nanotechnology is broadly conceived of as the next key to unleashing the 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 science and technology agencies, Congress and the military with very little public debate. Nanotechnology research, development, and education are being positioned as the cornerstones of a governmental campaign to propel US science beyond the next scientific frontier, as well as solidify US technological and economic dominance over the burgeoning field. The National Nanotechnology Initiative, along with other federally funded and mandated nanotechnology programs require intense public and academic scrutiny in order to achieve some level of transparency and accountability as researchers move forward toward "the nanotechnology revolution."

Chapter Three: Frederick Jackson Turner and the Frontier Thesis

Presented at the 1893 annual meeting of the American Historical Association, Fredrick Jackson Turner's frontier thesis, "The Significance of the Frontier in American History," attributed the uniqueness of US national character to the peculiar conditions of continental expansion of the United States. He argued, "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."[7] For Turner, the frontier is the "crucible" in which a distinctly American identity is forged. The pioneer experience, in what Turner describes as "free land," profoundly shaped the national character by exposing recent arrivals from the East and immigrants from Europe to harsh environmental conditions to which they were forced to adapt. The pioneer, trapper, miner and small farmer traded the stability of life in the settled areas of the East for opportunities in frontier climates, but in return were forced to adjust to the primitive conditions of the West. Turner believed, "This perennial rebirth, this fluidity of American life, this expansion westward with its new opportunities, its continuous touch with the simplicity of primitive society, furnish the forces dominating American character." The environmental and social conditions on the frontier transformed the pioneer as the

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[7] All quotes from "The Significance of the Frontier in American History" are drawn from the University of Virginia's collection of Turner's writings found at http://xroads.virginia.edu/~Hyper/TURNER/.

pioneer simultaneously transformed the frontier through settlement.

For Turner, the frontier is the crucial element that enabled the generation of a new and distinctly American culture out of the disparate European people transplanted to North America. He describes the frontier overwhelming the pioneer and settler, who survived the harsh conditions by adapting the skills and tools of Native Americans. Slowly the transplant began to transform the frontier through settlement and “improvements” to the land and what emerged, according to Turner, is neither a recreation of European society nor a facsimile of Native American culture, but rather something distinctly American. Coleman (1966, 22) writes,

> Turner's frontier dissolved older forms of society and generated from their ruins new institutions more appropriate to those liberty-loving individuals called Americans. The American, ample testimony confirmed, was a 'new man.' He had conquered a land at once beautiful and wild and rich beyond compare. His temperament was strong and his nature inquisitive; he was practical and uncommonly energetic; fierce devotion to the defense of liberty and to the cause of democracy was essential to his character.

For Turner, the frontier experience is utterly transformative, and more than a century later his thesis still plays an influential role in the social and political self-conception of the United States and its citizens.

Turner delivered the crux of his thesis in the first paragraph:

> Up to our own day 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.

Each successive advance into the "free lands" of the Great West defines the society seeking to inhabit the frontier; acting as the catalyst for the creation of a unique American society and unique American institutions and practices.

> Behind institutions, behind constitutional forms and modifications, lie the vital forces that call these organs into life and shape them to meet changing conditions. The peculiarity of American institutions is, the fact that they have been compelled to adapt themselves to the changes of an expanding people – to the changes involved in crossing a continent, in winning a wilderness, and in developing at each area of this progress out of the primitive economic and political conditions of the frontier into the

complexity of city life.

The transformative force acting upon American society was westward expansion and the demands for adaptation that westward expansion placed upon the institutions and practices that accompany settlement into the frontier. He differentiated the American frontier from European frontiers which, in his comparison, were merely boundary lines drawn between heavily populated areas. The American Frontier is "the outer edge of the wave – the meeting point between savagery and civilization." Turner saw that the transformative power of the Great Western frontier is its seeming emptiness and lack of civilization. It is a great unknown that acts upon the edge of the wave as it begins to break upon the "free lands."

It is startling for a contemporary reader of Turner's essay to see the West described as "free land," since it elides the fact that much of the frontier was instead populated by Native Americans. The idea that previously inhabited spaces, whether physical, theoretical, political, scientific, virtual, or metaphorical, are "free" or open to American exploration and expansion has long history in the political thought of the United States that Turner contributed to with his frontier thesis. He acknowledged the presence of the indigenous population of the continent, but only through the lens of the settler moving westward. The Native American population is something to be encountered; it is treated almost as an environmental factor of the frontier. Native American civilization constituted, along with nature, the "savagery" Turner described the wave of civilization washing over. His attitude toward the presence of the Native American population is instructive. Turner does not deal with the presence of Native American civilization in and beyond the frontier with complete indifference. His views are rather more complicated. Turner's settler is forced to adapt to external conditions of the frontier by adapting the methods of the Native American population:

> The wilderness masters the colonist. It finds him a European in dress, industries, tools, modes of travel, and thought. It takes him from the railroad car and puts him in the birch canoe. It strips off the garments of civilization and arrays him in the hunting shirt and the moccasin. It puts him in the log cabin of the Cherokee and Iroquois and runs an Indian palisade around him. Before long he has gone to planting Indian corn and plowing with a sharp stick, he shouts the war cry and takes the scalp in orthodox Indian fashion. In short, at the frontier the environment is at first too strong for the man. He must accept the conditions which it furnishes, or perish, and so he fits himself into the Indian clearings and follows the Indian trails.

The Native American population of North America, therefore, is the proto-infrastructure, or type of template, for methods of survival by the wave of frontier settlers moving into the West.

Despite the importance of this infrastructure for the settler, the frontier is still "savage" in Turner's opinion and needs to be civilized. For Turner, it is not until the settler begins to transform the frontier, including the preexisting aboriginal infrastructure, that something distinctly American, and civilized, emerges. With each successive expansion westward the process of the frontier repeats itself, becoming more uniquely American as settlers moved further into the continent and away from the influences of Europe and the Atlantic coast. Turner writes, "As successive terminal moraines result from successive glaciations, so each frontier leaves its traces behind it, and when it becomes a settled area the region still partakes of the frontier characteristics. Thus the advance of the frontier has meant a steady movement away from the influence of Europe, a steady growth of independence on American lines." The effects of the physical characteristics of the frontier are central to Turner's essay. Migration from the East into the frontier followed the course of the rivers that flowed into the Atlantic, Native American trails, and the valleys of the Appalachian Mountains.

As settlement crossed the mountains, into the Shenandoah Valley first and later into eastern Kentucky, Ohio, and Tennessee, the physical separation from the more heavily settled and continuous costal areas on the Atlantic seaboard contributed to the development of "peculiarly American tendencies." The isolation of settlements beyond the mountains necessitated the development of infrastructure, or "internal improvements" in Turner's words, that would connect the frontier with the trading centers of established East; binding the emerging society on the "outer edge of the wave" with the settled communities on the coast. Each successive wave of westward expansion across the continent ignited this process anew, driving the evolution of more "peculiarly American tendencies," but also creating the need for the construction of more infrastructural improvements to tie the new frontier settlements materially back to the nation. The development of infrastructural networks tying the frontier back to the settled areas of the East Coast is important as it allowed not only for the circulation of people, goods, and information westward throughout the nation, but also the political and social transformation of the whole of American society through frontier expansion.

Turner bluntly acknowledges in 1893 that the succession of frontiers across the continent had been won through the violence of the Indian Wars. While many individual pioneers, trappers, traders, and explorers ventured beyond the boundaries of the settled areas without the overt security of the federal government, the frontier was nevertheless made ready for mass settlement with the application of military force, the use of newly developed transportation technologies, and the development of infrastructural "improvements." Steamboats, railroads, and the Eire Canal enabled an influx of settlers into the frontier lands beyond the Appalachian Mountains, the Ohio River valley, the Mississippi river basin, the Great Lakes region, and the inner South.

However, as westward expansion further encroached on Native American territories, Turner admits that, "the management of these tribes became an object of political concern." It is too simplistic to say that these political concerns were merely about land, as trade with Native Americans created enormous wealth for companies and individuals, however the ultimate effect of these concerns was the eventual acquisition, by treaty or force, of the lands that now comprise the United States. It is important to recognize in Turner's essay that he clearly understood that the frontier, no matter how special it was in the development of a uniquely American society, was not simply a natural "gift" that sat empty waiting for penetration and settlement. Rather, Turner understands that the West truly was "won," with military force and technological development aiding the ingenuity and resourcefulness pioneer in settling the frontier.

Turner highlights the leapfrogging of the Great Plains and Rocky Mountains, especially the settlement of Utah and the California gold rush, as an impetus to the development of the Great Plains and unsettled interior. This is in part a story of technology and infrastructure. The settlement of remote areas necessitated the construction of infrastructure to connect the isolated frontier to the population centers and markets of the East. As railways and river ports were constructed to connect to the mining settlements in the Rockies, towns and cities sprung up along these transportation routes and encouraged farming and ranching in the Great Plains. For Turner, these developments echoed the necessity for and development of internal improvements several generations before. He writes, "At the Atlantic frontier one can study the germs of processes repeated at each successive frontier. We have the complex European life sharply precipitated by the wilderness into the simplicity of primitive conditions. The first frontier had to meet its Indian question, its question of the disposition of the public domain, of the means of intercourse with older settlements, of the extension of political organization, of religious and educational activity. And the settlement of these and similar questions for one frontier served as a guide for the next." Just as the first settlements in the Shenandoah Valley and eastern Ohio, Kentucky, and Tennessee precipitated the need for infrastructure to connect and bind these isolated pockets back to the East, so to did the new settlements of the remote Rockies and Pacific West. However, Turner correctly noted that with the extension of more advanced modes transportation, military protection, and government land surveys, the conditions of settlement had changed drastically from the earliest frontier forays using canoes and mules. The pace, scale, and scope of exploration and settlement had changed dramatically.

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. In this progress from savage conditions lie topics for the evolutionist.

It is interesting that 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 inanimate 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 social interconnection act as the life force of the nation, guiding its development and actions.

In addition to the "life" that settlement and commercial and social networks brought to the nation, Turner attributes the presence of Native Americans on the frontier as a profound unifying force. The concept that an external threat can unify a population is not novel, nor was it in 1893 when Turner first published his essay. However, if we follow Turner's logic that the progression of frontiers settled across the continent is the defining variable that contributes to American exceptionalism, and that the presence of Native Americans on the frontier greatly contributed to the unity of the new nation, then needs of the nation necessitated the annexation of Native American lands by force or treaty. Turner finds in early cooperative agreements between the colonies dealing with frontier security the germs of not only national cohesion but also American notions of martially enforced independence. He notes that "importance of the frontier, from that day to this, as a military training school, keeping alive the power of resistance to aggression, and developing the stalwart and rugged qualities of the frontiersman." Therefore, a natural frontier devoid of any human habitation cannot alone stimulate national cohesion and the development of uniquely American traits. The presence of an external threat, in this case Native Americans, was required to foster the growth of the United States.

Turner most bluntly discusses the role of the government in fostering frontier settlement in conjunction with the external threat of Native Americans. It is clear that the role of the government on the frontier in its most basic sense is to make the frontier both available and safe for settlement. Turner claimed that,

> The frontier army post, serving to protect the settlers from the Indians, has also acted as a wedge to open the Indian country, and has been a nucleus for settlement. In this connection mention should also be made of the government military and exploring expeditions in determining the lines of settlement. But all the more important expeditions were greatly indebted to the earliest pathmakers, the Indian guides, the traders and trappers, and the French voyageurs, who were inevitable parts of governmental expeditions from the days of Lewis and Clark.

Turner's discussion of the role of the government in surveying and pacifying the frontier is revealing, as it acknowledges a debt to Native Americans and French voyagers, entities that stand squarely outside of the narrative of Anglo-American settlement of the nation. Government expeditions to survey and determine "lines of settlement" on the frontier were heavily dependent upon these others, yet the government also established military outposts along the frontier to protect settlements from Native Americans. Nevertheless, Turner's essay highlights three significant functions of the government at work on the frontier: the acquisition of land (Louisiana Purchase), the surveying of frontier lands (Lewis and Clark, US Geological Survey), and the pacification of the frontier (Indian Wars, garrisons). The government's role on the western frontier was a messy enterprise with no clear logical progression to match

Turner's westward march. The federal government was at times proactive, and at times merely responsive on the frontier.

The frontier was also the catalyst for "the legislation which most developed the powers of the national government, and played the largest part in its activity." According to Turner, the political conditions precipitated by settlement of the frontier actively contributed to the development of the political cohesion. He attributes the "growth of nationalism and the evolution of American political institutions" to the demands of an ever-expanding western frontier. Nationalism in this context represents the growth of a sense of national interdependence rather than the political sentiment of national superiority that would come to dominate the definition of the term in the 20th century. The material needs of the frontier settlers and the ability of the commercial centers of the East to meet these needs drove the development of internal infrastructural improvements, which in turn spurred political debates about the merits of these projects that addressed constitutional questions vital to the political future of the nation. Turner attributes the rise a looser interpretation of the constitution (rather than a strict constructionist interpretation) to the westward advance of settlement, as Congress and the courts were forced to deal with conditions not foreseen by the original Constitution. Simply put, Turner saw in the growth of western settlement the growth of the modern federal government. He writes,

> Administratively the frontier called out some of the highest and most vitalizing activities of the general government. The purchase of Louisiana was perhaps the constitutional turning point in the history of the Republic, inasmuch as it afforded both a new area for national legislation and the occasion of the downfall of the policy of strict construction. But the purchase of Louisiana was called out by frontier needs and demands. As frontier States accrued to the Union the national power grew.

The admission of new states into the Union, not only expanded the territorial possessions of the United States, but also shifted the balance of power in Congress due to the constitutional provision that regardless of population, which governed the number of representatives each state could send to Congress, each new admission to the Union was represented by two Senators. Westward expansion slowly diluted the political primacy of the coast and shifted political power ever westward.

Turner also attributes the peculiar brand of American political individualism, an aversion to direct political control, to frontier conditions. He writes that, "Complex society is precipitated by the wilderness into a kind of primitive organization based on the family. The tendency is anti-social." Often described as rugged individualism, this form of frontier political belief manifested itself in a strong belief in liberty and democracy. Turner highlights the fact that frontier politicians in Virginia and New York propelled more liberal suffrage laws in those states and that the frontier states that joined the Union during the first quarter of the 19th century already had more democratic suffrage provisions than their costal counterparts. However, the frontier adherence to liberty and individualism led, in Turner's estimation, to the rise of notable dangers. He writes that,

> Individualism in America has allowed a laxity in regard to governmental affairs which has rendered possible the spoils system and all the manifest evils that follow from the lack of a highly developed civic spirit. In this connection may be noted also the influence of frontier conditions in permitting lax business honor, inflated paper currency and wild-cat banking.

Both the positive and negative aspects of Turner's frontier political ideology are alive and well in the political climate of the United States in the early 21st century, which echoes at times conflicting impulses of institutional democracy and individual liberty.

Despite uneven government policy toward the frontier, and attempts by politicians from the East to curb frontier expansion, the push westward continued unabated as farmers from the East and recent immigrants were drawn to the frontier often by the promise of cheap land, prospecting, commerce, or simply the chance to “start over.” For Turner the movement of immigrants of various nationalities to the frontier is the critical factor in creating a new composite nationality forged in the crucible of frontier conditions. Whereas the coasts were mainly settled by English colonists that maintained a sense of heritage based upon older European distinctions, the mixture of Scotch-Irish, German, Dutch, Scandinavian, and freed indentured servants in the interior blended into a uniquely American nationality. The new composite nationality was born out of the conditions of the frontier and the common experience of life on the edge of settlement, not, as Turner remarks, out of shared ancestry, language, or customs. Therefore, in Turner's essay, the American is strictly a product of the frontier experience. The frontier transforms as it is transformed. The idea that American identity is intrinsically tied to the exploration and settlement of frontiers is powerful and has influenced generations of politician and scholars subsequent to Turner's 1893 presentation to the AHA. The question that arises from Turner's essay is what happens when the United States runs out of frontiers to settle. If the US is propelled by the almost irresistible force of continental expansionism, it stands to reason that as settlement pushes against the natural boundary of the Pacific Ocean and the political boundaries of Canada and Mexico something would either have to replace the Great Western frontier, or the United States would have to adjust to existence without open frontiers.

The Science of Turner's Frontier

In his 1966 essay, "Science and Symbol in the Turner Frontier Hypothesis," William Coleman turns his attention to the uneven definition of frontier found in Turner's writings, and finds two overlapping possibilities. The first is the frontier as open space, or land not yet occupied by (white) settlers and therefore considered "free land," or land ripe for settlement. Coleman also provides an interpretation of Turner's frontier as a process of disruptive change and evolution. He writes (1966, 23) that "As the frontier passed over an area the usual sequence of stages of social transformation was set in progress, and a new and thoroughly American component of society emerged." The frontier was the transformative social, cultural, economic, and political process of generating a new and distinctly American society in "a virgin land." Coleman describes the idea of frontier as process as "universal and omnipotent." The Western frontier was in and of itself transformative, the experience of the frontier, for both those actively settling it and those back in the East, exerted a profound influence on the meaning of being American.

Coleman argues that elements of Turner's frontier thesis are drawn from contemporary scientific thought in the later 19th century (1966, 24). Turner's discussion of the frontier mirrored the themes and rhetoric of the emerging field of evolutionary human geography, which in turn utilized the metaphor of the social organism drawn from post-Darwinian environmental biology. How and why social organisms inhabit and evolve in new environments, subjected to new stimuli, possibilities, and constraints, is at the crux of Turner's examination of the frontier. Coleman examines the scientific theories operating at the time that Turner was working on the frontier thesis and locates in the work of "germ theorist" historians a concept of social transformation that helps explain some of the underlying assumptions of Turner's work. Coleman reminds us that two of Turner's teachers, Herbert Baxter Adams at John Hopkins and William Francis Allen at the University of Wisconsin, were both influenced to varying degrees by the germ theory of history (1966, 26). The theory held that social organisms were not a product of "spontaneous generation," rather they required a "social germ" to provide a "vital connection among all its temporal and spatial manifestations" (25). Thereby, American society was not wholly generated on the North American continent, but rather resulted from the germination of a seed, the social germ, transplanted from Europe into a new environment. However, the transplanted social germ was not merely a duplicate copy of its European antecedents; the conditions of the new environment profoundly shaped its evolution and subsequent replication on the expanding frontier. In "The Significance of the Frontier in American History" Turner writes that "Our early history is the study of European germs developing in an American environment," and specifically mentions social germs several times throughout the essay.

According to Coleman, Turner adapted the social germ theory of history to focus on the malleability and evolution of the institutions and customs of the social organism in the conditions of a new environment (1966, 27). Turner's social organism simultaneously transformed and was transformed by its environment. The social germ theory of history could help explain early history of European settlement in North America, however, it could not adequately account for the uniquely American society that Turner wished to examine. American society was not simply a clone of the European social germ from which it originated, but something independent, organic, and generated on American soil in interaction with the frontier environment. Coleman maintains that Turner was deeply influenced at both Wisconsin and Johns Hopkins by the application of physical geography to the study of human history (1966, 28-29). He writes that,

> The advantage offered the historian by the science of physiography was to permit more exact expression of the environmental factors that influenced the social organism. The metaphor of the organism suggested in turn the intrinsic plasticity of society when subjected to novel conditions (1966, 29).

Using physical geography in conjunction with the metaphor of the social organism led Turner and other historians of his era to adapt and apply concepts from Darwinian biology as various frames or approaches for the study of history. These adaptations and applications allowed Turner to foreground the influence of environment on the evolution of the adaptive social organism.

Another influential figure in the generation of Turner's frontier thesis was Richard T. Ely, a professor at both Johns Hopkins and the University of Wisconsin, who was a proponent of the descent doctrine, which held that society evolved in a sequence of stages, with each stage being defined by the social organism's interaction with the surrounding environment (Coleman 1966, 30). These stages are echoed in Turner's frontier thesis. With the exploration and settling of successive western frontiers, each newly settled region contributed to the evolution of a distinctly American society through the transformation of formerly "free land" into a civilized segment of the nation and the transformation of settlers from a loose amalgamation of Eastern transplants and European immigrants into a new composite nationality. Despite mixing scientific metaphors and, according to Coleman, apparently contradicting himself in the process, Turner essentially describes "the fundamental conception of nineteenth-century evolutionary theory: the interaction and consequent harmonious accommodation of organism and environment, in short, adaptation" (1966, 31-32). He describes Turner's concept of adaptation as owing a large debt to Lamarck, who asserted the unlimited transmutability of living things under the influence of environmental factors (1966, 32). Additionally, Lamarck also proposed that "sensate" beings, including human beings, began to develop a psychological desire or need to adjust to new environmental conditions. Despite the fact that that Lamarck's psychological component of adaptation eventually fell out of favor with environmental biologists, Coleman claims that it was never abandoned completely, and documents its popularity in the final quarter of the 19th century when Turner first presented his frontier thesis (1966, 33). The psychological element plays a large role in Turner's thoughts on the frontier, as he felt that the environmental conditions of the frontier produced a psychological desire in settlers to adapt to their new environment. The Great Western frontier was psychologically transformative for the settler, a factor that contributed to the evolution and development peculiarly American traits and a uniquely American society.

Of Turner's concept of the frontier process, Coleman writes that,

> Man and society patently are modified by environmental factors. On the miraculous frontier, man and society were separated from their past and forced to assume a new physical and spiritual appearance. Most importantly, human institutions were so disturbed by the shock of frontier conditions that the traditional forms of government collapsed (1966, 36).

For Turner, the American frontier promoted democratic tendencies in settlers due the need to adapt to environmental factors unlike anything encountered in Europe or on the Atlantic coast of North America, rather than simply serving as a catalyst for the slightly varied continuation of democratic germs transported across the Atlantic from

Europe. In other words, the democratic tendencies of Americans were not merely hereditary, but a product of the frontier environment. Coleman writes that, "The environment became a determinative factor. Americans were not born, but produced, produced in great part by their surroundings" (1966, 37). The environment was not the sole determinant; Turner acknowledges that some customs and practices did migrate westward with frontier settlers, and were retained by their descendants. Coleman highlights the seeming inconsistencies in Turner's essay as one of the reasons for its popularity (1966, 38). By blending "discordant themes," and being "alarmingly ambiguous," Turner managed to appeal to readers of varied opinions, who, by selectively reading the essay, saw in his frontier thesis a confirmation of their own views of American society. Nevertheless, the one point that Coleman argues that all readers could agree with is the assertion that

> [T]he frontier, however it might be defined as temporary place or territory, was universally a dominating process. If America had received germs of its society from Europe – and this Turner could not and did not wholly deny – still it had proved to be their superior. Its influence was exerted on the rugged lands of the frontier, at precisely the point where nature in its most potent guise and society in its least compact and most plastic phase came together and interacted one upon the other (1966, 38).

The enduring power of the frontier thesis, according to Coleman's reading of Turner, can be attributed to the relative ambiguity of the frontier as a concept that can be mapped upon the preconceived notions of American exceptionalism of its readers. It acts as an overarching metaphor for explaining the peculiarities of American institutions and customs through the prism of social history, political expansion, and distribution of geographic features across the North American continent.

Part of the appeal of Turner's thesis is the use of neo-Lamarckian psychological terms to describe the frontier as an abstract, as well as physical, concept. The frontier produced in the settler a psychological need to adapt, to evolve, and to break with the restraining habits of the past to develop the rugged democratic individualism that contributed dramatically to the unique nature of American politics. The frontier was, therefore, not only a physical place but also a state of mind. Furthermore, as Coleman explains, Turner's essay positions the Western frontier as a symbol,

> a poetic realm at once primal, unspoiled, and generative, and one more inclined to determine our illusions of what we are as individuals and as a nation than to influence what may be the real form and behavior of our society (1966, 44).

The enduring influence of Turner's thesis can be attributed in large part to the fact that the frontier acts as a powerful metaphor for an idealized self-conception of the United States and its citizens. Because the physical frontiers of the United States are finite, a matter recognized by Turner in 1893, his thesis provided readers with an evocative and nostalgic metaphor for American society viewed through the prism of an idealized past. However, with the disappearance of "free lands," rapid urbanization, and industrialization, the frontier was rapidly disappearing by the late 19th century. It is important to remember that Turner, as a historian, was concerned with explaining America's past, rather than its present or future. His thesis was based upon an era in US history that, at the time of writing, was fading into memory. Although the frontier thesis not intended as a framework through which to view the future problems of a rapidly industrializing American society, Turner's essay found great resonance with contemporary audiences. It not only provided a tool for explaining the nation's past and a nostalgic metaphor for understanding the American "character," but it also served as a comforting reminder of the resilience and adaptability of the social organism when faced with dramatic changes in environmental conditions.

Frontier Expansionism and Foreign Policy

The influence of Turner's frontier thesis on US foreign policy is examined in detail in William Appleman Williams 1955 article "The Frontier Thesis and American Foreign Policy." Williams argues that US politicians and statesmen used Turner's frontier thesis, in combination with historian Brooks Adams' assertion that American democracy could only flourish under an expansionist foreign policy, to justify imperial expansion in the late 19th and early 20th century (1955, 380). Both Turner and Brooks produced their theses in the final decade of the 19th century, an era of social crisis in the United States following explosive industrial and economic growth. Williams argues that the "coincidence and convergence" of economic revolutions in the steam, steel, communications, and agriculture sectors in the final third of the century prompted crisis conditions in the United States. He writes that,

> Bewildered by its quadruple triumph, the United States momentarily panicked. Then, reassured by illusions of ideological purity and international omnipotence, it embarked upon a second industrial revolution. But in that frightening pause between culmination and renewal Turner and Adams looked out upon a harsh and disturbing reality (1955, 381).

The disturbing reality that both men saw was the disappearance of the frontier that had inspired and molded the democratic impulses of the citizenry.

The economic consolidation that occurred during this rapid industrialization upset their notion of the pioneer and frontier settler moving westward to pursue independent opportunity and ownership, replacing the rugged individualism of the frontier with the collective experiences of the urban laboring class. Without expansion the nation faced the twin peril of monopoly capitalism and class revolution. For Turner, the individualism of the frontier had, as discussed above, effectively promoted the democratic principles that were exceptional to the United States. In order for American democracy to thrive it needed new frontiers. Therefore, according to Williams, "Turner had explained the past and implied a program for the present. Materialistic individualism and democratic idealism could be married and maintained by a foreign policy of expansion" (1955, 383). Expansion, therefore, was in the national interest, and Turner's thesis was critical in the popularization of economic imperialism as a policy goal (1955, 384). Both Turner and Adams were influential in policy circles in Washington, with Turner influencing Woodrow Wilson directly and Teddy Roosevelt indirectly, and Adams having the ear of Roosevelt and Wilson rival Henry Cabot Lodge, who chaired the Senate Foreign Relations Committee. Williams describes Wilson's policies as "classic Turnerism," highlighting the military interventions in Latin America and in revolutionary Russia, international free trade policies, entering the First World War against Germany, the Fourteen Points, and the League of Nations (1955, 388).

Williams argues that Turner was also especially influential on the early policies of Franklin Delano Roosevelt and the tenets of his thesis help explain the policies pursued by the US in the Second World War and the Cold War (1955, 388). Turner's thesis informed the New Deal emphasis on the expansion of economic markets abroad for the consumption of surplus American agricultural output. Williams writes that, "An expanding economy became the dogma of an industrial America" (1955, 390). The influence of Turner can also be seen in Roosevelt's "Good Neighbor Policy," which toned down the nation's military interventionist policies in Latin America in favor of lower tariffs and enhanced trade policies, and well as efforts to expand trade in Asia, with particular emphasis on China. Williams also highlights the Atlantic Charter signed by Roosevelt and British Prime Minister Churchill at the Atlantic Conference in 1941 that established US-Anglo plans for the post-World War II era that heavily promoted the principles of globalized free trade and economic expansion at the expense of territorial expansion (1955, 390). It was hoped that Russia would agree to the principles of the Atlantic Charter following the defeat of Germany, however the contrasting ideological influences of Marx and Lenin on one side and Turner and Adams on the other provided a philosophical schism to the Cold War, with economic liberalism and communism battling for acceptance by satellite and client states in the political frontier. Williams points to the Truman Doctrine as a pure articulation of Turner thesis (1955, 392), writing that, "The security and well-being of the United States depended upon the successful execution of America's unique mission to defend and extend the frontier of democracy throughout the world." Despite the fact that the theses of Turner and Adams did not directly advocate endless economic growth, they were widely interpreted to fit the ideological needs of politicians. These politicians unevenly applied their theories to policy recommendations, and their core tenets were synthesized into the broad American policy consensus of the Cold War -- that economic expansionism and the liberalization of trade was a panacea for the nation (1955, 392).

Turner on Turner

17 years after proposing his frontier thesis in Chicago, Turner delivered another influential address to the American Historical Association in Indianapolis in December 1910 and published a year later, entitled "Social Forces in American History." This speech was delivered during Turner's tenure as the president of the AHA, and Turner in essence is speaking back to himself, revisiting the theme of the disappearing frontier and the profound changes underway in the first decade of the twentieth century. Turner claims that,

> These changes have been long in preparation and are, in part, the result of world-wide forces of reorganization incident to the age of steam production and large-scale industry, and, in part, the result of the closing of the period of the colonization of the West (1911, 217).

Rapid urbanization and industrialization had led, in his estimation, to "the birth of an new nation in America" (1911, 217). Turner addresses the fact that the by the start of the twentieth century the frontier that shaped and defined "pioneer democracy" had disappeared in the span of one generation with "the final rush of American energy upon the remaining wilderness" (1911, 217). As the frontier disappeared, so too did its Lamarckian impact upon the national psyche, luring settlers and immigrants into the crucible of the nation with the promise of opportunity of the "free lands" of the West.

In "Social Forces in American History," Turner is preoccupied with examining the question of what direction American history would take in the absence of empty natural frontiers. More specifically, he attempted to ascertain what clues did 18th and 19th century American history hold for 20th century American society. He addressed the urbanization and industrialization of the nation as byproducts of the infrastructural improvements, especially transportation projects, made necessary by westward expansion. The connection of the West back to the commercial and transportation centers of the East intensified both industrialization and urbanization:

> The tremendous energies thus liberated at this center of industrial power in the United States revolutionized methods of manufacture in general, and in many indirect ways profoundly influenced the life of the nation.

> Railroad statistics also exhibit unprecedented development, the formation of a new industrial society (1911, 219).

Using Pittsburgh as an example of this process, Turner highlighted the discovery of iron ore in the formerly frontier lands south of Lake Superior as the catalyst for the explosion of industrial steel production and urbanization in that city (1911; 219, 226). However, in the absence of western wilderness and the Lamarckian psychological draw of the "free lands," new frontiers needed to be found to satisfy American expansionism.

Turner identified American expansionism as the catalyst that propelled the United States from a "pioneer democracy" to an imperial world power, noting:

> Having colonized the Far West, having mastered its internal resources, the nation turned at the conclusion of the nineteenth and the beginning of the twentieth century to deal with the Far East to engage in the world-politics of the Pacific Ocean. Having continued its historic expansion into the lands of the old Spanish empire by the successful outcome of the recent war, the United States became the mistress of the Philippines at the same time that it came into possession of the Hawaiian Islands, and the controlling influence in the Gulf of Mexico. It provided early in the present decade for connecting its Atlantic and Pacific coasts by the

> Isthmian Canal, and became an imperial republic with dependencies and protectorates-- admittedly a new world-power, with a potential voice in the problems of Europe, Asia, and Africa (1911, 219-220).

In the first sentence of this passage Turner highlighted the importance of mastering frontier resources to the process of expansion. By linking the areas of resource extraction to the centers of processing and manufacturing, the hubs of transportation, and commercial metropolises through infrastructural improvements, the nation bound its various stages of development into an organic, capitalist whole. If the American psyche demanded new frontier lands to settle and the American economy demanded new markets to trade in, then American military might was the primary guarantor of both.

Looking back over American conquests of the past two decades Turner saw that,

> This extension of power, this undertaking of grave responsibilities in new fields, this entry into the sisterhood of world states, was no isolated event. It was, indeed, in some respects the logical outcome of the nation's march to the Pacific, the sequence to the era in which it was engaged in occupying the free lands and exploiting the resources of the West (1911, 220).

The emergence of the United States as an imperial power was therefore a natural sequence in the development of the nation that began in earnest with the arrival of English settlers in Virginia in 1607 and the establishment of the Jamestown colony. Again, Turner emphasized the exploitation of resources as a primary motivating factor in American westward expansion. The need to locate and exploit resources propelled the United States, like the tip of Turner's metaphorical wave from 1893, to crash upon the remnants of the Spanish empire and the Pacific. Additionally, Turner reiterated his claim that American democracy was predicated upon the presence of abundant free lands to nurture the pioneer spirit of democracy (1911, 223-224). Therefore in the absence of an "empty" West, the nation needed to expand into new frontier areas, not merely to locate and extract resources, but to preserve the uniquely American brand of democracy.

Turner asserted that, in essence, American history since 1893 represented "efforts to find substitutes for that former safeguard of democracy, the disappearing free lands. They are the sequence to the extinction of the frontier (1911, 224)." American democracy is therefore intrinsically linked to the presence of frontiers. However, as the 19th gave way to the 20th century any new frontier lay beyond the continental boundaries of the nation and required the intervention of the federal government to pacify and occupy. Turner argued that "The present finds itself engaged in the task of readjusting its old ideals to new conditions and is turning increasingly to government to preserve its traditional democracy" (1911, 224). The reliance on the government to make new lands "free" was at once both necessary and at odds with pioneer liberty and the mistrust of centralized authority. In "Social Forces in American History," Turner dealt with the central problem present in his earlier frontier thesis: that the United States, its people, culture, and institutions were undergoing a transformation from pioneer democracy to a mature capitalist empire. The final consumption of the continental frontier shifted the emphasis of US government policy from pacifying the Great West for pioneer settlement, to pacifying the Pacific Rim and remnants of the Spanish Empire for commercial exploitation. Commercial exploitation favored the large capitalists, corporations, and industries rather than the pioneer individual so lauded by Turner in his earlier essay.

These changes prompted Turner to write that, "American history is chiefly concerned with social forces, shaping and reshaping under the conditions of a nation changing as it adjusts to its environment. And this environment progressively reveals new aspects of itself, exerts new influences, and calls out new social organs and functions" (1911, 225). In 1910, Turner was responding to the reshaping of American society through urbanization, industrialization, and agglomeration of capital, and posited that these changes had forced the nation to look for substitutes for the frontier, "that former safeguard of democracy." Turner's prescription is clear – in order to maintain the democratic evolution of the republic, new frontiers must be located and exploited. He does not, however, specify which frontiers should be sought out by the federal government, only obliquely referencing the imperial aspirations of the United States in the Pacific and crumbling Spanish Empire without commenting on the validity of these enterprises. Nevertheless, the influence of Turner's argument that frontiers were essential to the perpetuation of American democracy on major players in US foreign policy circles in the 20th is undeniable. Seventeen years later, Turner returned to the AHA to both recast and reconfirm his central thesis that the frontier is an essential stimulus shaping and defining American society.

In his 1910 essay Turner hinted that without frontiers to push the boundaries, both figuratively and literally, of society, a distinctly un-American consolidation of capital and power would occur to an even greater degree in future years than it already had by 1910. He used the trust busting of Teddy Roosevelt to round out his argument about the role of the federal government in frontier policy:

> [W]e have the voice of the insurgent West, recently given utterance in the New Nationalism of ex-President Roosevelt, demanding increase of federal authority to curb the special interests, the powerful industrial organizations, and the monopolies, for the sake of the conservation of our natural resources and the preservation of American democracy (1911,

> 223).

The past settlement of the West had created the economic conditions for the consolidation of capital in the hands of the few, and only the preservation of what was left of native frontier and the acquisition of new frontiers by the federal government could dilute the anti-democratic nature of this development. Turner therefore presented the frontier as a circular problem: the frontier creates wealth and promotes democracy in the nation as a whole, the absence of new frontiers leads to the undemocratic consolidation of capital, new frontiers are needed to remedy the situation, which in turn perpetuates both the positive and negative effects of the frontier, making the continual acquisition of "free lands" a necessity.

Finally, Turner diverted his attention to the examination of the social forces that shape American life and urged his fellow historians to learn from the example of the scientist. Interestingly, he used language reminiscent of his discussion of frontier pioneers to discuss the scientific enterprise:

> He has enriched knowledge especially in recent years by attacking the no-man's lands left unexplored by the too sharp delimitation of spheres of activity. These new conquests have been especially achieved by the combination of old sciences. Physical chemistry, electro-chemistry, geo-

> physics, astro-physics, and a variety of other scientific unions have led to audacious hypotheses, veritable flashes of vision, which open new regions of activity for a generation of investigators. Moreover they have promoted such investigations by furnishing new instruments of research (1911, 231).

Turner framed the scientist as a pioneer: entering and exploiting a no-man's land, combining the tools and practices of older disciplines like the settlers of the American West once melded various European customs and Native American practices into a peculiarly American culture, the production of hybrid disciplines and "audacious hypotheses." Turner's pioneer scientists not only wade into the "free lands" of science, but also, once there, open up these new hybrid regions of investigation to successive waves of new investigators.

Turner offered the geologist as an exemplar of the new hybrid scientist that historian should learn from (1911, 231). The geologist combined chemistry, physics, mathematics, botany, zoology, and paleontology in an attempt to describe the inorganic earth. The point of Turner's discussion here is to highlight the fact that geology as a field has accepted the fundamental complexity of geological inquiry. The physical properties of the earth have been affected by a highly interwoven series of factors, and therefore cannot be explained by a single theory or using the tools of a single scientific discipline. Turner believed the geologist "abandoned the single hypothesis for the multiple hypothesis. He creates a whole family of possible explanations of a given problem and thus avoids the warping influence of partiality for a simple theory" (1911, 231). Turner then immediately takes several sharp jabs at the specialist historians, notably the political and economic historians, warning other historians of the "warping influence" of disciplinary rigidity.

As a corrective to this warping influence, Turner holds up the geologist as a symbol of interdisciplinarity for the historian to adopt. Turner then warns of the dangers inherent for the "warped" historian fixed in a single point of view:

> Those who insist that history is simply the effort to tell the thing exactly as it was, to state the facts, are confronted with the difficulty that the fact which they would represent is not planted on the solid ground of fixed conditions, it is in the midst and is itself a part of the changing currents, the complex and interacting influences of the time, deriving its significance as a fact from its relations to the deeper-seated movements of the age, movements so gradual that often only the passing years can reveal the truth about the fact and its right to a place on the historian's page (1911, 231).

In this simple statement Turner charted a powerful and influential roadmap for rethinking the task of the historian and acknowledged that history is the study of what we today might call complex systems. His phrase “changing currents” suggests both the power and unpredictability of the ocean, which can either propel or punish the voyager, as well as the alternating current of electricity that changes direction and magnitude cyclically. The object of historical inquiry is therefore subjected to powerful external stimuli and the cyclical impulses of interacting forces that exert influence upon the object, while at the same affecting the currents in which the object swims and forces acting upon it. In other words, Turner is arguing, well before the concept was adopted from electrical engineering into an increasingly wider assortment of disciplines in the second half of the 20th century, that historical systems cannot be accurately examined unless one is aware of the effect of feedback on the area of historical inquiry.

Chapter Four: The Myth of Origin: ***Science – the Endless Frontier***

For(e)ward

In his 1945 report, *Science – the Endless Frontier*, Vannevar Bush enshrined both the boundless promise and historical gravity of Frederick Jackson Turner's 1893 "frontier thesis" directly in the title of his treatise. The blunt title let the author symbolically link the policy recommendations contained in the report with the beneficial political, social, and economic developments associated with the American frontier expounded upon by Turner. Additionally, the use of "frontier" tapped into the public perception of the frontier as a space of social and economic opportunity and reinvention. The term further evoked the historic bounty of plant, animal, and mineral resources present in the Western frontier and the fortunes made by those willing to venture out into the unknown. By describing science as an endless frontier, Bush claimed the scientific enterprise as a space of endless returns and a treasure chest of opportunity waiting to be opened.

Bush's description of science as a frontier is not without precedent, and echoes language used by others in the political and scientific communities to describe areas of undiscovered scientific knowledge. However, by entitling his report *Science – the Endless Frontier,* Bush pushed the metaphor of scientific frontiers beyond simple shorthand for undiscovered truths to enshrine science as the new American frontier. The frontier rhetoric of *Science – the Endless Frontier* is in part a direct response to President Roosevelt's November 17, 1944 letter to Bush, then serving as the Director of the Office of Scientific Research and Development, commissioning the report. Roosevelt wrote that,

> New frontiers of the mind are before us, and if they are pioneered with the same vision, boldness, and drive which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life.[8]

Roosevelt's conceptualized scientific frontiers as discrete areas of inquiry that can and should be exploited with the vigor of the war effort and as a means of achieving national prosperity. Roosevelt's invocation of the frontier and pioneer metaphors appear limited to the very pragmatic process of conducting cutting edge scientific research that may lead to economic and social benefit. The frontier and pioneer metaphors simply stand in as evocative terms for the process of conducting cutting edge scientific research. However, with the pen of Vannevar Bush, the frontier metaphor transformed from a simple rhetorical device into a fully developed metaphor for American exceptionalism.

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[8] All further quotes from *Science – the Endless Frontier* are taken from (http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm).

In the July 25, 1945 transmittal letter for *Science – the Endless Frontier* Bush responded directly to the section of Roosevelt's letter quoted above, transforming science from one of the "new frontiers of the mind" into the indispensable American frontier. Bush elevated science from a beneficial area of endeavor to an essential enterprise ensuring economic prosperity, social progress, and national security. Science becomes as end unto itself:

> The pioneer spirit is still vigorous within this nation. Science offers a largely unexplored hinterland for the pioneer who has the tools for his task. The rewards of such exploration both for the Nation and the individual are great. Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress.

Bush used the language of Turner's frontier thesis to transform science into an essential frontier for exploration, and cast the scientific community in the crucible of pioneers. The quote above also exemplifies Bush's of science as the ideal venue for the full expression of the "still vigorous" pioneer spirit of the American people, and therefore the successor to the physical frontier of the American West. Science is therefore the new American frontier and the indispensable key to national well-being and security. Bush recognized 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.

Despite Bush's acknowledgement that science must act as part of a team, and that it is but "one essential key" to national well-being, it is clear that in his mind science is the first among equals, and the field upon which all others depend for success. Bush, therefore, argued that the government's proper role regarding science is to open the "free" lands of the scientific frontier to exploration by providing infrastructural and material support to scientific pioneers. *Science – the Endless Frontier* is dedicated to the proposition that science is essential to national well-being, ensuring economic prosperity, social progress, and national security, and that these benefits can only be achieved through adequate government investment and the creation of a stand-alone national science agency to facilitate support and coordinate policy.

Bush pressed this point succinctly in the Executive Summary under the heading "A Program for Action" without mincing words:

> The Government should accept new responsibilities for promoting the flow of new scientific knowledge and the development of scientific talent in our youth. These responsibilities are the proper concern of the Government, for the vitally affect our health, our jobs, and our national security. It is in keeping with basic United States policy that the Government should foster the opening of new frontiers and this is the modern way to do it.

In the first sentence Bush used the word “flow” to describe the production of new scientific knowledge, which he linked relationally with the production of new scientific talent. Flow is a term from fluid mechanics that that describes the motion of a liquid. As a descriptor of a physical phenomenon, the use of flow in conjunction with the production of knowledge provides a vivid mental picture of the process of discovery on the scientific frontier. For Bush, scientific knowledge is a frontier resource, much like iron ore or timber, a preexisting reserve waiting for discovery. Since science is fundamentally concerned with unlocking the "truth" about the laws of nature, and nature preexists and operates independently of science, Bush emphasized support for the process of basic research, from which he believes advances in applied research and technological innovation inevitably flow. As research is conducted on the scientific frontier, new knowledge is exposed, creating the need for infrastructure to facilitate the flow of this knowledge from the periphery to the center and providing lifeblood of scientific-technical enterprise.

Pushing the flow metaphor further can ascribe other fluid properties to his concept of scientific knowledge as a resource. Like a liquid, knowledge is both substantial (liquids have both mass and volume), yet fundamentally amorphous in its natural state. By describing scientific knowledge using a metaphor derived from fluid mechanics, Bush established the fundamental knowledge of the laws of nature as a natural resource in itself – something immutable and pure – to be sought after and extracted. This view also then privileged a method resource management calling for an extensive, federally funded, infrastructure program to properly harness the innate, and natural, power of that knowledge. Bush therefore advocated the creation of reservoirs of scientific knowledge for the nation to draw upon as a resource to drive scientific progress. The metaphor of the reservoir is an important one that is constantly revisited throughout the second half of the 20th century in regard to scientific and technical knowledge, and is often used in conjunction with the National Science Foundation, an organization that owes a substantial debt to Vannevar Bush and *Science – the Endless Frontier* for its existence. However, the reservoir metaphor also carries with it an implied threat. If not properly managed and maintained the reservoir may diminish, leak, or overflow, threatening both its content and the possible destruction of downstream infrastructure through flooding. If the flow of new knowledge from the frontier precipitates the need for the establishment of infrastructural improvements to contain and harness this resource for later use, then the existence of these improvements necessitates the perpetual support of the government to maintain them, lest they fall into disrepair and become a liability rather than asset. The reservoir becomes a self-fulfilling proposition; once it is deemed necessary for national well-being, it must be built, and once it is built it must be maintained so that nation well-being is not imperiled.

The second sentence of the Bush passage quoted above called for government intervention in “opening new frontiers” as a continuation of long standing policy. He further claimed that government sponsored scientific exploration “is the modern way” to promote the opening of frontiers. Bush proposed that the scientific frontier replace Frederick Jackson Turner’s disappearing Western frontier as the crucible in which the institutions and culture of the United States are formed, and American exceptionalism expanded. It worth noting that the history of “opening new frontiers” that Bush cited is deeply problematic. The “opening” of the West was accomplished, as Turner openly admitted, through a series of Indian Wars and neo-imperial policies directed toward the disintegrating Spanish Empire and Pacific Rim. Turner’s admission of these facts underscored the notion that the “free lands” of the frontier were never really free. The western lands were unoccupied by American society, but were in many places inhabited by Native American tribes and nations. Nor was the occupation of the frontier without cost, as tremendous amounts of blood and fortune were expended in its conquest at the behest of the federal government. Bush would have certainly been aware of these facts, however his advocacy for government support for science, and the creation of a federal agency to facilitate this, is based upon the view that scientific knowledge is a pure natural resource to be discovered rather than won through conflict. Basic research into the fundamental laws of nature as described by Bush is often dubbed science *qua* science, or science for the sake of science. Basic research is therefore a natural enterprise, since it is carried out purely for the sake of itself. While it is naïve to think that government support for basic research is devoid of politics, the concept of science *qua* science is instrumental in understanding the role that basic research played in Bush's proposal. As the means to achieve the political goals of national well-being and security, basic research is in and of itself a pure enterprise. The rhetorical power of this cannot be overlooked. It enabled Bush to view the scientific frontier as an idealized space where basic research into the laws of nature will furnish the nation with a pure reservoir of knowledge, applicable to research and the development of tools and techniques of a beneficial political nature. Additionally, in theory, it served to incubate Bush's proposed national science agency, focusing on the promotion and support of basic research, from the political concerns of the federal mission-oriented agencies with a scientific portfolio.

Setting the Scene

Science – the Endless Frontier is not a philosophical document dedicated to promotion of basic research for its own sake. It is clearly a political proposal, and is intimately concerned with concrete steps for fostering scientific research for the laudable policy goals of enhanced national prosperity and security. In order to bolster his claim that substantial federal investment in the production of both new scientific knowledge and new scientists is a worthwhile policy pursuit, Bush dedicated himself to a substantial discussion of the practical uses of basic research. After a brief discussion of employment in the radio, air conditioning, rayon, and plastics industries, he declared that the products of these industries "do not mark the end of progress – they are but the beginning if we make full use of our scientific resources." For Bush, science truly is an endless frontier, with sequential progression from one advance to the next. Science is therefore a perpetual source of progress, provided that the government properly supports its conduct and efficiently manages its output. He wrote that, "to achieve these objectives – to secure a high level of employment, to maintain a position of world leadership – the flow of new scientific knowledge must be both continuous and substantial." To ensure the continual flow of new knowledge, and therefore economic growth and national security, political aims through and through, Bush pushed for massive government investment in the scientific enterprise. The rhetoric of progress that pervades the report almost dares its intended audience, the President of the United

States, his cabinet, and his advisors to stand in the way of ignoring the new magical frontier of science at the risk of imperiling the welfare of the nation.

As Bush argues for government support for science, there can be little doubt that he viewed the conquest of the scientific frontier as vital to the perpetuation of American power. He declared the exploration of the scientific frontier as the legitimate successor to the physical and economic frontiers that Turner discussed in 1893 and 1910:

> 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.

Bush is clearly focused on the exploration of the scientific frontier as a national and perhaps even nation-centric issue. The report is not overly concerned with the universalism of scientific inquiry, despite the paeans Bush pays to the purity of basic research. This is strictly a strategic necessity for the United States. Bush is explicit in this regard, and he reiterated his claim that science directly contributes the life, liberty, and happiness of the nation many times throughout *Science – the Endless Frontier*. He further argued 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 of pioneer democracy and a profound sense of nationalism, he proclaimed, "without scientific progress we could not have maintained our liberties against tyranny." The purity of science is a bulwark against the craven machinations of alien powers that strive to deprive the United States of its liberty. The use of tyranny, rather than fascism or imperialism, is instructive, as it elevates science's protective powers from a localized instrument in the Second World War to a perpetual force against all enemies. Tyranny has a long history in American political thought, and is most closely associated with British rule over the American colonies. The American Revolution that ended British rule is generally regarded as the overthrow of tyranny and, in the words of Abraham Lincoln in the Gettysburg Address, the birth of "a new nation, conceived in Liberty."

Bush submitted *Science – the Endless Frontier* to President Truman on July 25, 1945, two and a half months after the surrender of Nazi Germany, ten days after the successful "Trinity" nuclear test in the New Mexico desert, and only two weeks before the use of atomic weapons on Hiroshima and Nagasaki in Japan. The specter of the atomic age cast a long shadow across the report, and informed Bush's statement that scientific progress was essential to the defeat of tyranny. As a scientist and head of the OSRD, he would have been intimately familiar with the race to harness nuclear fission and develop nuclear weaponry among the United States and allies, Nazi Germany, and the Soviet Union. By 1945, Bush would have also been familiar with Albert Einstein's August 2, 1939 letter to Roosevelt expressing concern over the prospect of Nazi Germany developing a nuclear weapon, and urging the president to take action (Einstein, 1939). The letter, signed by Einstein at the urging of fellow physicists Leo Szilard, Edward Teller, and Eugene Wigner, helped persuade the Roosevelt to take action. The letter was prompted by the discovery of nuclear fission by German scientists Otto Hahn and Fritz Strassmann in December 1938 and the suspension the sale of uranium from Czechoslovakian mines that were under German control by Nazi regime. Szilard, in particular, was concerned that the Nazis would use the discovery of fission to produce a nuclear device with the uranium at its disposal, and asked Einstein to sign the letter in order to get Roosevelt's attention. The letter urged the United States to undertake a massive effort to develop the capacity to harness nuclear fission before the Nazis were capable of doing so.

The letter, however, did not kick-start the massive research campaign that Szilard had hoped for. The development of a comprehensive US atomic program took several years to develop. The President formed the Uranium Committee in 1939, which was later rolled into the newly formed National Defense Research Committee (NDRC) headed by Bush in 1940. In 1941 the NDRC was reformed as the much more powerful Office of Scientific Research and Development (OSRD), again under the leadership of

Bush, and with complete control over the Uranium Committee now called S-1 Section. The S-1 Section was reorganized as the S-1 Executive Committee in June 1942 and focused on the development of a nuclear weapon in cooperation with the US Army. In late 1942 the S-1 Executive Committee created two sites to support the US Army Corps of Engineers' newly formed Manhattan Project in Oak Ridge, Tennessee and Los Alamos, New Mexico. Eventually, as the Army's Manhattan Project became the dominant focus of US atomic efforts, the S-1 Executive Committee's operational stewardship of nuclear research waned, yet the group remained influential in an advisory capacity (Zachary 1999, 189-217).

As the head of both the NDRC and OSRD, Bush would have been intimately familiar with the progress of US efforts to produce a nuclear weapon as he wrote *Science – the Endless Frontier*. Bush's familiarity with the atomic research program recast his statement that scientific progress had protected the United States from tyranny in a new light. Exploration of the scientific frontier is not merely a research exercise with universally beneficial outcomes, although the basic research may be; rather it was a strategic enterprise to provide the nation a distinct advantage over its rivals. Bush reiterated Turner's unusual dialectic that the nation had to "win" that which was ostensibly "free." A failure to "win" the "free lands" of atomic research would constitute a distinct danger, as the Einstein-Szilard letter clearly indicated, and could have led to the nation being subjected to the tyranny of Nazi Germany. Bush's invocation of freedom from tyranny through research is a powerful rhetorical move designed to persuade President Roosevelt at the close of the Second World War that the heightened funding of the war years and consolidated federal coordination of scientific research, epitomized by the OSRD, continue into the post war era. Bush advocated the establishment of a perpetual federal enterprise not only to tap the rich vein of new knowledge of atomic physics, but also to win the scientific frontier for the United States. In the passage, Bush presaged the ideological, diplomatic, military, scientific, and technological struggles between the United States and the Soviet Union that would come to characterize the Cold War – proxy contexts designed to achieve strategic victories in the metaphorical "free lands" that had not yet been annexed by either side. The contours of what President Eisenhower would dub the "military-industrial-complex" in his 1961 farewell address are on full display in Bush's rhetorical masterpiece of declaring the scientific frontier the frontline in the struggle against tyranny.

In the third chapter of the report, "Science and the Public Welfare," and under the sub-heading "Relation to National Security," Bush elaborated on his claim that science is a crucial battleground. He claims that, "In this war it has become clear beyond all doubt that scientific research is absolutely essential to national security." Bush once again explicitly links the successful prosecution of the war, popularly conceived of as a struggle against expansive totalitarian regimes, to the mobilization of the US scientific community and the development of technology. He cited the struggle against German U-boats as a triumph of "scientific techniques" and the development of radar as provoking "scientific countermeasures." Bush stated that, "This again represents the ever continuing battle of techniques." Implicit in his discussion of techniques is the fact that the technological measures and countermeasures developed to prosecute the war were the product of basic research that produced new knowledge that was then applied to the development of technologies. Bush quoted a joint letter from the Secretaries of War and Navy to the National Academy of Sciences to underscore his point, in which they write that,

> To insure continued preparedness along farsighted technical lines, the research scientists of the country must be called upon to continue in peacetime some substantial portion of those types of contribution to national security which they have made so effectively during the stress of the present war.

Because war had become increasingly technical in nature and required the material support and total mobilization of the populace, the perpetuation of some aspects of the scientific war effort should remain in place. Bush returned to the theme of the Einstein-Szilard letter, that failure to "win" the "free lands" of scientific research could lead to the inability of the United States to effectively defend itself from tyrannical enemies. He pointedly warned that, "We cannot again rely on our allies to hold off the enemy while we struggle to catch up." To be prepared to fight and win the next conflict, the United States needed to be at the forefront of scientific research and the development of military tools and techniques. The only path to insure success in what Bush perceived would be the increasingly technical and total combat of the future, was the peacetime mobilization of the scientific community. In order to stay ahead of future enemies, whomever that might be, the United States needed to achieve and maintain a position of scientific preeminence.

A Citadel for Science

However, it would be reckless to only ascribe military overtones and motives to Bush and his report. Although the Second World War and dawning of the atomic era contributed greatly to the tenor of the report, the purpose of *Science – the Endless Frontier* is to argue for the creation of civilian-run science and research agency. Bush maintained that the creation of such an agency is not only in keeping with the tradition of government support for science, but is also essential to the promotion of economic growth, physical welfare, and national security. Bush advocated the creation of an agency fundamentally concerned with providing infrastructural support to the pioneers of pure science. He described the void that the new agency would fill thus: "There is not now in the permanent Governmental structure receiving its funds from Congress an agency adapted to supplementing the support of basic research in the colleges, universities, and research institutes, both in medicine and the natural sciences, adapted to supporting research on new weapons for both Services, or adapted to administering a program of science scholarships and fellowships." Bush ascribed to the new agency the task of carrying out the Government's responsibility to promote the "flow of new scientific knowledge" and the development of scientific talent. Bush's recommendations are plainly self-interested. The perpetuation of Government support for science after the conclusion of war meant the continual flow of financial and material support for an enterprise in which Bush was anything but a disinterested observer. Nevertheless, he justified his call for the establishment of a federal science agency with his Turneresque rhetorical argument about the defense of democracy against tyranny, as well as straightforward appeals to national interest. Bush wrote that, "On the wisdom with which we bring science to bear in the war against disease, in the creation of new industries, and in the strengthening of our Armed Forces depends in large measure our future as a nation." The implied warning is that without serious federal support for science, the peaceful future of the United States would be jeopardized.

Bush augmented his claims by asserting that support for science is a proper concern of the Government, and recounted historical instances of federal support as evidence of this. He noted that in the 19th century the Government established the Coast and Geodetic Survey, the Naval Observatory, the Department of Agriculture, and the

Geological Survey, as well as supported scientific research through Land Grant College Acts. However, he argued that the scientific research carried out by preexisting government agencies lies somewhere between basic research and applied research directed toward a specific goal. He described government science prior to the Second World War as a mission-oriented hybrid of basic and applied research, where the federal agency responsible for the research is neither constrained by the industrial or commercial need to realize an immediate payoff, nor completely free to conduct open-ended basic research without regard to practical benefits. Bush, therefore, saw federal science agencies as competent but essentially "limited in function." To remedy this, he argued for the creation of a central, comprehensive science agency, lamenting that,

> 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.

It is worth noting critically that the absence of a central government agency does not *ipso facto* necessitate the creation of one. Bush attempted to rectify this by claiming that there are areas of research in the public interest – he cites the military, agriculture, housing, public health, medical research, and research the requires massive capital investment – that would be inadequately funded in the absence of federal intervention. However, his argument is speculative. From his vantage point in 1945 it is impossible to predict with certainty that future agricultural research, for example, will be woefully under funded without the creation of a federal science agency. The question of self-interest is also raised through Bush's explicit mention of his own outfit, the OSRD, as the only example of a coordinated government support for science in the national interest, and as the template for the new peacetime science agency. The remainder of *Science – the Endless Frontier* is therefore dedicated to making the case that (1) science is essential to national wellbeing, (2) adequately funding scientific research will lead to national wellbeing, and (3) a central, federal agency is critical to this enterprise. Criticism of Bush's approach, and its subsequent adoption by science policy practitioners and the science community is presented in a subsequent chapter.

It is worth noting here that Vannevar Bush, outside his capacity as the Director of the OSRD, was a northern, laissez-faire Republican opposed to government control over the scientific research. Bush's experience at the head of the OSRD, overseeing the wartime mobilization of the scientific workforce and being at least tangentially tied to the successful development of atomic weaponry, convinced him of the necessity of a government agency to coordinate and support national science policy. Nevertheless, Bush was wary of government control of science, writing that,

> [W]e must proceed with caution in carrying over the methods which work in wartime to the very different conditions of peace. We must remove the rigid controls which we have had to impose, and recover freedom of inquiry and that healthy competitive scientific spirit so necessary for expansion of the frontiers of scientific knowledge.

He returned again to the frontier metaphor to describe scientific research and ascribes pioneer characteristics to scientists – freedom of inquiry and healthy competition. In Turner's frontier thesis competition, aided by the absence of cultural, economic, and physical control mechanisms, allowed the pioneer the freedom to reinvent himself, and thereby reinvent the nation. However, by 1945 science had become an increasingly expensive enterprise, dependent on material infrastructure and the influx of affordable labor in the form of graduate students and apprentice scientists. Bush's recommendation, discussed in greater detail later in this chapter, to establish of a federal science agency is aimed at establishing a federally funded infrastructural support mechanism for basic research and the training of new scientists. Bush did not advocate the creation of an agency to conduct research and assiduously avoided placing any government control over the actual work of bench scientists; rather he proposed an agency that is primarily concerned with material support for science, leaving the actual direction and conduct of research in the hands of researchers.

To sell his recommendations, Bush described several areas of fruitful scientific research that could stagnate without government support, thus endangering the health, prosperity, and security of the nation. In addition to Bush's arguments regarding national security, he utilized the military imagery of "The War Against Disease," which garnered its own chapter, to underscore the necessity of federal funding for science. Bush recounted a long list of health achievements – the decrease in overseas disease death rates in the US Army between the First and Second World Wars, the increased life expectancy, and decline in childhood disease – and attributed these positive results to "an expanding body of new scientific knowledge." Despite these advances, Bush listed a host of "unsolved problems," including escalating rates of cardiovascular disease, infectious diseases, cancer, and mental disease that demand immediate attention. Unsurprisingly, Bush saw the remedy in expanding "knowledge of the human organism and the nature of disease," improved and extended medical facilities, and the training of medical practitioners and health researchers. Naturally, the expansion of medical research, facilities, and staff is a perfectly sound idea, yet some of Bush's political leanings came to the fore in this discussion. His discussion of support for medical research focused unsurprisingly on the war effort, a "proper" concern of the federal government, however he was careful to distinguish between government support and intervention. Discussing the development of penicillin and anti-malarials, Bush writes that, "In achieving these results the Government has provided over-all coordination and support; it has not dictated how the work should be done within any cooperating institution." Furthermore, he attributes the discovery of new therapeutic agents and methods to basic medical and scientific research, and the development of these agents and methods to cooperative interplay between medical schools, university science departments, the government, and the pharmaceutical industry. Bush was very clear about the utility of government support, but is also equally clear that he feels that the government should in no way direct actual bench research, interfere with the freedom of scientific inquiry, or tamper with the profits of the private pharmaceutical industry. In Bush's model, the Government acts as the facilitator of scientific research through setting priorities, providing funding, and building infrastructure -- never through direct intervention in the research process.

At the heart of Bush's call for the establishment of a science agency was his view that basic, undirected research is a critical component to a successful national science enterprise and a proper concern of the federal government. Because basic research is conducted without regard to practical outcomes – science *qua* science – the outcome of its pursuit is the generation of new scientific knowledge about the fundamental laws of nature. This knowledge provides the building blocks for applied research dedicated to solving a specific problem or developing a tool or technique. Bush described the relationship between basic and applied research thus, "The scientist doing basic research may not be at all interested in the practical applications of his work, yet the further progress of individual development would eventually stagnate if basic research were long neglected." He also highlighted the unpredictability of basic science, noting that many scientific discoveries are generated from research initiated with a wholly different purpose in mind. For Bush, the importance of basic research is twofold: it provides a font of knowledge for the scientific community to draw from, and its inherent unpredictability ensures that some significant discoveries will arise as a natural byproduct of undirected research. Bush saw that basic research,

> [P]rovides scientific capital. It creates a fund from which the practical applications of knowledge must be drawn. New products and processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science.

It is interesting to note Bush's use of economic metaphor to discuss new knowledge derived from basic research, as it appears again in descriptions of the NSF's mission in subsequent decades. Bush viewed newly generated knowledge as a resource derived from exploration on the frontiers of science. Earlier in the report he described knowledge as "flowing" from the frontier, using the water metaphor to emphasize his point. His switch from the water to economic metaphor is not random; rather both metaphors describe the storage and preservation of a resource for later use either in a reservoir or bank. Bush is not only concerned with the discovery and flow of new knowledge but also with its conservation, preservation and dissemination for later use. This concept would become integral to both the internal and external conception of the NSF's mission, and would also play a role in the NSF's later interest and involvement in the promotion of information management and information science.

Bush shifted gears and turned his attention toward the practical application of scientific knowledge to the development of useful technologies. He believed, "Today, it is truer than ever that basic research is the pacemaker of technological progress." Technological innovation is derived from ideas drawn from the reservoir of new scientific knowledge created by research on the frontiers of science. If new scientific knowledge provides the foundation upon which technology is built and is indispensable to the innovation process, then the generation and conservation of this resource is of paramount importance to the scientific and technological progress of the nation. In laying out his call for a national basic research agency, Bush returned to the rhetoric of national interest and national independence to bolster his argument. He wrote, "A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill." This passage echoed his earlier warning that in military conflicts the United States could no longer sit on the side lines and play catch-up while relying upon allies to hold off an enemy. By advocating national self-reliance in scientific and technological matters Bush evoked Turner's frontier thesis to stress the importance of uniquely American enterprises. Bush argued that true industrial power and economic strength would arise from a national program of support for basic science and the native development of new scientific knowledge, just as Turner had previously located the growing industrial might of the United States in the exploration of its native frontier. Bush declares that,

> We can no longer count on ravaged Europe as a source of fundamental knowledge. In the past we have devoted much of our best efforts to the application of such knowledge that has been discovered abroad. In the future we must pay increased attention to discovering this knowledge for ourselves particularly since the scientific applications of the future will be more than ever dependent upon such basic knowledge.

Echoing Turner, Bush called for cutting the scientific umbilical cord that attached the United States to Europe and more fully developing an independent and self-sufficient American scientific enterprise. His statement also belied an understanding of the shift in power occurring as the Second World War drew to a close, with the emergence of the United States as the sole world power with an intact scientific and industrial infrastructure.

Bush's agenda for supporting native basic research emphasized enhanced government support for institutions that conduct basic research rather than the initiation of new government-run programs or the expansion of government wartime research. His main focus was expanded government support for college and university centers of basic research, since they both develop trained scientific researchers and generate new scientific knowledge. In describing the central role of academic research institutions, Bush reused many of the metaphors and ideas expressed elsewhere in *Science – the Endless Frontier* to highlight their central role in fostering basic research. He wrote that academic research institutions

> [A]re charged with the responsibility of conserving the knowledge accumulated by the past, imparting that knowledge to students, and contributing new knowledge of all kinds. It is chiefly in these institutions that scientists may work in an atmosphere which is relatively free from the adverse pressure of convention, prejudice, or commercial necessity... All of these factors are of great importance in the development of new knowledge, since much of new knowledge is certain to arouse opposition because of its tendency to challenge current beliefs or practice.

Bush's assertion that academic research centers are responsible for conserving scientific knowledge provided the first concrete example of how he believed something as esoteric as the creation of a reservoir of ideas would function in reality. The university would act as a repository for this accumulated knowledge through institutional memory, its written holdings, the expertise of professors and researchers employed there, and the flow of new researchers through its halls. Federal support directed toward colleges and universities would strengthen the fundamental research infrastructure of the nation by maintaining academic research institutions as reservoirs of scientific knowledge, as well as the training grounds for the new generation of scientists that will perpetuate the nation's scientific enterprise.

The importance of developing new scientific talent cannot be underestimated, as it provides the lifeblood for Bush's model of a national research infrastructure. New scientists trained at colleges and universities flow either back into academic research institutions or into private industry and government laboratories. Bush is especially concerned with the latter two, as they are primarily engaged in applied research that is a critical step in the development of new tools and techniques that can be applied to national needs. He pointedly stated that, "The simplest and most effective way in which the Government can strengthen industrial research is to support basic research and to develop scientific talent." Bush returned to this point throughout his report, and even dedicated a chapter, "Renewal of Our Scientific Talent," to the importance of scientific training. However, before analyzing this chapter, it is worth noting that Bush devoted several paragraphs to policy issues that are informed by his political opinions as a laissez-faire Republican. He was concerned with the flow of new scientific ideas and talent into private industrial research, in addition to academic and military laboratories, and clearly viewed economic growth as vital to national security and wellbeing. In a brief, yet telling passage, he advocated the promotion of what today would be described as public-private-academic partnerships to enhance the flow of knowledge from academic centers to private industry. He saw that,

> The benefits of basic research do not reach all industries equally or at the same speed. Some small enterprises never receive any of the benefits. It has been suggested that the benefits might be better utilized if "research clinics" for such enterprises were to be established. Businessmen would thus be able to make more use of research than they now do.

The research clinics that Bush proposed are another physical manifestation of the idea to create reservoirs of scientific knowledge that can be drawn upon, in this case very literally by private industry. While Bush does not offer specifics on how these "research clinics" would operate it is clear that he is proposing an infrastructural project that could conceivably be initiated or managed by a future federal science agency.

Two concrete areas in which Bush proposed political intervention are industrial income tax law and patent law. Bush viewed the laws in place in the early 1940s as inhibiting technological progress. Bush argued that, "Government action in respect to this subject will affect the rate of technical progress in industry. Uncertainties as to the attitude of the Bureau of Internal Revenue regarding the deduction of research and development expenses are a deterrent to research expenditure." Bush euphemistically referred to what he perceives as disadvantageous tax regulations as industrial uncertainty about deductions. What he advocated is expanding the availability of deductions to industry for research expenditures, which he felt would enhance, rather than inhibit, research into and the development of new tools and techniques. Bush's recommendations for patent law took a similar path. He sought to eliminate uncertainties in the laws that "have impaired the ability of small industries to translate ideas into processes and products of value to the nation," and attributed these uncertainties to the "difficulties and expense" of navigating the patent system. Bush's goal in highlighting the "uncertainties" of both the tax and patent law systems was eliminating the unnecessary bureaucratic hurdles that he felt inhibited private industrial innovation. Bush's arguments are interesting as they hinge on the economic barriers to industrial innovation that arise from bureaucratic regulations, while at the same time calling for a massive increase in government support for scientific research and research infrastructure. For Bush, the proper role of the federal government is to support and subsidize the sectors of the research apparatus that do not provide a direct return on investment, notably basic research, in order to provide the reservoir of knowledge necessary for technological innovation. Without this support, he argued, national research needs would go unmet and national competitiveness would stagnate.

In Bush's estimation, only the federal government could adequately meet this challenge. He wrote that,

> Further, we cannot expect industry adequately to fill the gap. Industry will fully rise to the challenge of applying new knowledge to new products. The commercial incentive can be relied upon for that. But basic research is essentially noncommercial in nature. It will not receive the attention it requires if left to industry.

Following Bush's logic, the rightful role of the government is to financially and materially support potentially unprofitable basic research in order to build a reservoir of knowledge that private industry will draw upon to conduct applied research and develop profitable tools and techniques. The transfer of knowledge from basic research institutions to industrial firms will flow naturally, he assured his audience, as a function of commercial incentive. His pronounced emphasis on commerce underscored his belief that economic competitiveness is an essential aspect of national wellbeing and security, and therefore a proper governmental concern through support for research and that enhances private industrial competitiveness. Bush, however, did not call for full government subsidization of industry, nor did he absolve private businesses from responsibility for supporting the scientific enterprise: “We must endeavor to preserve as far as possible the private support of research both in industry and in the colleges, universities, and research institutes. These private sources should continue to carry their share of the financial burden.” In his model, Bush expected industry to reinvest its profits into the system through supporting institutions of basic research and scientific training, closing the circle of what he views as the mutually beneficial partnership between the public, private, and academic scientific sectors.

One resource that all three sectors share, and have a vested interest in supporting, is new scientific talent. For Bush, these crucial pioneers discover new scientific knowledge, and as such, their training is of paramount importance. He wrote that,

> {W]e have drawn too heavily for nonscientific purposes upon the great natural resource which resides in our trained young scientists and engineers. For the general good of the country too many such men have gone into uniform, and their talents have not always been fully utilized.

Bush’s description of young scientists as a natural resource presents as interesting dichotomy in which the scientist is both a natural resource that needs to be cultivated and the pioneer that discovers scientific resources. This view diverged from the pattern laid out in Turner's frontier thesis in which individuals (of European ancestry) are treated as frontiersmen, pioneers, trappers, farmers, or settlers driven by internal and drawn by external factors to enter the frontier. They are not created and formed to be settlers. Turner described human beings (excluding Native Americans) as agents while non-human things – nature, rivers, prairie, ore, timber, etc. – are treated as resources. Bush though, extended the label of natural resource to scientific talent and the concepts of resource management, cultivation, and conservation along with it. The production of scientific talent is therefore an area that can be controlled through rational management, in this case by the federal government. Until talent is declared an essential resource, its targeted cultivation as a matter of policy makes little sense. It is one thing for the government to passively support the development of scientists by providing general funds to colleges and universities, and quite another to declare scientists an indispensable national resource and devote funds directly to their development. Like other raw resources, scientists need to be processed, in this case educated, before being of value to the nation. The infrastructure that enables this process – schools, laboratories, and equipment – becomes a central component of the production of new scientific talent. The abundance any raw resource is useless without the means to transform it into a finished product. By declaring human beings a raw resource that can, and should, be developed into new scientists, Bush's agenda for a federal science agency privileged support for the infrastructural mechanisms that make the creation of scientists possible.

Due to the personnel demands of the war Bush forecast massive deficits in trained scientists for both research and teaching purposes, and unsurprisingly called for a comprehensive plan for attracting, retaining, and training new scientists. Bush referred to need to study the "use of our basic human resources and formulate a program which will assure their conservation and effective development," and focused on driving talented individuals into the university science education system. He made a broad proposal that students should be granted admission to institutions of higher education based on ability rather than wealth, but neglected to mention his vision for amending the admission system. Bush's next proposal is focused on the "generation in uniform" and made sure that those of scientific inclination are not "lost." He proposed that the military review its records, identify individuals that have shown "evidence of talent for science," and order them to institutions where they can receive scientific training. His plan to order scientifically inclined soldiers to receive training is an interesting, if rather dramatic and anti-democratic proposal. It exposed Bush's estimation of the severity of a potential postwar deficit of scientists, and highlighted his belief that scientific employment levels are intrinsically linked to scientific progress. He is a proponent of a more-more philosophy regarding science – if there are more scientists to conduct research, then more fundamental new knowledge will be generated, leading to more applied research and development, which will drive the economy and provide security and lead to more scientific progress. He argued, in essence, that science is endlessly beneficial (hence the "Endless Frontier") and that more science equals more benefit. Science therefore does not adhere to the law of diminishing returns that states that after a certain point each additional unit of input (in this case scientific labor) yields less additional output (scientific knowledge, for example). This concept is critiqued in greater detail in a subsequent chapter, however, it is worth noting here that this is the fundamental concept supporting Bush's claim that science is a frontier of endless bounty, and his argument that increased government spending on science will produce ever greater returns on initial investment.

It must be noted that it is unclear from the literal wording of the passage whether Bush is discussing a projected employment deficit based on the continuation of wartime levels of scientific research and development, or the level of research and development in place prior to the United States' entry into the Second World War. However, from statements made throughout *Science – the Endless Frontier* regarding inadequate scientific progress prior to the war and Bush's praise for the scientific efforts of the wartime OSRD, it is apparent that Bush is projecting this deficit under the assumption that research and development should continue at or above wartime levels. This assumption bears some scrutiny as it fundamentally shaped the perception of what the proper level of national scientific progress should be, and drove all of Bush's policy recommendations. Had Bush felt that prewar science levels were adequate would he have never proposed the creation of a federal science agency, but instead advocated a transition program to return the nation to pre-war levels of support for science? Or perhaps he would have argued for the creation of a federal agency with the mandate only to support the government laboratories that existed prior to the war with some coordination between the agency and the Departments of War and Navy. Since his arguments for expanded government support for science stem from Bush's wartime experience running the OSRD, as well as the general view that science was a critical component in the successful war effort, one can infer that Bush either felt that the pending postwar period would either be characterized by economic, cultural, and/or social competition of some variety that required enhanced scientific progress or would be a short lived era of peace before the outbreak of a new war. Failure to adequately prepare for these scenarios could mean the United States would have to tempt fate by plowing headlong into another crash program to improve national readiness at time of crisis. Another, more cynical, argument is that Bush recognized the rhetorical power of the argument that science had helped win the war and argued that it could help win the peace, through jobs and security, if only the government would fund it adequately. The flip side of this rhetorical argument is the implied threat that the failure to sufficiently fund science at or above wartime levels could lead to the United States either stagnating economically (a realistic concern coming out of a war with massive government expenditures) or squandering the chance to enhance national security and sliding unprepared into another armed conflict. Bush dramatically ups the ante in *Science – the Endless Frontier* by calling for a new federal agency and expanded support for science by promising potential infinite return on investment and darkly implying that the failure to adopt his proposals could have dire consequences for the nation.

Bush, did not however argue for a continuing militarization of science at the end of the war, and drew a very sharp distinction between inherently independent science and science directed toward military ends. He argued that,

> Like troops, the scientists have been mobilized, and thrown into action to serve their country in time of emergency. But they have been diverted to a greater extent than is generally appreciated from the search for answers to the fundamental problems - from the search on which human welfare and progress depends.

Bush clearly stated his priorities by declaring the war a diversion from basic scientific research. He did however make an interesting link between scientists and soldiers, drawing a parallel between the services of both groups. Bush placed the mobilized scientists and troops on equal footing by writing later in the same paragraph that,

> The mobilization of science behind the lines is aiding the fighting men at the front to win the war and to shorten it; and it has resulted incidentally in the accumulation of a vast amount of experience and knowledge of the

> application of science to particular problems, much of which can be put to use when the war is over.

Bush argued that scientists have not only been of assistance to the troops in the field, but have actively shortened the war through research and development, and therefore contributed to victory. Additionally, since scientific knowledge is a reservoir that can be drawn upon for future research and the development, the scientists have, in addition to their war effort, simultaneously laid the groundwork for a prosperous and secure peacetime. This is an uncontroversial, yet astounding, statement that speaks directly to Bush's claim the science is an endless source of benefit. The labor of scientists, even when diverted from fundamental research, is of such great value that the incidental byproducts – experience, knowledge, techniques, and tools – are of use to the perpetuation of scientific progress. This echoed Bush's more-more argument, and underscores his adherence to the belief that science is fundamentally good. Science, no matter how narrowly applied to a specific problem, is a net positive, and is a therefore a proper concern of the federal government.

Bush used this claim, as well as the assertion the science is a frontier of endless benefit, to propose the creation of a federal science agency to support and coordinate scientific policy and research in the United States. The two major areas of government responsibility, the generation of new scientific knowledge and the creation of new scientific talent, are so vital to postwar prosperity and security that the creation of an agency with an overarching mandate to support these twin endeavors was necessary to replace the patchwork of federal and private institutions in place in 1945. Bush wrote that,

> There should be a focal point within the Government for a concerted program of assisting scientific research conducted outside of Government. Such an agency should furnish the funds needed to support basic research in the colleges and universities, should coordinate where possible research programs on matters of utmost importance to the national welfare, should formulate a national policy for the Government toward science, should sponsor the interchange of scientific information among scientists and laboratories both in this country and abroad, and should ensure that the incentives to research in industry and the universities are maintained.

His proposals were explicitly infrastructural in nature. The new agency furnished, coordinated, formulated, sponsored, and ensured, but never researched. Bush was adamant that the new agency would only support scientific research and education, and should conduct no research of its own. The new agency should not become an operating agency with its own scientific agenda and the attendant pressure to demonstrate results, which he felt was not conducive to basic research. The creation of a of a new agency is also necessary because "nowhere in the Governmental structure receiving its funds from Congress is there an agency adapted to supplementing the support of basic research in the universities, both in medicine and the natural sciences; adapted to supporting research on new weapons for both Services; or adapted to administering a program of science scholarships and fellowships." The mission of the new federal agency was to act an organization dedicated to the support of the national science enterprise, providing coordination and infrastructure from the established seat of power in Washington, DC. The new agency would act, in essence, as the conduit between the halls of power in the capital and the scientific community spread throughout the country – an idealized firewall between science and politics. While it is impossible to believe that Bush believed that science could ever be completely shielded from political influence in a model where the scientific community relied so heavily on federal funds, he clearly went to great lengths to portray basic science as fundamentally pure and worthy of being left alone from the meddling of bureaucrats. In order to make this argument work, Bush must repeatedly remind his audience that basic research often does not produce an immediate return, however the nation could, and would, reap a substantial long-term return on its investment if basic research were simply allowed to progress unimpeded.

Conquest

While the most obvious reward of long-term pioneering science, according to Bush, is the generation of new scientists and new knowledge, there is another reward that reveals itself woven through the subtext of *Science – the Endless Frontier*. That reward is the chance to "inhabit" of the "free lands" of science. Bush reminded his audience, notably President Roosevelt and the powerbrokers in Washington, that the race to achieve scientific milestones is critical to the nation's resistance to tyranny. Failure to quickly extend American research efforts into the further reaches of the scientific frontier could allow the enemies of the United States to achieve research and developmental successes that would imperil the ability of the United States to defend itself. Bush specifically revisited some of the more menacing developments of German military – the U-Boat, the V-1, and V-2 rockets – with the clear intent of highlighting the threat that a technologically sophisticated enemy poses. Although the Allied nations were able to eventually develop countermeasures to these weapons systems, their development, combined with Bush's warning that the United States can no longer afford to play technological catch-up, served as the tangible threat that drives his call for an enhanced federal science initiative. Unlike the Turner's physical frontier, Bush's scientific frontier is not a discretely bounded area that can be conquered to the perpetual exclusion of all others. Since basic research is the exploration of the fundamental laws of nature, and natural laws and phenomena are not beholden to political boundaries, it is impossible to preclude scientists from other nations from conducting basic research. It is certainly true that secrecy regulations and patent laws can retard the flow of information from the nation to another. However, as the example of the atomic research demonstrates, it is quite possible for the scientists of several nations to achieve technical success semi-independently, since the atom is not the exclusive property of any nation. Additionally, new scientific knowledge derived from unclassified basic research is generally published in academic journals for broad dissemination, building a "reservoir" of knowledge that researchers in any nation can draw upon.

Since the persistent monopolization of a scientific frontier is impossible, speed becomes the primary strategic issue. The objective of a national strategic research program becomes winning the race to be the first nation to research a specific phenomena or develop a certain technology or technique. If decision makers assume that all, or most, of a nation's primary adversaries will eventually arrive at the same scientific or technological destination, it becomes imperative to reach the destination first, since this is the only way to exclusively enjoy the benefits that accrue from exclusive exploitation of a scientific discovery. The strategic advantages of activity on the scientific frontier are speed-based, and range from scoring public diplomacy victories to producing commercially viable technologies to achieving technological military superiority. Scientific and technological innovations become milestones in a perpetual race rather than destinations in their own right. The rush to develop the next game-changing technology or unlock a new secret of nature will eventually supplant each previous milestone. The never-ending race to explore and inhabit the "free lands" of science mirrors progression of Turner's physical frontiers across the North American continent, with the important exception that the scientific frontier, in Bush's mind, is "endless." With the progression from one physical frontier to another the varied characteristics and cultures of the settled lands from which exploration is initiated are synthesized to form a unique composite culture that in turn influences the nation as a whole. Progress on the scientific frontier, as proposed by Bush, follows a similar form. Belief in the transformative power of new frontiers on scientific progress and national well-being dictates that progress must be perpetual and endless, for science is the one field, Bush reminded us, that all others depend. A steady stream of new scientific knowledge derived from basic research must fill the reservoir that applied research and technological development rely on. The entirety of the report relied on Bush's argument that failure to continuously progress on the scientific frontier could lead to stagnation and significant damage to the nation. *Science – the Endless Frontier* is therefore not only a call for the establishment of a federal science agency, but a blueprint for foreign and domestic policy based on the hopeful promise of perpetual scientific revolution.

Chapter Five: 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, science and technology 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 science and technology policy. In 1942 Senator Harley Kilgore (D-WV), 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, 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 science and technology priorities.

The founding of a federal agency for the support of scientific research was delayed during the late-1940s while the President, Congress, Washington's scientific insiders, and industry struggled over the constitution and portfolio of the new agency. This allowed a number of federal agencies to partially fill the void that the absence of the science agency created, namely federal support for academic research and science and technology policy coordination. 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.

The establishment of the AEC effectively transferred the control of atomic energy from military to civilian hands and the ONR was directed "to plan, foster, and encourage scientific research in connection with its paramount importance as related to the maintenance of future naval power and the preservation of national security" by Public Law 588 of 1946. In July 1947 President Truman signed the National Security Act to create the National Military Establishment (NME), the office of the Secretary of Defense, the United States Air Force (USAF), the CIA, the NSC, and the National Security Resources Board (NSRB). The NME was created out of the War Department and the Navy Department, and the USAF (formally under the aegis of the Army) was granted separate status and brought under the NME umbrella. The Act was amended in 1949 to create the DOD with a single cabinet level secretary that reported to the President on behalf of the combined branches of the military, subordinating the secretaries of the various branches to the Secretary of Defense. The CIA was formally founded as the first peacetime intelligence agency in the U.S., heir to the wartime Office of Strategic Services (OSS) that was disbanded in October 1945, and replaced the Central Intelligence Group founded by Truman in January of 1946.

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, 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 progression 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.

The progression of federal agencies founded or reorganized during immediate postwar period, and the delay in creating the NSF is important as it helps explain the character and role of the Foundation in the federal science apparatus, a role that Kevles (1977, 358) has described as "puny partner in the larger federal establishment." The wrangling over the shape of the NSF between the New Deal populists led by Senator

Kilgore and the conservative laissez-faire scientific elite headed by Vannevar Bush certainly and dramatically shaped the nascent NSF. Throughout all the wrangling between the Congress, the scientific elite, and President, the Truman administration managed a tremendous reorganization of the federal apparatus with the creation and/or reorganization of the previously mentioned agencies. What this meant for the NSF is that the other agencies that preceded its creation in 1950 not only took on tasks that could conceivably have fallen under the purview of a federal science agency, such as support for academic research, but also gained an advantage in the competition for attention, appropriations, resources, and qualified staff by entering the pantheon of federal agencies before the NSF.

Don K. Price, Dean of the John F. Kennedy School of Government (1958-1977), former 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 – indeed if you read the Bush report, the general atmosphere there was that this was going to be much more nearly a monopoly on Government research than worked out after the thing had gotten set up. Because in the interval the National Institutes of Health had

> gotten rolling, the Office of Naval Research had gotten rolling, the Atomic Energy Commission had gotten rolling, and 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 stinging, and 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.

The delay in creating the Foundation and the compromises that had to be struck provided a fairly unsteady start the NSF enterprise, and produced a cautious policy agenda embodied by Alan T. Waterman. Waterman was Bush's choice for Director of the NSF and an alumnus of Vannevar Bush's OSDR, and the ONR. Many of the policy attitudes held by Waterman during his reign as Director of the NSF can be traced to his progression through the federal science apparatus. Kleinman (1995, 157) described Waterman as "the embodiment of the values of elites in the scientific community." As a member of OSRD Waterman had worked under Bush, a strident laissez-faire conservative who was wary of government influence over the direction of scientific research and had demanded as much autonomy as possible at OSRD. A fundamental component of Bush's attitude was that the primary role of federal support for science should be restricted exclusively to basic research unlikely to be supported by industry, an attitude shared by Waterman.

Following a postwar move to ONR as Chief Scientist, Waterman made remarks at the first meeting of the Naval Research Advisory Committee in October 1946 that succinctly encapsulated his attitude on government support for basic research. Waterman believed that,

> [T]he establishment of this Office has brought about two significant steps. The first is the explicit recognition of the importance of fundamental research as applied to national security; the second is the realization that there is an advantage in some degree of separation between fundamental research and development with its associated research" (in van Keuren 2001, 209-10).

His belief in government support for basic research was rooted in the laissez faire attitude of the scientific elite that held 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. Waterman brought these attitudes with him to the directorship of the NSF.

In a November 21, 1972 interview John Steelman, Assistant to President Truman and Chairman, President's Scientific Research Board, 1946-1947, recalled that a list of 10 names had been submitted to the National Science Board for the vacant position of Director of the NSF and that Waterman had come in next to last.[9] He claimed that he was then asked by Truman to call around and to gauge the opinions of the scientific community, and confirmed that the job had informally been offered to Karl Compton (president of MIT 1930-48) who was not interested but supported Waterman for the position. Steelman, however, categorically denied rumors that the job had been offered to 12 or 13 people before the administration turned to Waterman, dismissing these claims as nothing more than attempts by those who coveted the job to explain why they hadn't received it. He recalled that Truman favored Waterman over other names on the NSB list because Waterman, unlike the others, was a known quantity who 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, 1). Steelman neglects to mention the tremendous influence that William T. Golden, special consultant to the BoB, exerted on

[9] Waterman was in fact the 7th name on the ten-name list (Blanpied, 1995: 24).

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 Nov. 29, 1950). Additionally, Waterman enjoyed the support of the U.S. scientific elite, including Vannevar Bush and Nobel Laureate, I.I. Rabi (Blanpied 1995, 24), and appeared to Truman as the perfect man to bridge the gap between the academic elite and the Washington bureaucracy without unnecessarily upsetting the tenuous balance between Congressional progressives who wanted a powerful federal science agency and the laissez faire scientific elites wary of any government influence over science policy.

The newly formed NSF arose out of compromise struck between the competing visions of a science agency put forth by New Deal Democrats and the Truman Administration on one side, and Bush and Congressional Republicans on the other. Kevles describes this compromise thus:

> Through the legislative history of the Foundation, Bush's program, rooted in and justified by *Science -- The Endless Frontier*, won its strongest adherents from conservative Republicans... Bush was willing to endorse an end to *laissez-faire* in American science insofar as he was willing to put the government into the business of funding academic research. But while Kilgore's program aimed at organizing scientific research in the best interests of meeting the nation's social and economic needs, Bush

> essentially aimed at enlisting the nation's social and economic resources in the interest of advancing the best science (1977, 26).

Waterman’s ability to straddle the fine divide between political oversight and control of the scientific enterprise and the belief that science was best served by protecting its autonomy, may have ultimately been his greatest asset in the eyes of both Truman and Bush. Waterman’s nomination by Truman may have been based in part on the President’s awareness that Waterman would be unlikely to upset the status quo and challenge the Executive Office for an increased role in the coordination and execution of overall US science policy, or upset the tenuous balance between congressional progressives and the laissez faire scientific elites.

In a December 7, 1950 conversation with Lee DuBridge, president of Cal Tech and founding director of MIT's Radiation Laboratory, Waterman entertained speculation about becoming involved with the fledgling National Science Foundation. His cautious responses foreshadowed his steady yet circumspect leadership of the Foundation. He claimed that

> [M]y basic position is that I feel the [NSF] should in any case get behind fundamental research in science and get this on a good solid basis, handle fellowships and the Roster of Scientific Personnel, and other things in their

> charter which will assist the cause of science (Waterman Dec. 7, 1950).

Furthermore, Waterman discussed the role of the NSF in the eventuality of war, presumably on the Korean peninsula. He stated that,

> I should like to feel that I could be useful to the [DOD] and if the Board of the Science Foundation permits it to be of assistance on request... I believe things could be handled in the Foundation in such a way as to have any such effort to help [the DOD] be temporary in nature (Waterman Dec. 7, 1950).

This statement belies Waterman's fundamental attitude that the NSF, as the federal patron responsible for basic research, remain as distanced as possible from becoming permanently enmeshed in support for applied and mission-oriented research.

In mid October 1952, Paul E. Klopsteg, the associate director for research at the National Science Foundation from 1951 to 1958, met with Vannevar Bush at the Cosmos Club, an elite institution that counted many of Washington's inside powerbrokers among its members and frequent guests. In an October 21, 1952 diary note Klopsteg recalled his discussions with Bush that day. Bush advocated a much stronger role for the Foundation in policy formation than the course embarked upon by Waterman.

Klopsteg quoted Bush stating, "that everything possible should be done to assure that other agencies will recognize the Foundation's leading position in the functions enumerated in the law" (Klopsteg, 1952). Klopsteg's recollections of the meeting presented Bush pushing for simultaneously for both an expanded role for the Foundation and a consolidation of its power base.

During lunch Bush recommended convening a group of "the most eminent persons available" to review national science policy and the lead role of the NSF in guiding national policy, and "once a project is undertaken and the members of the study group have agreed to serve, publication of the facts would strongly fortify the Foundation in its position of leadership" (Klopsteg Oct. 21, 1952). Addressing the relationship between the federal government and research universities Bush advocated a similar approach, stating that,

> [T]he Foundation should undertake an independent study by a group of the most eminent people that can be induced to serve... If such a study were inaugurated, and the advertised, this also would result in the establishment of leadership in this field by the Foundation. Similar studies and reports by other groups... would be ancillary to that of the NSF" (Klopsteg Oct. 21, 1952).

Furthermore, Klopsteg noted that Bush "was emphatic in stating that it is completely improper for military agencies -- now that the NSF has been established -- to contract with universities for basic research, and would abolish this function in OOR, OSR, and ONR" (Klopsteg Oct. 21, 1952).

In a January 22, 1973 interview, William D. Carey, of the BoB, addressed the early formation of the National Science Foundation and the events of the early 1950s that helped shape the organization. Responding to a question about Executive Order 10521 from March 17, 1954 (Administration of Scientific Research by Agencies of the Federal Government), Carey described the climate surrounding the increased role that the order provided the NSF coordinating national science policy. He recalled 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, 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 inside of the federal government. 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, 7).

In the interview, Carey recalled his frustration that Waterman had not "waded into the fight" and pushed for a stake in the generation of national science policy. Nevertheless, Carey expressed his admiration for Waterman, his integrity, and his record of achievement with the Navy and at the Foundation, however he stated that Waterman "frustrated me because we wanted an operation from the Foundation that would serve the presidency in guiding the Government's relationships with science over the long term... [W]e never got it from the Foundation, either in Waterman's time or since" (1973, 8). This statement is not surprising taking into account the position of the NSF as the "puny partner" in the federal science apparatus at its inception, and perhaps more importantly the institutional culture instilled at the Foundation through Waterman's directorship that strenuously resisted any policy coordinating function.

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, 12).

This last quote summarized 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. It is in this attitude that another key to Truman's nomination of Waterman may be found. James E. Webb, Director of the Bureau of the Budget and Under Secretary State in the Truman administration, claimed that President Truman felt that overall policy coordination was a Presidential responsibility. Webb recollected that, "President Truman never intended to surrender the ultimate responsibility for interdepartmental coordination" (Webb, 1973).

Another contributing factor to the "slow" growth of the NSF is the fact that its inception corresponded with the initiation of combat on the Korean Peninsula in the summer of 1950. This prompted a slowdown in support for fundamental research and locked in wartime production levels at the mission agencies until 1953. In a December 5, 1950 memo, William T. Golden, special consultant to President Truman on mobilizing the nation's scientific resources, recounted a conversation with Vannevar Bush in which both agreed that during military mobilization in Korea NSF appropriations should be reduced well below the proposed $10 million budget, with Bush suggesting a meager appropriation of $200,000 (Golden Dec. 5, 1950). Nevertheless, Bush anticipated the basic research programs of other federal agencies, specifically mentioning AEC and ONR, would be turned over to the NSF once it was operational and the "Budget boys [Bureau of the Budget]" had determined funding levels across the federal science apparatus. Challenged by Golden, Bush went on to state that he felt that this would be a positive step, even during wartime, implying that the NSF was the appropriate home for all basic research.

In subsequent conversations with other scientists, military, and political figures, Golden addressed the issue of NSF appropriations, and reiterated his opinion that the Foundation should receive a substantially reduced budget during war mobilization in Korea. In December 6, 1950 memo Golden laid out his argument, stating that,

> The principal reason for this is that the consequence of our military defeat in Korea will and should be a great increase in the emphasis on year-term programmatic research and development in the Department of Defense

> and related agencies and of course on actual production. The National Science Foundation should not be given funds or otherwise encouraged to compete with these programmatic military agencies in the quest for scientific talent etc.-- certainly not at this time since the National Science Foundation is supposed to support only basic and non-military scientific research and development (Golden Dec. 6, 1950).

Golden's position carried the day inside of the Truman administration and the NSF was granted an initial operating budget of $151,000 dollars and a mere $3.5 million in its first full operating year (FY52), establishing the agency as truly a "puny partner" in the federal science apparatus.

It became imperative for the young NSF in the funding turbulence of the early 1950s to expand its constituent base both inside of the federal government and the scientific community. To do so the NSF focused its attention on several areas that were to become mainstays of Foundation policy over the years – grants to fund basic research, investment in scientific equipment and facilities, and perhaps most importantly scientific manpower. 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 development and support of scientific manpower to provide security to the United States.

In a February 12, 1960 letter to Senator Henry M. Jackson, Chairman of the Subcommittee on National Policy Machinery, Waterman elucidated the NSF position on the relationship of science and technology to national security, in response to the Senator's October 28, 1959 request to do so. In the opening paragraphs of the letter Waterman reiterated the generally held sentiments that the relationship between science and technology is strong, that it is important for policy makers to be familiar with the latest science and technology developments, and that it is advantageous to have persons with science and technology backgrounds throughout the federal government. Again, he took pains to draw distinction between the need for scientific advice on policy matters and the need for scientists at the highest level of the federal government to drive policy, testifying that

> Scientific and technical advice must continue to come from the men working in the various scientific fields. Persons having policy-making or policy-executing responsibilities in the Federal Government, however, must be able to recognize the importance of particular trends or developments in science and technology and call upon detailed scientific advice" (Waterman Feb. 12, 1960).

For Waterman, the relevance of the NSF in policy matters rested in its scientific objectivity and again used this letter to distance himself and the Foundation from any formal role in the generation of science policy. He did, however, advise Jackson that the addition of an official with a scientific background to the State Department's Policy Planning office would augment State's understanding of the role of science and technology in foreign policy; a suggestion that again left the NSF unencumbered by an official role in policy formation. The most Waterman would commit to was the inclusion of NSF officials in an inter-agency group, including Defense, Agriculture, and the NIH, to regularly brief "policy formulating groups" at State as a means of providing "fuller contact with respect to scientific developments between policy-making State Department officials and agencies actively engaged in scientific activities" (Waterman, February 12, 1960).

Waterman warned Jackson that, "while foreign affairs and military preparedness are highly important interests which must be taken into account in establishing national science policy, they are not the only interests involved in the development of such policy" (Waterman Feb. 12, 1960). This quote neatly sums up Waterman’s position on science and technology and foreign policy throughout his tenure as Director of the NSF -- that foreign policy and military considerations are merely components, not the drivers, of national science policy, and should not obscure broad federal support "pure" basic research and investment in scientific manpower.

Asked by Lomask about the continued difficulty in setting up a "responsible science mechanism in the White House..., which would be responsive to the Presidency," Carey elaborated:

> I think the problems, the reasons, why it's so difficult runs very deeply into attitudes on the part of different presidents and to the behavior of the science community... Part of the problem I believe is that the President is a political man and he inevitably constructs a calculus of policy and objectives and power. And the President expects others to appreciate his problems and they don't always appreciate them and they sometimes disagree with him. It's characteristic of the science community to be very individualistic, to take the view that the Government's responsibility is to be a source of generous support of science, that Government should appreciate the potential of science in a civilized society, and it should provide the resources and the means and not ask many questions. And the science community feels that on matters of national policy it should not be penalized.
>
> …
>
> The problem...is an intrinsic one because the relationship between science and politics is a very unstable one with little continuity. And I think that it will always be very, very difficult to keep communications open, to align

> objectives of the Government on one hand and the science community on the other in any symmetrical, and I think we have to accept it and not to expect that a miracle is going to be passed that will give the science community the assurance and stability that it would like to have (Carey 1973, 14-15).

NSF and Polar Research

The NSF's involvement in polar research stems from the 1953 request by the National Research Council for the NSF to spearhead the US involvement in the third International Geophysical Year (IGY) scheduled to run from July 1, 1957 through December 31, 1958 with an emphasis on polar research, sponsored by the International Council of Scientific Unions, specifically to obtain and administer government funding (England 1982, 297). The NSF was asked to lead this initiative due to the high level coordination needed between public and private institutions, which the NSF had experience with under its mandate. This request was viewed by NSF Director Alan Waterman and the National Science Board (NSB) as an opportunity to not only engage in an exciting endeavor but a chance to gain additional congressional appropriations to supplement the Foundation's budget (England 1982, 298). In order to steer the budging request as smoothly as possible through the federal bureaucracy the NSF solicited support from the departments of State, Defense, Commerce, and the Office of Defense

Mobilization. A Letter from the chairman of the NSB, Chester Barnard, to President Eisenhower extolled the benefits of the IGY to the advancement of science, technology, and international cooperation (England 1982, 298).

Although there was some initial skepticism by the House appropriations subcommittee, USSR involvement in the IGY initiative prompted congressional approval of the appropriation, albeit for less than requested. In order to meet the costs of providing logistical support to a planned NSF Antarctic expedition, the DoD requested its own congressionally appropriated budget, which provoked a strong response for the NSF. Director Waterman demanded NSF control over the entire budget and the power to disburse funds to cooperating government agencies in order to stave off the chaos of separate funding streams and priorities. Agreement between the NSF and DoD was essential to the success of the IGY project, especially the NSF's Antarctic expedition, which would be impossible to mount without the logistical support of the military.

In an attempt to distribute the burden of staging an Antarctic expedition, NSF Director Waterman appealed to the State Department and White House for support as a matter of national interest. The appeal was effective, and the White House threw its support behind the expedition in March of 1955. However, by July 1955, the White House announced plans to have the Navy launch an unmanned earth-orbiting satellite that would be used not only for military purposes but for IGY-related research as well. The White House initiative prompted resistance from Defense Department, which was wary of having to fund the launch and maintenance of the satellites that would not be used exclusively for military use. The DoD demanded a substantial chunk of the 1955 IGY budget to cover its satellite costs, and the NSF, which had only recently won control over the budget, was forced to compromise and cede funds to the Naval Research Laboratory to underwrite satellite development (England 1982, 300).

The DoD attempted to gain control over the 1956 IGY budget in order to protect its control over the satellite program and fund its development, and used support for the IGY as an opportunity to supplement its budget. The DoD was also successful to some degree in shifting the emphasis of the IGY to its satellite program, and the NSF was forced to appeal to highly placed individuals at the Budget Office and White House to protect the budget and its oversight of the IGY initiative (England 1982, 299). By 1957, tensions between the NSF and DoD reached such a point that the DoD threatened to halt all cooperation in the IGY project. A compromise was reached that shifted responsibility for requesting additional funds to the Defense Department (England 1982, 300). While this diffused the budget impasse it raised the suspicion the military would co-opt and "nationalize" the IGY project (England 1982, 301). A Soviet announcement to put a satellite in orbit compounded these concerns as the military went all out to win the race to launch an operational orbital satellite putting the success of this venture above any scientific concerns of the NSF and civilian scientists. To add insult to injury, the Secretary of Defense, Charles Wilson, blamed the scientists involved in the satellite project for the failures that the program had encountered (England 1982, 301).

If it can be said that the NSF's involvement in satellite development through the IGY program fell prey to the military and foreign policy concerns that dominated the Cold War, the Foundation's Antarctic research initiatives were considered an unqualified success for international and interagency cooperation in the sciences. By the start of the research period on July 1, 1957 the United States had established six scientific research centers on the Antarctic continent with the logistical support of the Navy (304). By the conclusion of the IGY on December 31, 1958 plans had been put in place for a continued US scientific presence in Antarctica under the stewardship of the NSF. But perhaps the biggest success of the IGY was the signing of The Antarctic Treaty December 1, 1959 by twelve of the nations that had participated in research on the continent, including the US and USSR, which preserved Antarctica for peaceful scientific purposes. Article I of the Treaty expressly prohibited any military activity on the continent including the establishment of military bases and the use and or testing of weapons, while Article III enacted a regime that allowed for the mutual inspection of all research facilities. The NSF's research presence in Antarctica continues to this day and it remains the sole US federal agency to fund and carry out polar research on the continent.

Perhaps of even more importance that the successful establishment of a continued research presence in Antarctica after the IGY is the effect that its coordination had on the NSF itself. Its leadership role cemented its place as a permanent government agency able to play hardball, and demonstrated that it was capable of managing complex initiatives with a host of subcontracted public, private, and academic institutions. The IGY experience also propelled the NSF into the realm of "big science (England 1982, 350)," or large, coordinated, scientific endeavors, and also established the role of the NSF in cooperative international science. However, not all of the lessons learned during the IGY experience were positive. The wrangling with the Department of Defense over budgetary concerns and the military's co-opting of satellite development for strategic and political purposes met with the resistance of many within the NSF and US scientific community. Part of the concern was certainly about the militarization of science, but much of it was jurisdictional as well. Although the NSF emerged from the 1950s with an enhanced position within the federal framework and as a proponent of international scientific cooperation, the IGY experience and the Cold War climate reinforced the importance of highlighting the strategic and diplomatic importance of the "big science" programs that the Foundation sought undertake. One of the lasting impact that the IGY would have on the NSF, beyond a continued polar research presence in Antarctica, would be a commitment to cooperative international science and the experience of managing interagency coordination and funding under tight pressure for competing agencies.

This was especially important concern from 1954 onward in wake of an Eisenhower executive order that, instead of installing the NSF as the principal governmental agency for funding basic scientific research as the Foundation had hoped, distributed responsibility and funding for basic research across the federal bureaucracy (England 1982, 311). Contributing to the emphasis on strategic and national interest, was the Russian launching of Sputnik in October 1957 shortly after the start of the IGY space race between the superpowers that followed. It became imperative for the NSF, as well as all other agencies receiving funds through congressional appropriation, to demonstrate importance of their projects the nation's strategic interest as the Cold War intensified and science and technology moved to the front lines of the ideological battle between the superpowers. The NSF was allocated $134 million for FY1959, the first budget after the Sputnik launch, an increase of nearly $100 million dollars over the previous fiscal year in order bolster the Foundation's underwriting of basic science research, especially at the university level, to meet the challenges of the Cold War. The mission of the NSF became part of the overall US effort to mobilize a massive science and technology offensive and the agency found its budget increased to $500 million by 1968.

Public Diplomacy

In a May 1, 1957 conversation between Waterman and Detlev Bronk, from the National Academies of Sciences and Chairman of the National Science Board, Waterman notes the public diplomacy aspects of the International Geophysical Year, which the NSF had been tasked with coordinating. Bronk informed Waterman that a BBC correspondent who was producing a program on the IGY to air on June 29, 1957 had approached him. Bronk stated that "the BBC representative said that he felt that the program would be a flop if they did not have something about the satellite [Vanguard], that the people in England thought the satellite was the apex of the program. This is a good indication of the significance of the IGY program from the standpoint of general public interest" (Waterman May 1, 1957). These comments interestingly foreshadowed the massive effect that the Sputnik launch six months later was to have on world public opinion and the overwhelming reaction of the United States government and every player in the federal research and development apparatus.

The public diplomacy importance of the IGY satellite program was further explored in July 20, 1957 phone conversation between Waterman and Hugh Odishaw, the executive director of the U.S. National Committee for the International Geophysical Year from 1954-1965. Waterman had called to get an update on the satellite program and rumors that there was a push to launch a test satellite into orbit in November 1957. Odishaw responded that he disapproved of the November target date as "it [the satellite program] has international implications which are not good." He reported to Waterman that "the military is going into a 'crash' program and the story is that corners will be cut," which would have "...national and international implications" (Waterman July 20, 1957). Odishaw felt that this rush stemmed from the fact that the U.S. and U.S.S.R. were in a race to see "who will get one up first," and could be a major embarrassment to the U.S. should an attempt to launch a satellite fail due to technical deficiencies resulting from a hasty launch whose sole purpose was to precede a Soviet launch.

These conversations highlight the increasing importance of scientific and technological achievement to the prosecution of the public diplomacy aspect of the Cold War. High impact achievements were increasingly seen by both the U.S. and U.S.S.R. as milestones in the battle between the superpowers to demonstrate the superiority of their respective systems and to sway international public opinion in favor of one side or another. The NSF under the leadership of Waterman was uncomfortably unprepared to engage in the high stakes and high visibility science and technology projects that this strategy demanded. Despite increasing budget appropriations and a more stable role in the federal science apparatus, the NSF under Waterman remained cautious of overstepping its bounds and engaging in anything outside of its comfort zone of support for basic research, facilities, and manpower. This attitude would come under direct challenge following the Soviet Sputnik launch

Science Policy As Political Warfare

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.

To understand the impact of political feedback on the formulation of U.S. Cold War science policy, it is useful to look at one particularly illustrative example from the history of the NSF. The context for support for science in the U.S. fundamentally changed in the wake of the Soviet Sputnik launch in October 1957, and the NSF reliance on the rhetoric of the scientific objectivity and the linear model faced its greatest challenge. Alan Waterman was called to appear before the U.S. President's Committee on Information Activities Abroad (Sprague Committee). On June 20, 1960. President Eisenhower had appointed the committee to examine U.S. international information activity, specifically the image of the United States abroad, focusing extensively on the role of science and technology in fostering a positive global image of the United States.[10] Mansfield Sprague, former counsel for the Secretary of Defense, chaired the committee, which included representatives from the Executive Branch, CIA, Department of Defense, and United States Information Agency.

Shocked by the successful Soviet launch of the Sputnik satellite on 4 October 1957, 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. The meeting sought to address this, gathering to discuss "The Impact of Achievements in S&T Upon the Image Abroad of the United States" (Sprague Committee Meeting Notes 1960, 1-14).[11] During the meeting Waterman was forced to confront the stark reality of conducting science policy in an era of shifting geo-strategic priorities. Waldemar Nielsen, the Executive Director of the committee on loan from the Ford Foundation, asked Waterman whether national interest was best served

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[10] For a more detailed discussion of the Sprague Committee and its relationship to U.S. telecommunications policy see Schwoch. 2008. *Global TV: New Media and the Cold War, 1946-1969*.

[11] All further quotes in this section are drawn from the Sprague Committee Meeting Notes of 06/20/1960.

by concentrating solely on basic research or by giving special consideration to research with a pronounced "impact factor." Waterman warned against "steering" basic research, which he felt inhibited free scientific inquiry, and compared this to the overly programmatic practices of the Soviet Union. Arguing that the U.S. must present its "real image," Waterman suggested that the U.S. would do best to target international scientific elite with objective and verifiable results rather than dazzle the masses with "impact" projects. He cautioned Nielsen that most people were "suspicious of propaganda."

After some back and forth about countering the psychological impact of Soviet science, Waterman was challenged by former Eisenhower advisor and psychological warfare expert C.D. Jackson to explain why science should be afforded "laissez faire" status when so many other areas of policy were subject to some level of government influence. Jackson citied the Soviet Luna 2 moon shot in September 1959 as a project of slim scientific significance but global psychological importance. He challenged Waterman to explain why the U.S. could not support policy that mixed scientific importance and psychological impact. Waterman again cited the danger of "programming" science, stating that a U.S. plan to orbit the moon was scientifically more significant than hitting the moon, as the Soviets had done. Undeterred, Jackson pressed on, pointing out that while the Pioneer satellite project was scientifically sophisticated, it would do little to impress a global audience.

As the meeting wore on, committee members questioned Waterman on the appropriate mechanism for considering the psychological impact of scientific projects. He dodged this series of queries by repeating that the NSF listened to the scientific community and gave priority to those projects that "point toward hitting pay dirt." Attempting to get Waterman to answer more specifically, Jackson asked how and by what government procedure the "science fiction by-product" was considered. After Waterman cautioned restraint, he was again pushed by Jackson to consider psychological impact. The NSF Director failed to take the bait and reiterated his stance that the "support of science was keyed to feasibility… giving [the scientist] the illusion of freedom in the conduct of his research, stressing that the creativity of the scientist is the most important." As his presentation ended it should have be apparent to everyone present that the NSF principle of supporting only non-directed basic research was falling out of step with current thinking inside of the U.S. government.

This point was emphatically driven home at the end of the meeting as Jackson warned that he had built up "a considerable head of steam" and would not be as "punctilious" as Waterman in airing his views. He reminded the committee that their purpose for meeting was to determine "whether the U.S. was going to operate through conventional diplomacy or through political warfare," and railed against the "missed opportunities" and "screwed up" publicity that past projects had received. Responding to complaints that securing federal funding and support for projects was difficult enough without considering public relations strategies, Jackson declared that,

> Some decisions have to be taken even though the blood runs in the corridors. Blood in the corridors is a part of the struggle in Washington and is not to be dreaded. Psychological warfare can be cranked into the decision-making machinery but it has to be done over the broken bodies of many people. This should not prevent our continuing to work on the problem.

To Jackson, shifting the emphasis of national science policy into alignment with strategic priorities was simply a matter of sheer political will – Washington insiders and power brokers should make policy with a hammer when necessary. Waterman's abdication of a policy coordination role for the NSF in 1954 may have secured the NSF tenuous position by avoiding stepping on the toes of larger, older, and better-funded federal agencies, however, however it left the Foundation as only one of many federal agencies that funded science, and a relatively weak agency at that. As the events of the Sprague Committee meeting indicate, Alan Waterman's strategy of scientific objectivity as the driving principle behind NSF operations ran headlong into a new political reality that would force the Foundation to adapt. In the post-Sputnik era science would increasingly called upon to play a more active and visible role in public diplomacy efforts and what Jackson bluntly referred to as "political warfare." In order to remain relevant and responsive to both the Executive Branch and the scientific community, the NSF utilized the post-Sputnik government-wide increase 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, 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, 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 (1987, 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 (1987, 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, 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, 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, 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, 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, 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, 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, 168) to 6% by FY 1970 (NSF 1971, 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, 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, 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.

Applied Social Science Research

During the Cold War the NSF, like all federal agencies involved in the funding of scientific research and technological development, was called upon to contribute to the overall strategic goals of the nation. In the case of the NSF this meant the support of basic science research, primarily at US research universities, from its inception in 1950 through the late 1960s. The NSF's strategic value during the early stages of the Cold War was twofold; the Foundation acted as a conduit for the funding of basic research and its maintained active contact with the academic scientific world and was active in development of the young scientists and engineers needed to staff the R&D institutions instrumental to US strategic initiatives being articulated primarily at the Pentagon. The Department of Defense was far and away the biggest single patron of the sciences in the US from the end of the Second World War through the mid 1960s, and contributed roughly 80 percent of all federal funds for scientific research and development during the 1950s (Leslie 1993, 1). However, as the 1960s wore on and tensions over military funding of research came under greater scrutiny on campuses across the country, other federal agencies, including the NSF, began to take on a more direct role in funding applied research. Otto Larsen, the author of *Milestones and Millstones: Social Science at the*

National Science Foundation, 1945-1991, describes the political forces that shaped the Foundation's increasing shift away purely basic research toward applied research and priorities during the mid-1960s.

As social and infrastructural problems became major areas of concern during the 1960s an increasing number of congressional representatives and officials in the federal bureaucracy began to push for the application of applied science, especially social science and engineering, to the problems facing the nation (Larsen 1992, 69-70). In July of 1968 President Lyndon Johnson signed an amendment to the National Science Act of 1950 to create a social science division at the Foundation with the mandate to support applied research. As NSF budget appropriations rose following the Sputnik launch, a number of its congressional overseers became frustrated with what they felt was the passivity of the Foundation, which stemmed from their perception that "outsiders," or the principal investigators responsible for generating grant proposals for basic research funding, had become too influential in shaping the national scientific agenda (Larsen 1992, 70). Confronted with the perception of mounting social disruption, this attitude spurred the push to make science more directly serve the national interest through its application to the problems that the nation faced. This in turn provoked fears that support for basic research would be ignored and that science funding for academic institutions could be used to drive a new policy of goal and mission oriented research that served the narrow interests of politics (Larsen 1992, 71). Nevertheless, with the creation of a permanent social sciences division and a mandate to support applied research, the NSF found itself in the position of having to produce tangible results if it was to continue receiving generous support from Congress.

Challenged to provide results and maintain its budget from the mid 1960s onward, the NSF was nudged by political desire for applied social sciences to accept these changes and once its mandate was amended in 1968, applied research became an official focus of the Foundation (Larsen 1992, 79). Larsen describes this maneuver as something akin to the Foundation leadership and the National Science Board "swimming with the tide" (1992, 80). One of the effects of this shift toward applied social science was the promotion of "multidisciplinary problem-solving research centering on the behavioral and social sciences" (*The Behavioral and Social Sciences: Outlook and Needs*, joint report of the Committee on Science and Public Policy of the National Academy of Sciences and the Social Science Research Council in Larsen 1992, 80). Rather than solicit research grant proposals for applied research, the NSF was urged by its congressional overseers to seek out and fund applied research that had broad and national application. This shift toward applied research had the effect of encouraging and stimulating interdisciplinary research at the university level as well as opening the NSF to increased surveillance and oversight by Congress (Larsen 1992, 82). A provision in the 1968 amendment to the National Science Foundation Act required that budgeting requests no longer be simply submitted to the full House and Senate

Appropriations Committees but receive direct approval of the their oversight subcommittee first (Larsen 1992, 82). As the 1960s ended, this extra layer of oversight and control produced not only greater congressional power over the NSF's purse strings, but ensured that internally Foundation officials would continue to swim with the applied research tide and ensure that their colleagues did the same.

The effect of this monumental shift from basic to applied research was to have a profound and lasting impact not only on the NSF but the network of academic and research institutions that drew funding from the agency. There are two very important legacies that arose from this shift that would eventually provide the foundation for the tremendously successful stewardship of the Internet and its subsequent commercialization. One was the promotion of interdisciplinary research, especially at the university level, prompting coordination between social and "hard" sciences, especially the fields of engineering and computer science. The second was a focus on large-scale projects of "national" scope and importance. The experiences with the short lived yet highly influential and controversial Research Applied to National Needs (RANN) program provided the NSF with the experience of identifying and working on large scale projects of national importance, but equally significant to future developments was the failure of RANN and the subsequent shift in Foundation policy *back* toward (it is impossible to completely return and a hybrid emphasis emerged) an emphasis on basic research. But the end of the RANN program in the mid 1970s and shift back toward basic research equipped the NSF with the ability to deal with the complexity of a new computer communications network of national scope and the flexibility to fund promising research proposals from principal investigators in the field and provide the researchers with room to incubate innovation without top down control and oversight. The growing pains that the NSF endured between its inception in 1950 and experience with RANN in the 1970s left it with an asymmetrical approach to technology support and funding that aided its brief yet influential stewardship of the Internet.

Chapter Six: National Science Foundation Support for Computing and Information Management 1950-1970

Introduction

The history of computing at the National Science Foundation stretches back almost to the founding of the organization in 1950. In a 1994 article entitled "Arming American Scientists: NSF and the Provision of Scientific Computing Facilities for Universities, 1950-1973" Aspray and Williams describe the NSF's programs to provide computer infrastructure to US colleges and universities as "one of the foundation's important contributions to American higher education and scientific research." However, they also correctly note, that computing was not an original priority of the NSF, as most prototype computers were not yet in operation (Aspray & Williams 1994, 60), nor was anything resembling computer science even recognized as an independent discipline. In fact, it would be another twelve years before the first dedicated computer science department in the United States was founded at Purdue University in 1962.

In 1950 most computer-related research was conducted in science, engineering, and mathematics departments that had well developed disciplinary histories. The organization of the NSF at its inception reflected the boundaries of the traditional disciplines with Directorates for Mathematical, Physical, and Engineering Sciences and

Biological and Medical Sciences (NSF 1953, 35). There was no specified directorate or program tasked with the support of computer-related research in any form. Nevertheless, in 1952 the Foundation made a small grant to Bryn Mawr physicist Rosalie C. Hoyt to examine "Bioelectric Behavior in Filamentous Algae, Investigated With the Aid of a New Analogue Computer" (NSF 1952, 47). In 1954 the NSF issued its first exclusively computing-related grant to John von Neumann to host a conference on High-Speed Computing in Meteorology and Oceanography at UCLA (Aspray & Williams 1994, 60; NSF 1954, 30). By 1955 the foundation had formed an Advisory Panel for University Computing Facilities with von Neumann serving as the first chairman, along with the physicist Edward Teller and mathematician Stanislaw Ulam (NSF 1955, 94). The creation of this group was precipitated by a May 1955 a presentation by von Neumann to the National Science Board on support for computing facilities (Aspray & Williams 1994, 61). These facilities were conceived as campus resources for scientific research; that is, they served as tools for the advancement of general scientific research rather than as laboratories for computing research and development.

The NSF 1955 Annual Report included for the first time a section dedicated to "High-Speed Computation," and described computing as the answer to problems of increasing complexity faced by physical scientists and engineers as experimental advances had "rendered useless many linear mathematical models that were formerly adequate" (NSF 1955, 53). The report relayed the sentiment of "many scientists," and certainly those involved in the production of the report, that further progress in their fields would stagnate without adequate access to high-speed computing. The report mentioned the "interdependence" of computation and mathematics and physics, acknowledging that in the mid-1950s the primary scientific use of high-speed computation was, as the name implies, the machine-aided resolution of the complex computational problems at the core of both disciplines. Nevertheless, the authors of the report described the need for computer facilities as interdisciplinary in nature, as high-speed computation was becoming increasingly integral to research in other physical science, mathematical, and engineering disciplines (NSF 1955, 53). To this end, the report took a proactive view of computer development and advocates, albeit in general terms, an "investigation into the theory and engineering of the computing machines."

Perhaps the most interesting aspect of the 1955 Annual Report is the attention paid to modeling and simulation in the fields of meteorology, astronomy, and quantum mechanics that points to an increasing awareness among scientists that high-speed computation would provide the scientific disciplines something more than the means to calculate complex equations arising from their scientific data. The realization in the mid-1950s that highly complex scientific phenomena could be modeled and simulated mathematically through computing began to shift some research out of the laboratory and field into an abstract space created by computing. According to the report,

> Meteorologists have dreamed for generations of something akin to a laboratory with capabilities reasonably approximating the atmosphere. This dream now appears to be coming to fruition with completion of the first successful machine-produced predictions of large-scale atmospheric motions. The ultilization [sic] of high-speed computing machines obliterates the boundary between dynamic and synoptic meteorology by making it possible to test suggested models simulating the atmosphere and also to evaluate quantitatively the effects of varying parameters believed important in influencing weather (NSF 1955, 54).

Computational advances enabled the creation of parallel research environments for any scientific discipline in which data could be rendered into numerical form, allowing scientists virtually control otherwise uncontrollable physical environments.

The generation, dissemination, and preservation of scientific information had been additional NSF area of interest since its inception. The 1956 Annual Report raised for the first time the possibility of utilizing "electronic computers" to do so, yet also acknowledged "that systems for indexing and classifying scientific information which take advantage of machine capabilities remain to be developed" (NSF 1956, 77). The report addressed the problem of how to mechanically translate the conventional language of scientific publication could be converted into a "regularized machine language" to enable machine based storage and distribution of scientific information as well as mechanical translation from one written language to another. The latter function was of particular interest during the Cold War, as the United States sought means to quickly and efficiently translates Soviet scientific information into English in order to keep abreast of 'what the other side was up to.'

Overload: The Management of Scientific Information

In remarks to the annual meeting of the Association of American Publishers Professional/Scholarly Publishers on February 9, 1999, NSF Director Rita Colwell addressed an area of fundamental concern at the close of the twentieth century – the need to manage information wisely in order to promote the efficient dissemination of scientific knowledge and avoid the pitfalls of information overload. Her talk, entitled "Turning the Clock Forward: Not Just Faster But Wiser," captures the sense that that the development of advanced information and communications technologies simultaneously creates opportunities and pitfalls. Early in her speech Colwell states that, "We may not like change, but it is a constant ingredient in our lives. At the end of this 20th century, the pace of change is in overdrive" (Colwell Speech)[12]. Her choice of the words 'constant' and 'pace' represent a vision of technological change that is

[12] The entire speech can be found at http://www.nsf.gov/news/speeches/colwell/rc90209amerpub.htm

persistent in its 'overdriven' acceleration, and altogether common in both technical and lay communities concerned with technology. Colwell continues in this vein:

> We all sense the enormity of change that electronic, digital, and global are bringing to every facet of our national and personal existence. It's exciting but sometimes unsettling… Every sector in our economy and our culture is confronting the pervasive impact of information technologies (Colwell Speech).

Technological progress is addressed through the prism of simultaneous optimism and caution borne of "unsettling" change. She uses combative language to describe the confrontation between economies and cultures and "pervasive impact" of information technologies.

Colwell presents the audience with a paradox of information management that is at the center of her discussion. For the Director, rapid advances in information and communications technologies present both an opportunity and challenge for information management: they enable broader access to new information sources and practices while simultaneously outstripping the capacity of entrenched information management mechanisms to efficiently deal with these enhanced access and new practices. Colwell's remarks were neither novel in content or timing. They echo a half-century of concern over the problem of information overload in the context of accelerating technological change, especially the explosive development of information and communication technologies.

In "Liquifying Information: Controlling the Flood in the Cold War and Beyond" Bowles (2000) explores the history of "information overload" in the context of the "information revolution" of the second half of the twentieth century. He argues that a society that values information so highly – a society that applies the word information as a prefix to the terms "age, society, culture, economy, revolution, environment, anxiety, and fatigue" to describe its conditions and contexts – is susceptible to information overload. Since the beginning of the information age, which Bowles situates at the end of the Second World War and start of the Cold War, intellectuals have viewed information as an external force that needed to be managed (Bowles 2000, 225). With the publication of Claude Shannon's 1948 article "A Mathematical Theory of Communication" and the origins of information theory as an applied mathematics discipline, information became something quantifiable that could be measured, and importantly according to Bowles, something that could be managed through "new computer systems to inscript, preserve, store, retrieve, disseminate, and use the information" (Bowles 2000, 226-27). Bowles cites the publication of Vannevar Bush's 1945 article "As We May Think," Norbert Wiener's work on cybernetics in the late 1940s and 1950s, and J.C.R. Licklider's 1965 book *Libraries of the Future* as representative of thinking in US intellectual communities about the need and means to control information (Bowles 2000, 228-29). By the early 1960s these ideas resonated within the halls of the NSF. The NSF 1961 Annual Report specifically mentions Wiener and Shannon in a discussion of support for the emerging field of communications sciences, and makes a nod toward von Neumann through the mentioning the importance of "the development of a theory of the logic of automata and computing devices" (NSF 1961, 33). While the ideas of Wiener, Shannon, and von Neumann had entered into the conceptual vocabulary of the NSF in conjunction with the emerging field of communication science, perhaps a more influential reason for their resonance at the Foundation can be found in the increasing importance of information management to the prosecution of the Cold War.

Bowles argues that in addition to the arms and space races that we associate with the Cold War an information race existed as yet another arena of quantifiable benchmarks that the superpowers could use as measure of comparison, with information overload as this competition's primary threat (Bowles 2000, 228). The information race however, had little to do with the quantity of information produced by one side or the other; rather it centered on the ability to control the information being produced, "thereby assuring the continued advancement of their ideologies" (Bowles 2000, 228). One side of the equation was naturally enough the efficient management of relevant domestic information, however access to, and the processing of, foreign information was another matter altogether. The first two sentences of Exchange of Science Information section of the NSF's 1954 annual report highlight the growing importance of access to Soviet scientific knowledge in the 1950s:

> In the interest of scientific progress American scientists must be informed on research developments throughout the world. At this particular time, however, the most acute need is for more widespread knowledge in the United States of the status of Russian science (NSF 1954, 57).

Not only would access to international scientific information help ensure the progress of American science, but access to Russian scientific literature would allow the US to peer behind the Iron Curtain and benchmark Soviet scientific progress to provide clues about their advances in numerous fields, including atomic research. In 1953-54 the NSF tasked the American Physical Society (APS) to assemble a plan for improving US access to Soviet scientific literature in 1953-54. As part of this task the APS undertook a survey of its 600-person plus membership to determine what they felt was the importance of the project. The survey respondents identified two critical reasons for improving access to Soviet scientific literature: the "technical value" of the information contained therein and "[b]ecause of the national danger of underestimating the strength of the U. S. S. R., particularly as far as scientific advances are concerned" (NSF 1954, 57). The ability to quickly translate, disseminate, and synthesize the scientific literature of the

Soviets quickly became an integral part of the overall US need to manage scientific information. Another front in the Cold War had opened, this time on the rarified and esoteric battlefield of academic and scientific publication.

As the Cold War progressed the concept of information overload became increasingly embedded in a political framework, as scientific competition between the US and Soviet Union intensified as exemplified by the launch of the Soviet Sputnik satellite in 1957. Science became an important component of US Cold War public diplomacy and propaganda efforts (Schwoch 2008), and the ability to manage and disseminate scientific information was a critical component of this strategy. Bowles points to the very real concerns in elite US scientific and policy circles that VINITI, the All-Union Institute for Scientific and Technical Information founded in 1952 that abstracted and translated scientific and technical literature for dissemination to Soviet scientists, was able to provide a level of information management that far exceeded anything that the US could muster (Bowles 2000, 230). While Bowles acknowledges that management of the perceived information crisis did not determine the outcome of the Cold War for either side, it "was extremely important in providing a justification for establishing the computer as the main tool for information processing" (Bowles 2000, 232-33).

The idea that the nation faced an information overload also became a central theme of NSF's coordination of scientific information through the establishment of the Office of Science Information Service (OSIS) under the provisions of Title IX, National Defense Education Act of 1958. OSIS formally replaced the Office of Scientific Information that had been in operation since 1952. Burt Adkinson, who joined the NSF after nearly a decade as the head of the Reference Department of the Library of Congress, became the director of the new program. The mission of OSIS was "the development of integrated systems, national in scope, designed to give every U.S. scientist and engineer effective access to the significant results of the research conducted by all other scientists and engineers" (NSF 1961, 120). The idea of information overload is more forcefully expounded in the NSF 1961 Annual Report, which states that "With the accelerating flood of scientific information in recent years, resulting from the many-fold expansion of research, has come an increasingly imperative need for such a national plan [of information management]" (NSF 1961, 123). The impetus for the creation of OSIS was the 1958 President's Science Advisory Committee report Improving the Availability of Scientific and Technical Information in the United States that proposed the creation of the office and the passage of the National Defense Education Act of 1958 that authorized its creation (Wooster 1971, 331; NSF 1959, 92). The NSF 1959 Annual Report discusses the founding of the OSIS and attributes the necessity for its services as the need to manage information lest the nation's scientific community suffer information overload.

> Scientific information has become a major problem, particularly since World War II, as a result of rapid scientific progress multiplying the volume of new scientific information beyond the point where it can be effectively published or handled through existing methods. Accompanying this problem there has been an increased consumption of fundamental science by technology. Formerly the timelag between development of a fundamental idea and its utilization by technology was measured in tens of years; now it may be measured in months and weeks.
> (NSF 1959, 92)

This passage displays a fascinating articulation of the triangulation of science, technology, and information focused on technological development. Information and information practices are recognized as critical links between the practice of fundamental, basic bench science and the development of advanced technologies. Not only do they act as conduits of scientific knowledge they act as accelerants to the process of technological development. Nevertheless, the development of new information technologies and practices leads to the paradox of Colwell's speech: the development of tools that enhance the efficiency of the dissemination of information helps create the need for greater measures of information management.

One idea that the NSF had supported early in its endeavors to manage scientific information was the use of mechanical tools to perform information processing. Two areas that characterized this effort were mechanized information searching and the mechanical translation of scientific literature. By 1955, the Foundation was actively thinking about mechanized searching as a means of improving the location and retrieval of scientific information, yet acknowledged that little progress had been made in this area (NSF 1955, 80). The NSF 1955 Annual Report draws heavily upon a February 16, 1955 Vannevar Bush speech entitled "Communications – Where Do We Go From Here?" to the Founding Anniversary Meeting of the American Society of Mechanical Engineers that echoed themes that he had laid out a decade earlier in "As We May Think" in the *Atlantic Monthly* and in 1939's *Mechanization and the Record*. Bush remarked that,

> We are making enormous strides in the development of methods for creating a record of what we learn-in printed words, by photography, or on a magnetic tape. We are also making strides in developing means for the transmission of ideas from one to another or from a central point to great audiences. But in one exceedingly important phase of the whole problem we are making little progress indeed. This is the phase of finding in the record the information that we need. (Bush in NSF 1955, 80)

The quote is used in the report to set up a call for an expanded effort to develop an effective mechanical system for information archiving, searching, and retrieval. The use of Bush's speech is significant in two regards. First, it links the NSF's mid-1950s information management efforts to Bush's seemingly prophetic vision of the proto-hypertext Memex (memory expander) computing machine that would subsequently influence numerous advances in hypertext computing. Secondly, the use of Bush's speech highlights the long shadow that he cast over the Foundation despite having seen his influence in the Truman Administration diminish rapidly in the late 1940s and early 1950s, and having withdrawn his name from consideration from the first National Science Board.

By 1958 mechanical translation techniques were being supported by the NSF in addition to support for the computer indexing of scientific information and operations research into the patters of scientific communications. By 1959 with OSIS in operation the NSF undertook support for five mechanical translation projects, with special emphasis on Russian to English translation that would enable faster access to a broader range of Soviet scientific literature. The NSF 1959 Annual Report highlights work being done under the aegis of the Foundation at the Harvard Computation Laboratory where a Russian-to-English automatic dictionary of electronics and mathematics was in operation, as well as work at Georgetown on the mechanical translation of Russian chemical texts and the University of California on Russian biochemistry (NSF 1959, 95).

One year later in 1960, the Foundation had expanded its support for mechanical information searching, supporting large-scale projects at Western Reserve University, the Chemical Abstracts Service, and most interestingly a "program to investigate the organization of large files of information with a multi-level structure and self-organizing capability at the Electrada Corporation" (NSF 1960 Annual Report). By 1961, the mechanical processing of scientific information had become an explicit priority of the Foundation with a dedicated Document Research program with the explicit goal of supporting research toward

> (1) new and more effective systems-mechanized where possible-for processing, storing, and searching large volumes of scientific information, and (2) mechanized production of accurate and readable translations of foreign language materials into English. (NSF 1961, 124)

The Document Research program was established in response to the perceived 'problem' of inefficient US information management techniques to support the "development of systems using high-speed electronic and mechanical equipment for organizing and searching information and for translating scientific texts" (NSF 1961, 124) as a means of providing a solution. In order to make mechanical information management and translation possible, the NSF supported research in a broad range of fields including early software research for a normalized language for information searching systems, software for mechanical content analysis and language parsing, and linguistic research to provide a better understanding of syntax, grammar, and semantics (NSF 1961, 125-26). By the early 1960s it was apparent that advances in computing not only increasingly enabled the manipulation of the complex data sets needed for the effective management of scientific information, computers were also the only tools the looked capable of keeping pace with the explosion of information that needed to be managed. Nevertheless, the Foundation recognized that results of these disparate research projects could only provide incremental advances toward the long-term goal of automatic language processing, providing the building blocks of a sound foundation for computerized information management (NSF 1963, 122).

In 1965 the NSF trumpeted the imminent arrival of a "national science information system" based upon significant recent progress in the management of scientific information that built upon "a decade of research and experimentation (NSF 1965, 139). The NSF's 1965 Annual Report highlighted the work of the Chemical Abstracts Service (CAS) on "on techniques and concepts necessary for the mechanization of a chemical information service capable of coping with the increasing flow of information in this discipline" as a major advance in this endeavor. The findings of the CAS supported the premise that a large-scale "operational mechanized system" for registering chemical compounds was possible and that the registry could support both search and retrieval functions (NSF 1965, 139) Under the leadership of the NSF a multi-agency taskforce that included the Department of Defense, and the National Institutes of Health was convened to supported continued CAS research that would serve as the first phase and prototype of a computerized "national information system" linking a major scientific society and government. The basis for the system was to build a database of chemical compounds with unique identifying numbers that could be tracked across all relevant publications in the database. A key feature of the system was the ability to recognize a compound that had previously been indexed and assign the same tracking number to it in order to build a linked structure of references, as well as the ability to automatically recognize previously un-indexed compounds and assign new tracking numbers (NSF 1965, 140).

Interestingly, the imagined uses of the system foreshadowed some of the more radical advances in scientific computing that would occur in later years. The chemical reference system was designed as an automated library of chemical information, able to be searched and cross-referenced based upon index number as well as chemical structure, but was expected to expand to support the searching of chemical substructures to "help chemists to relate structure to chemical activity, and perhaps even design chemicals" (NSF 1965, 140). The fact that the authors of the report imagined that their computerized system would be of use in designing chemicals, foreshadowed advances in computer simulation for scientific research and recognized the importance of the efficient management of information for simulation. Without computers capable of storing vast amounts of cross-indexed data and effective search and retrieval software, accurate simulation would be impossible. While computer simulation of chemical research was not on the immediate horizon for the authors in 1965, it certainly was within the widest realm of what they imagined as they wrote that “the system is designed to help answer certain types of chemical questions that defy existing information systems” (NSF 1965, 140). Additionally, the Foundation was moving forward with programs to implement analogous nation information systems for the fields of physics, engineering, and meteorology, however there was little progress in the biological, earth and social sciences (NSF 1965, 141-42). This status report reflects a number of factors in play in 1965 including the relative importance of establishing a national information system to the respective disciplinary societies and the basis of each discipline in mathematics or the ability to ‘operationalize’ data for computer manipulation. Nevertheless, the Foundation reported that it was in contact with the pertinent disciplinary societies in order to forge a closer working relationship regarding the establishment of computerized information systems (NSF 1965, 142).

The 1965 report also highlights the growing recognition at the NSF of the importance of information networks for the management of scientific information. While not explicitly endorsing inter-networking as we currently understand it, the report lays the groundwork for the ideas of information systems and networking that would become more prevalent in the Foundation in subsequent decades. The report states that,

> Information systems or centers that provide documents, secondary indexing and abstracting, or other information services, and libraries that store and make available the literature of science, are interdependent. The relationships involve connections between Federal services and those provided by State, local, or private agencies; between services that are universal in scope and those that are subject-specialized; and between those that provide a variety of services and those that concentrate on a particular kind (NSF 1965, 144).

Recognizing the interdependence of the of the various actors – systems, libraries, federal, state, and local agencies, and private entities – involved in the management of scientific information is a critical step toward developing information networks that take into account the need for interoperation among all of the disparate actors involved. To do so requires the development of common protocols that facilitate communication between different nodes in the network. To do so the NSF contracted with the Information Dynamics Corporation to develop a computer simulation of information network characteristics and configurations designed to "understand" and "manipulate" network service and usage patterns (NSF 1965, 144). At the time of publishing the analytical tool produced by Information Dynamics could only model hypothetical networks but was being improved to analyze existing information systems. This project highlighted yet another step that the Foundation had take by the mid-1960 to mathematically model information and information flows with the result being a tool that could simulate communication networks and conditions to more efficiently manage information. The availability of more complex computer capabilities and an increasing awareness that predictive modeling and simulation techniques could be implemented not only in the analysis of existing networks but also in the development of effective systems marked another step toward the application of information and communication technologies as advanced simulation systems across the physical, earth, biological, and social sciences.

In fiscal year 1966 the NSF allocated $11.6 million in funds for research and development in support of the science information program, distributing funds to scientific societies, universities, library associations, museums, federal agencies, and international organizations (NSF 1966, 121). The 1966 Annual Report compared science information to a “natural resource without which the Nation’s progress in science and technology would be slow or nonexistent” (NSF 1966, 121). However, the report continues, the “efficient production, preservation, and exploitation of science information is complicated by many factors,” and cites the accelerating production of science information, disciplinary fragmentation and lack of communication mechanism between disciplines, and a shortage of professionals trained in information management (NSF 1966, 121). The upshot of this section of the report was to highlight the increasingly interdisciplinary information needs of the scientific community and the problems of that previously developed systems that served homogeneous disciplinary populations. The report carries on where the previous year's report left off – an emphasis on research and development that strove to interconnect the various actors, databases, and techniques involved in the nation's production and processing of information into series of national science information systems largely inside of the prevalent disciplinary structures (NSF 1966, 122-24). Although the NSF's direct support was channeled to disciplinary networks, the Foundation participated in federal efforts to establish an information system of national scope that would be of use to all scientific disciplines through their involvement in the multi-agency Committee on Scientific and Technical Information (COSATI), and support for the Committee on Scientific and Technical Communications that was established in 1966.

The NSF's actions in the second half of the 1960s were not without detractors. Melvin Day, a career civil servant who started service in the AEC in 1946, published the influential *Nuclear Science Abstracts*, moved to NASA for a decade during the 1960s, and joined the NSF's OSIS for two years starting in 1970, lambasted the Foundation's support for narrow disciplinary science information systems during this period as shortsighted in a November 2004 interview (Day Interview 2004).[13] He recollected

[13] Entire interview can be found athttp://www.infotoday.com/searcher/apr05/ardito_bjorner.shtml

during the interview that

> NSF made grants to each of the major U.S. science information systems, like physics, chemistry, biology, mathematics. That was done by Burt Adkinson. Burt came from the Library of Congress. His approach was different from mine. This is what I didn't like at NSF.
>
> Burt said to just give them the money; it wasn't important whether or not one system would talk to another. My position was, if you're going to use public funds, then the public ought to benefit. And the way the public benefits is if they can talk to each other. You see, if we hadn't done that, you wouldn't have much of the national network that we have today (Day Interview 2004).

Despite Day's hints at the shift in networking that would take place in the 1970s, the late 1960s saw a continuation of the trend at the NSF toward narrowly defined communication systems, with the continued development "discipline-based information systems" highlighted as an area of Foundation emphasis in 1967, along with coordination among federal agencies, and support for research into information processing techniques (NSF 1967, 159). The NSF allocated 73% ($7.7 million) of all funds available to their science information program to support for discipline-based information systems as compared with 52% of funds for fiscal 1966 (NSF 1967, 160). These figures support Day's claim that the OSIS under Adkinson's directorship focused almost exclusively on narrowly conceived information networks rather than interoperable networks and presage battles inside of the NSF in the coming decades of support for inter-networking of communications systems.

Despite the validity of Day's statement, the NSF did continue to fund grant projects that utilized computer technologies for information management and processing in integrated systems and networks, without regard however for questions of future interoperability with other systems. One project highlighted in the 1967 Annual Report does though exhibit the evolution of support at the Foundation for the principles of interoperability, albeit limited to the components of individual systems. The NSF sponsored research into the development of a computer-based bibliographic data system at the University of Chicago that applied computers to traditional library practices. The NSF claimed that

> The novelty of the project lies in its fitting together a total integrated system out of assorted data-handling systems for various library operations. Traditionally these operations-bibliographic processing, catalog searching, circulation control, and related library service operations are handled manually (NSF 1967, 1963).

In order to accomplish this, researchers needed to operationalize previously manual functions and create protocols that allowed the mechanisms that handled these functions to communicate with one another. Perhaps the most exciting portion of the University of Chicago system was the projected creation of a system of remote terminals that could query the library database to retrieve desired information and improve the "speed and efficiency" of library information management and enhance "both intellectual and physical access" to library records. The NSF expected the University of Chicago project to serve as a prototype for academic libraries across the country and stipulated that after the completion of the project all results, including computer programs and documentation would be made available (NSF 1967, 164). The idea that previously separate manual functions could be computerized, brought under the umbrella of a single information system, and controlled remotely was certainly in play at the NSF during the late 1960s. It would be a number of years though before these principles would be applied to a national system of information management.

In 1968 the NSF celebrated the ten-year anniversary of the OSIS by using the twin themes of information overload and information management to justify its existence in its 1968 Annual Report. The report claimed that

> OSIS was established in recognition of the importance of information to the health of the nation's science and engineering [sic] efforts and the need to help scientists and engineers cope with the rising tide of information. That scientific and technical literature increases in volume along an exponential curve with a doubling time of 8 to 15 years is a well established phenomenon.

Again the Foundation returns to the themes of accelerating pace and utilizes water as a control metaphor to make tangible the threat of information overload. Bowles persuasively examines the use of water as a control metaphor during the Cold War in "Liquifying Information: Controlling the Flood in the Cold War and Beyond." Bowles notes that although many metaphors have been used to describe information overload, the predominant metaphor in the US during the Cold War and beyond has been to describe this problem in terms of water and control, with the words flood, tide, and deluge as prominent examples (Bowles 2000, 234). Bowles links the use of the water control metaphor in the early Cold War to the use of the same metaphor to describe Communist expansion in the postwar era by Western commentators (Bowles 2000, 235). He argues that "our experience with large bodies of water is one of awesome, untamed power and impenetrable mystery" is used to make tangible the abstract threat of information overload and communism (Bowles 2000, 236). Taking the metaphor one step further, Bowles argues that the mechanisms to control, contain, and manage water (dams, tidal barriers, etc.) were used to explain the role that computers could play managing information overload and containment could play in hemming in communism. He argues:

> Both information and communism were believed to be forces that the U.S. had to impose control in order to preserve democracy. Thus, the metaphor helped powerful social groups to sell and persuade others of their answers – new technology and military containment – to the most pressing problems of this era (Bowles 2000, 236).

How the metaphor was used to justify its policies and programs varied from group to group. At times it was used to push for funding and support for radical new projects, what at other times it was employed to defend more conservative choices.

Despite facing "the rising tide of information" the OSIS justified its support for disciplinary information systems based on "the recognition that the mass of information available on a given subject is never used in its entirety by the total community of users of science information" (NSF 1968, 204). This quote is interesting because it highlights the Foundations view that the utility of an information system should be maximally efficient from a user perspective rather than from a system standpoint. This should come as no surprise since the NSF's primary constituency was the scientific community and its efforts in science information management was geared toward efficient dissemination of information to end-users to fuel the furnace of US science. The report continues in this vein with a vigorous defense of its discipline-based approach:

> In addition, the volume, diversity, and complexity of information for the many scientific and engineering fields mitigates against a single collection which serves all scientists and engineers. It follows, therefore, that the development of discipline-oriented science information systems for the major disciplines is a necessary and efficient way of managing "blocks" of information (NSF 1968, 204).

The fact that the authors of the report felt the need to so vociferously defend their approach indicates that at least some criticism of their practices had reached the ears of those inside of the NSF, and that the principles of unified systems and interoperability were gaining traction in some parts of the research community. However, in light of the quotes above and the fact that OSIS had spent the better part of a decade funding and promoting discipline-based information systems it is safe to assume that in 1968 the institutional inertia at the NSF to continue down this path strongly outweighed newer ideas that privileged more universal and interoperable networks for information management and dissemination.

By 1969 there was movement toward a holistic approach toward information system development, even if these systems were limited in scope to traditional scientific disciplines. The language that the NSF used to describe information management in the late 1960s had shifted away from individual processing advances and toward looking at systems that integrated various techniques, functions, tool and actors into networks. A technical emphasis on the interoperability of the various nodes in the network accompanied this rhetorical shift. In a section of the 1969 Annual Report dedicated to "Information System Development" the NSF laid out its three goals for this area:

> (1) Exploitation of technology for greater speed efficiency, and dependability; (2) integration of information processes and functions, whereby only one intellectual processing of any item for the item is needed; and (3) coordination with other information systems in order to serve multiple requirements. (NSF 1969, 99)

Despite this expansive view of interoperability entering into the NSF's annual reporting of their science information activities, their practical emphasis remained the continued development of discipline-based systems. Nevertheless, continued work on these systems, especially the flagship CAS system, coupled with ideas of interoperability helped build a foundation for later networking support at the Foundation. The NSF trumpeted 1969 as the year that the CAS system reached maturity, and the system was seen as the incubator for a number of technical advances in computerized information processing, sorting, and retrieval. In addition to achieving operational milestones, the CAS system had developed a user base at the three universities where it had been implemented, was being expanded across a broader network of institutions to share the data processing burden, had established research contracts with the National Library of Medicine and National Cancer Institute, and was negotiating contracts with NASA and the Food and Drug Administration (NSF 1969, 99). These CAS milestones highlight one of the growing areas of strength of the NSF – the ability to create, manage, and support a network of scientific, technical, academic, industrial, and federal constituents. The ability to act as a part of and/or lead a public-private-academic consortia of actors would prove to be a critical skill for the NSF, as large-scale scientific and technical projects of increasing complexity became the norm in subsequent decades.

The idea of coordination went hand-in-hand with the NSF's more holistic thinking about information networks at the turn of the decade. Beyond rhetorically supporting interoperability, albeit in discipline-based systems, the NSF was beginning to think about future networking problems that could arise as independently developed systems began to share data and resources.

> With the development of discipline-oriented information systems, the formation of university-centered information systems, the continual expansion of information systems and services, the need for planning in science information systems becomes mandatory. The situation is analogous to the construction of a building without the aid of blueprints – the resulting structure may be functional, but its structural soundness, serviceability, and value would be doubtful (NSF 1969, 101).

It appears from that the impetus for this statement came from a report issued by the Committee on Scientific and Technical Communication (SATCOM) a joint venture of the National Academy of Sciences and the National Academy of Engineering started in 1965 and supported financially by the NSF. In 1969 SATCOM published a report entitled "Scientific and Technical Communication –A Pressing National Problem and Recommendations for Its Solution." According to the NSF, the report

> [R]ecognizes the need for a planning and coordinating mechanism for the heterogeneous complex of scientific and technical communication activities that have emerged in response to locally perceived needs and opportunities rather than having developed in an orderly, planned manner (NSF 1969, 101).

This quote highlights an interesting feedback loop initiated in part by the NSF. STACOM was formed and supported under the auspices of the NSF's science information program, produced a report calling for better coordination of the "heterogeneous complex" of communication systems and practices (partially a result of the NSF's development of discipline-based information systems), and had that report quoted approvingly by the NSF in a section of its annual report dedicated to "Planning, Coordination, and Cooperation." What may appear as the NSF working at cross-purposes – simultaneously promoting discipline-based systems as well as approvingly quoting a call for greater coordination to avoid the interoperability issues raised by the heterogeneous complex of systems that it had created – can in fact be seen more as a sign of a maturing learning to effectively manage existing projects while providing room for future growth. Constituencies, once created, need to be nurtured. The NSF's tactical shift to embrace solutions to network interoperability issues of their own, while refusing to abandon the discipline-based information systems that it had carefully nurtured over the better part of the decade is the quintessence of the Foundation's unique non-mission role in the constellation of federal agencies that support science. The Foundation's actions created a problem/opportunity/need for additional research and coordination that the NSF itself could ideally support.

One paragraph later in the 1969 Annual Report we see the first explicit formulation of the principles of interoperability by that would come to characterize the development of Internet. The report states,

> The subsystems of an information network must be able to exchange information. Information, especially in machine format, can be interchanged if the same standards are used for input and output by the exchange systems (NSF 1969, 101).

The standards that the report mentions can easily be recognized as the precursors to computer networking protocols that facilitate communication across and interoperable network of systems. These goals would filter into Foundation grants to universities to help facilitate to coordination of the heterogeneous information systems that had already been developed with Foundation support. One year later in 1970 the NSF elevated inter-networking to a guiding principle of its science information program. One of the five top-level goals for the program was to foster "…cooperation, coordination and standardization among the various components of the present science communications complex which will lead to national and international networks of information services" (NSF 1970, 89)." By the turn of the decade, whether driven by the SATCOM report or the criticism of individuals like Melvin Day, the NSF's had clearly begun to embrace, or come to terms with the reality of, interoperable large-scale distributed computer networks as part of the future of information management.

An Enduring Theme

Returning to Rita Colwell at the podium of the Association of American Publishers Professional/Scholarly Publishers annual meeting in 1999, it is interesting to note the persistence of the twin tropes of information overload and information management. She echoes the Cold War discourse that Bowles described as she discussed the role of scientific and academic publishing in midst of an information explosion that the NSF was beginning to come to terms with at the start of the 1970s. Earlier in the speech Colwell had indicated that the information revolution is both part of the cause and solution of what appears to be a circular issue. The academic publisher she argued, as a conduit of new information, can positively shape the dissemination of knowledge through the use of new information tools and practices for enhancement of information management. Colwell returns to the fundamental paradox of the information revolution at the center of her speech:

> A new role for publishers with the powerful tool of information technologies is to insure that "knowledge does not become too great for communication...."

> We already know that in using the Web, scientists have cited information overload as their most pervasive problem. Publishers are in an important position to be part of the solution to this problem…
>
> Out of massive information, you can help create knowledge as you develop collections. Creating high quality collections will move us from the quagmire of "everything" to a higher plateau of meaning and usefulness.

Colwell's speech is interesting for a variety of reasons, not least among them is the fact that in 1999, a decade after the fall of the Berlin Wall, information overload remained a central theme of information management. Her statement that knowledge may overwhelm the ability to efficiently communicate/manage it, provides a sense that knowledge exists and expands in a natural, wild, or unfettered capacity beyond human control. The flip side of this acknowledgement is that the untamed and inevitable growth of knowledge can only be reigned in through man-made control mechanisms. In the final years of the Twentieth Century the expansion of information and communication technology access and use across all sectors of the US society, due in part to projects and programs supported by the NSF, provides in Colwell's terms both the cause and means to control the explosion of information. The seeming inevitability of knowledge growth and technological progress ensures that this chicken and egg cycle will continue for the foreseeable future, creating new problems to tackle, new areas to fund, and new coalitions to form. Information overload and the need for the efficient management of scientific information is a self-fulfilling prophecy. The NSF, as a non-mission federal agency, has played, wants to play, and will play a critical role in this ongoing cycle.

Chapter Seven: Networked Computing – Building the Internet Age

Large Scale Computing Projects

> Science and technology policy helps to initiate and shape knowledge-based innovation. But the perception endures that the research produces the innovation, and the policy is secondary or even beside the point of technical success – the evaporation of the government role in the creation of the Internet stands as a prominent example. We tend to sleight attention to those policies as either contributory to the success of innovation or as worthy of attention in and of themselves (Guston and Sarewitz 2006, 7).

A September, 1986 Congressional Research Service (CRS) report "The Impact of Information Technology on Science" prepared for the House Committee on Science and Technology,[14] addressed the accelerating changes taking place in computing during the mid 1980s and examined the impact that these changes were having on the conduct of scientific research. The Introduction to the report dispensed with the usual recantation of amazing technological progress – increasing processor speed, increasing storage

[14] Congressional Research Service. "Background Report No. 5: The Impact of Information Technology on Science." Library of Congress, Task Force on Science Policy. Committee on Science and Technology, US House of Representatives. Ninety-Ninth Congress. Second Session. September 1986.

capacity, decreasing cost, decreasing size – assuring the reader that these trends should continue unabated until at least 1990 (CRS 1986, 2). If these trends continue, the report promised, and improvements in software design, fiber optics, and advanced telecommunications technologies keep pace, their combination will "open up a broad spectrum of new facilities, systems, and services" (CRS 1986, 4) The facilities, systems, and services mentioned in the report are the building blocks for what we recognize now as the Internet, global and interoperable voice, image, and data networks, and networked data storage and retrieval capabilities. The report recognized that "increasingly distance is becoming irrelevant" as the internetworking of information and communications technologies increases.

What is striking about the Introduction, yet neither uncommon nor surprising, is that the intertwined themes of time and space play a prominent role in the discussion of technological progress. Accelerating change and collapsing distance are phenomena to be kept up with, managed, or overcome. The report immediately warned:

> that policy makers both in the public and private sectors will be confronted with choices and required to make decisions that may have a significant impact on the ability of scientists and others to utilize fully the capabilities that information technology offers… [D]ecision makers continually may find themselves grappling with how to fashion

> institutional frameworks that can accommodate and support the rapid pace of technological development and its integration into various societal sectors (CRS 1986, 5).

The report continually returned to the theme of speed and the need to manage technological progress, stating that "information technology is important not only because it speeds up certain analytical processes, but also because it opens up new lines of inquiry and makes new methodologies possible" (CRS 1986, 5). The point of this language is to set up the very simple premise of the report, which is that as computer development accelerates and prices fall the "average" scientist will benefit and his or her research will be improved as a result. Higher resolution, better displays, enhanced three-dimension modeling, and networking are all mentioned as advances that will enable better science. Interestingly these are all aspects that create the possibility of scientific simulation that allows researchers to build, model, and experiment in a purely virtual realm.

The Introduction to the report finally addressed the strategic importance of the impact information technology on science in terms of US preeminence in scientific research and technological development. The report uses boilerplate language highlighting the "internationalization" of science and foreign "competition" to position "the need for state-of-the-art computer and telecommunications technologies" as critical areas for congressional inquiry (CRS 1986, 6). The report then addressed one of the fundamental questions of US research and development – the appropriate level of Federal support needed to maintain the preeminent position of US science. Citing the high cost and high risk of software development, the report states that Federal support appears justified, but notes that in "an atmosphere of budget austerity" alternative funding mechanisms, notably private sector involvement, must be sought. This section of the report highlighted the conundrum facing policy maker during the mid 1980s. How to best balance the "needs" of the scientific community required to maintain research and development preeminence while at the same time supporting the funding priorities of the Reagan administration and enduring a massive federal budget deficit.

The report examined in detail the impact that ICTs have had on scientists and research institutions returning to the theme that accelerated pace of computing development greatly enhances the conduct of scientific research, pointing out that the incorporation of microprocessors into scientific instruments "caus[ed] the distinction between separate computer and instrument to disappear" (CRS 1986, 7). The importance of this development cannot be overestimated, especially in terms of simulation. The report highlighted simulation several times and approached its development in terms of increased speed and power. The report offered a number of examples of simulation to illustrate the importance of the advent of the computer/instrument in scientific research: three dimensional molecular simulation;

modeling the disintegration of the West Atlantic Ice Sheet; modeling quantum reactions in chemistry, solid-state and nuclear physics, organic and inorganic chemistry, catalysts, astrophysics and astrochemistry, pharmacology, biochemistry, and molecular biology; the modeling of complex biological systems previously only possible through animal experimentation; and the simulation of social processes (CRS 1986, 8). Each example is a case of research made possible, not simply enhanced, by advances in computer technologies.

The same arguments regarding speed and power are brought forth in the report regarding supercomputers, especially their ability to model and simulate scientific and engineering problems (CRS 1986, 9). The processing power of supercomputers enables a speed of calculation that makes advanced computation in the fields of nuclear weapons design, cryptographic analysis, and integrated circuit design, among many others, possible (CRS 1986, 9). The authors of the report moved on to highlight the 1985 testimony of several scientists in front of the House Committee on Science and Technology on supercomputing claiming that massive federal investment in supercomputing was necessary in order to enable tremendous scientific advances in experimental physics, chemistry, and biology and magnetic fusion. One witness mentioned that super computing resources in 1985 were inadequate to ensure the promised advances. The report also cited witness testimony calling for more powerful supercomputing resources for the design simulation of the proposed Superconducting

Super Collider (SSC). The use of this testimony is interesting in hindsight for several reasons. First, it highlights the understanding in the scientific community that simulation was beginning to play and would continue to play an important role in research. Second, it should come as no surprise that researchers would testify that resources were inadequate and call for the funding of new supercomputers that would help their research and ensure their continued employment. Finally, using the example of the SSC, a program cancelled by Congress in 1993 after massive cost-overruns, mismanagement, and shifting funding priorities at the end of the Cold War, highlights how the momentum of scientific funding can shift rapidly in a short timeframe. At the time that the report was published in 1987 the SSC was one of the premier large-scale US scientific projects to receive Federal support. Despite $2 billion having already been spent, the SSC was still cancelled, proving that appropriations and momentum alone cannot ensure the inevitability of a scientific program, especially large, fixed-cost scientific infrastructure projects.

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 (NSF December 7, 1960). 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 computer 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 its 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 infrastructural investments in computing and distribute the potential benefits of its overall investment strategy to its many constituents.

NSFNET

The Foundation's nano-activities represent the synthesis of five decades of NSF history and are shaped by the triumphs and setbacks of that history. The direct antecedent to the NBIC initiative is the success that the NSF had with the commercialization of the Internet. However, two very important Cold War era experiences helped shape the organizational structure and operation of the Foundation in profound ways that enabled the positive development of the 1980s and 1990. The first is the NSF's participation in the International Geophysical Year (IGY) from July 1957 through December 1959, which saw its full emergence as a permanent federal agency and produced a lasting Foundation presence in Antarctica and a continued commitment to international, cooperative science. The IGY also produced the first bitter lesson as the Foundation engaged in budget battles and bureaucratic turf wars with the Department of Defense. As the Cold War intensified with the launch of Sputnik in October 1957 the NSF's importance as a critical funding agency for basic research and the development of young researchers and engineers grew. By the turbulent mid-1960s perceptions of deteriorating social and infrastructural conditions in the US compelled Congress to push the NSF to shift its focus away from basic research and toward applied social science that "produced results." After Congress altered the Foundation's mandate 1968 to emphasize the support of applied research, and increase congressional oversight, the effect was a pronounced shift in the agency toward interdisciplinarity and applied research into projects of national scope and importance. The experience with large scale applied research in the early to mid-1970s, and the subsequent shift back toward basic research in the 1980s provided the NSF with a solid institutional foundation from with to approach the development and oversight of NSFNET.

The NSF's successful stewardship of the Internet from a government/ military/academic network with a small community of specialized users to a fully commercialized information system by 1995 with long term social and economic impact raised the bar for future NSF sponsored techno-scientific initiatives. The management of the NSFNET and its subsequent commercialization demonstrated the NSF's ability to successfully manage complex systems that rely on interdisciplinary cooperation and that provide a substantial return on investment, and generate significant advances in R&D that is in the strategic national interest of the US without having to exercise direct control of the entire research and development process. By playing a critical role in the NNI and spearheading NBIC convergence, the NSF hopes to replicate and improve upon its success with the commercialization of the Internet.

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, 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 1983, 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 1983, 4-6). Additionally, the NSF Director announced the Foundation's intention to "develop advanced computational resources locally at universities" (Knapp 1983, 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 1983, 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)[15]. Mosaic built upon research conducted at the NSF Supercomputing Centers in the storage, archiving, and retrieval of information from across the NSFNET,

[15] http://www.nsf.gov/news/news_summ.jsp?cntn_id=103050

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 NSF and the Emergence of the Internet

A particularly interesting case study of the NSF's involvement in the development of the nascent Internet is provided through the history of Gordon Bell's employment and activities at the Foundation in the mid-to-late 1980s. Bell, a 23 years (1960-1983) veteran of Digital Equipment Corporation (DEC), served as the first Assistant Director of the National Science Foundation's Computing Directorate in 1986-87, and led the multi-agency the National Research and Education Network (NREN) panel that produced an influential 1987 report that proposed the basic infrastructure of what we now recognize as the Internet.[16] Bell was also an author of the first High Performance Computer and Communications Initiative, culminating in the High Performance Computing Act of 1991.

In an April 1995 interview with the David K. Allison, Curator, Division of Information Technology and Society, National Museum of American History, Bell elaborated upon his tenure at the NSF and discussed his involvement in the development of the Internet.[17] Asked by Allison about his experiences moving from

[16] Federal Coordinating Council on Science, Engineering and Technology. (November, 1987). "A Report to the Office of Science and Technology Policy on Computer Networks to Support Research In the United States: A Study of Critical Problems and Future Options." Volume I, Recommendations.

private industry to the NSF, Bell responded that he viewed the Foundation as "another startup," attributing this to the presence of Erich Bloch in the Directorship (1984-90). Bloch had joined the NSF from IBM where he had been responsible for the development of the IBM 360 computer. Bloch was in many ways a radical departure from the previous Foundation directors. He was the first director to come from private industry, the first without a PhD, the first non-academic, and the first foreign-born director of the NSF. In the interview Bell recollected Bloch's instructions to him upon assuming leadership of the Computer and Information Science and Engineering Directorate.

> His charter to me: "Pull all of these various parts of NSF that do computing research together and create the directorate for computing – we'll call it CISE for Computer and Information Science and Engineering." That was a tremendously exciting thing to do. I loved it. It was a nice size group – about 50. Our budget was $120 - 130 million. I don't know what the budget is today, probably $2 or $3 hundred million. That was just a great time, -- to get the various divisions in place and to establish their direction and priorities.

Bell's comment highlights the changing structure of computing inside of the NSF

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[17] All quotes from Bell are taken from his April 1995 interview with David K. Allison, Curator, Division of Information Technology and Society, National Museum of American History, Smithsonian Institution. http://americanhistory.si.edu/collections/comphist/bell.htm

during the mid 1980's, as diverse programs across various directorates were either consolidated into the newly formed CISE or tasked with cross-directorate cooperation. Prior to the consolidation of computing activities under Bell, sections of the Foundation's computing research was distributed across directorates and programs and served to foster innovations focused on more narrowly defined disciplinary pursuits. As the convergence of information and computer technologies accelerated in the 1980s, so to did the organizational convergence of once separate fields, such as electrical engineering and information science.

Throughout the interview, Bell stressed the importance of Bloch and his management philosophy and techniques to the reorganization of computing activities at the NSF. Bell stated that,

> I don't think I could have dealt with NSF under anybody but Bloch. He had already been there for two or three years and changed NSF already. He really had influenced that organization enormously, in delegating responsibilities, cutting through bureaucracy, everything. NSF doesn't have a departmental boss, it isn't under the Department of Commerce, so we didn't have a lot of hierarchy. There was no hierarchy above us. It had a board of directors, the National Science Board. So in a sense, it was only a thousand person organization. So it was really quite small. And I'd say

> entrepreneurial, too, at that time, even though every congressman and senator tried to influence the outcome for their constituents.

Bell's comment points toward the interesting dichotomy between internal and external bureaucracy at the NSF. On one hand he lauds Bloch for and cutting through the internal bureaucracy at the Foundation where programs incorporate a mix of career staff and academic specialists who rotate through the Foundation for several years, reviewing and administering grants in their area of disciplinary expertise. On the other hand, Bell credits the absence of an interfering external hierarchy for allowing the NSF a level of operational freedom that many other federal agencies lacked. If, according to Bell, the NSF enjoyed a substantial level of autonomy, and the process of cutting through internal bureaucracy by delegating responsibility was the key managerial innovation brought about by Bloch, then the entrepreneurial potential of the NSF was merely a dormant, or underutilized, feature of the organization. In Bell's recollection of his experiences at the NSF under Bloch, he inadvertently highlights the advantages of the grant-based, infrastructure-oriented, operational strategies of the Foundation.

By the mid-1980s the external autonomy of the NSF was certainly more secure than during the cautious days of Waterman's leadership, owing to more than three decades of experience engaging in, or strategically avoiding, the political battles for prominence and funding in Washington. Bell mentions congressional interference almost in passing, yet political pressure certainly had been a major influence on the Foundation, even preceding its inception in 1950. What he fails to mention is that the NSF was, and is, dependent on continuing congressional appropriations to remain operationally viable, and therefore subject to at least some persistent external pressure to conform to certain expected standards and operational norms. These pressures manifested themselves in annual, rather than daily or monthly cycles. This allowed the Foundation a great deal of operational autonomy and wide latitude to fund and oversee support for even the most esoteric scientific research, provided it could be justified as contributing in some capacity to the NSF's overall mission. Additionally, with the importance of "basic research," and the NSF's role in supporting it, rhetorically secured through broad political acceptance of the tenets of the linear model, the Foundation was able to operate with a degree of freedom by the mid-1980s.

The absence of concern over congressional oversight in Bell's statement is telling, indicating that by the mid-1980s questions over NSF appropriations were focused on "how much" money would be made available rather than "if" funds would be disbursed at all. The Foundation's permanence was, for all practical purposes, no longer in any doubt. It was in this environment that Bloch was appointed director. He was certainly an interesting choice by the Reagan Administration to lead the NSF, as he fell far outside the mold of previous directors. However, his appointment seems to be a case of the right person, in the right place, at the right time. The relative institutional security of the NSF at the time of his appointment, as well as a perceived crisis allowed him to institute the more "business-like" changes that Bell lauds, and attract individuals, like Bell, from outside the NSF's academic orbit to Washington.

After joining the NSF and taking over the CISE Directorate, Bell set about reorganizing computing activities at the Foundation initially encountering "a lot of push back." Bell was successful in bringing the supercomputing centers – Carnegie Mellon, Cornell, Princeton, UCSD, and the University of Illinois – into the CISE yet he failed, in his own words, "to integrate supercomputing into computer science." The conflict within the NSF between the new computer science directorate and supercomputing mirror tensions being played out in the field, as the need for supercomputing resources was being eroded by parallel processing and networked computing. Supercomputers carried an extremely high fixed cost and were highly specialized, often running code designed for a specific system, of which there may only be a handful in operation. The operation of these systems required specialized communities of researcher and operators that constituted formidable interest groups. Bell recalled in his interview that, despite resistance, he

> …did influence supercomputing and spent a lot of time just working on the program, pulling it together, and building a strategy: "Folks, we're all going to run UNIX. We need standardization because it is a question of

> programs. To use supercomputers you've got to have a vast array of applications. I want to integrate that into the computer science community where the folks all speak some dialect of UNIX."
>
> …I said I want compatibility up and down the line so I can take a program from an SGI or a Sun and run it on a super or minisuper from Convex. Another thing I asked for: "I want you to support a whole set of new and diverse kinds of computing facilities. We need to get into massive parallelism. This is after we've got stability." I wrote a lot of policy papers about the future and the need for flexibility.

Bell was prompted to action in part by the fact that two of the supercomputing centers that he inherited, UCSD and Illinois, were running Department of Energy code. Bell refused to devote time and resources to developing and maintaining another agencies code, something he thought was "stupid." While on the surface Bell's refusal to support DoE code may seem like nothing more than petty inter-departmental squabbling, it in fact was part of his larger push to promote interoperability by eliminating pockets of highly specialized programming, instrumentation, and practices that hampered interoperation with other systems and had become self-perpetuating entities.

Bell's influence extended beyond pushing for interoperable systems, as the head of

CISE he was able to wield influence on the distribution of the directorate's funds. He recalled that the head of the supercomputing program was planning to expand to other campuses, something that Bell thought premature at best. Worried that planning for the new centers was proceeding without adequate knowledge of the demand for more supercomputing capacity, Bell opposed the plans. In his estimation the program director for supercomputing

> … was playing the Washington trick – the way you get power is through budget, the way you get budget is to get a program started. The reason we've got such a horribly unbalanced budget is because of the bureaucrats, who in fact get something funded, then their constituents say: "Hey, you can't cut this, I'm dependent upon this."

Throughout the interview Bell displays a fundamental admiration for entrepreneurship and market principles, and impatience with bureaucracy and waste. These attitudes are prominently on display as he discusses his battle with the supercomputing community. Bell seems especially irked by the inability of the supercomputing centers to interoperate, something he considered a waste of resources. The fact that the centers used supercomputers from different manufacturer made interoperability a necessity.

According to Bell, things came to a head when ETA Systems, a spin-off of Control

Data Corporation (CDC) failed to deliver the ETA-10 supercomputer planned for the John Von Neumann Center at Princeton on time. Bell refused to approve their budget as a countermeasure. He recalled that,

> …this was a totally novel concept within the government. How can you cut a center's budget? Congressmen, senators, staffers were all calling my office. I said: "This is not a grant, this is a contract. You have no machine so why would do [sic] we pay?" Well CDC needs the money. Ok, when CDC can deliver the machine, they get the money. CDC never delivered. And Erich [Bloch] backed me up.

In a subsequent comment Bell again stated that his stance could have only functioned with Bloch at the helm of the Foundation. Without reading too much into Bell's admiration for Bloch, it is apparent that there was a certain amount of "action" happening in computer science at the NSF, partially a result of both Bloch and Bell. Perhaps their shared experience in private industry and computer engineering, the relative external autonomy that Bell had previously mentioned, and measures to consolidate computing activities at the NSF created "space" necessary for potentially paradigm shifting changes to computing to take place at the Foundation.

In addition to battle over establishing and funding new supercomputing centers, Bell also shifted control of NSFNET away from the supercomputing program and established networking as its own division reporting directly to his office as the Assistant Director of CISE. In the interview, Bell claims that he based this decision on his experience at DEC, where he had worked on building DECnet, a networking technology that was designed to make a "collection of computers work as one." He felt that an independent group focused exclusively on networking would better serve the needs of users spread across the constellation of network users. Nevertheless, this move must also be viewed in light of Bell's run-ins with the supercomputing program. His experience with mini-computing and the VAX put him on a career trajectory very different that the supercomputing folks, and his bias toward networking and parallelism certainly influenced his opinion of the supercomputing program. Nevertheless, his biases appear validated, as supercomputing demand has diminished greatly as networking and parallel processing have exploded.

During his tenure at the NSF, Bell was appointed Chairman of the Subcommittee on Network Infrastructure and Digital Communications for the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET). During a three day February 1987 workshop in San Diego the group developed a preliminary plan for a National Research Network with three-phases of increasing bandwidth, based on what Bell describes as an "aha" moment on the final day when he drew a slide to illustrate his concept (see figure 1). Bell's plan was to increase capacity from 56 kilobits to 1.5

megabits by 1990 by using T1 trunk lines, then increase bandwidth up to 45 megabits during the first half of the decade, and finally migrate to gigabit capacity by the late 1990s.

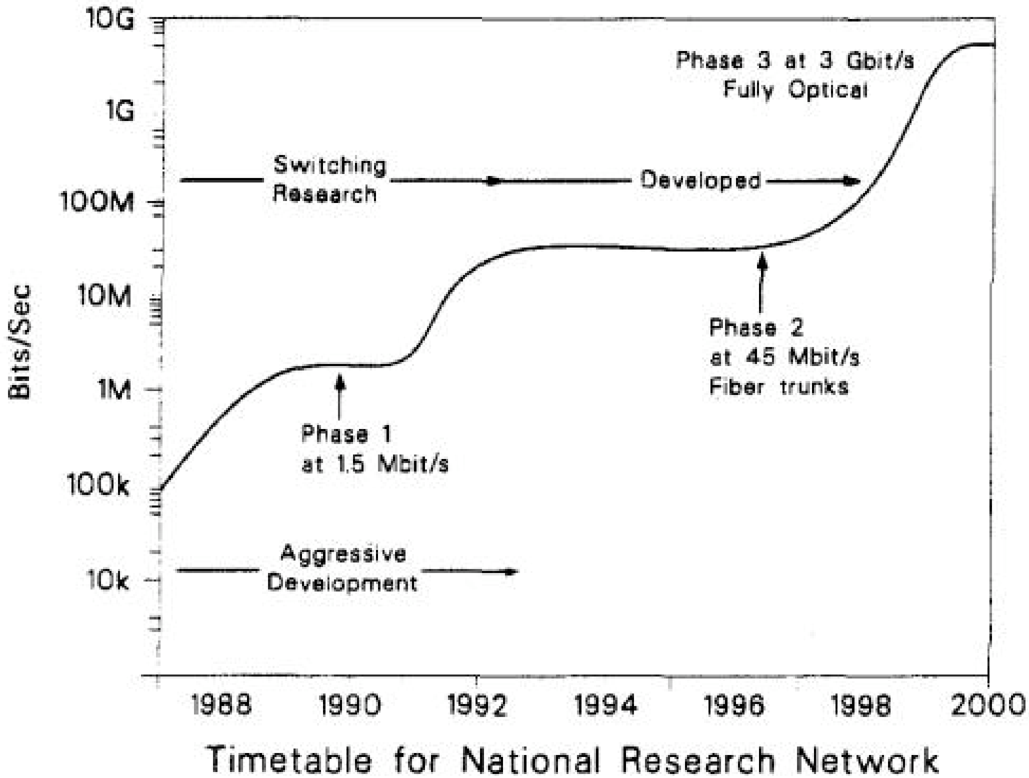

Figure 1. Plan for NREN created at the February 1987, San Diego NSF sponsored meeting. Source: Bell interview.

Bell's mantra at that meeting was to insist on an operational network as soon as possible, realizing that "without a system running no one is going to believe you about the future." Once operational at what Bell considered a minimal acceptable level of service, persuading stakeholders that more bandwidth was possible became infinitely easier. However, the mission of the working group meeting in San Diego was to network the supercomputing centers, something that precluded them from examining the potential end-user applications that could accompany a more robust network with greater capacity. Bell recalled that,

> It [the network plan] was proposed to be used for supercomputing. Well, all the networkers knew it wasn't supercomputers. There was no demand. We knew that supercomputers needed bandwidth, they needed to communicate, but when you really force people to use them they would prefer their own machines. I talked to various folks at DOE about this dilemma. If you really want to get a lot of power together why don't you have Los Alamos run all your computers. You've got plenty of power, you have it together. The networking is just fine. In supercomputing there is no reason to have more than one computer in the center of the earth.

The fact that the federal government had sunk a great deal of fixed costs into the establishment and operation of the supercomputer centers forced the National Research Network group to consider the linking the supercomputer centers first and foremost among their priorities. While those present working on networks, according to Bell, realized that supercomputer demand was waning, their presence forced the construction of high-speed and robust network backbone between the centers that would form the basis of the NSFNET backbone.

Accidental Success?

The idea that the NSF experienced unexpected and unprecedented success when it initiated the commercialization of the Internet in 1990 with the relaxation of its "acceptable use" policy is borne out by research done by Shane Greenstein and presented in "Commercialization of the Internet: The Interaction of Public Policy and Private Choices," which claims that the commercialization of the Internet "surpassed the forecasts of the most optimistic managers at NSF (Greenstein 2001, 1)," and was aided in part by the several NSF policy decisions. These decisions include the NSF focus on interoperability and cooperative engineering which allowed for relatively problem free interconnection of diverse with the public backbone (Greenstein 2001, 10), as well as and its funding and establishment of decentralized regional networks allowing a degree of user shaping of technology (Greenstein 2001, 32-33). Additionally, Greenstein demonstrates that the NSF's commercialization of the Internet occurred at an opportune moment when a combination of economic, business, and structural factors made Internet research and development and rapid commercial diffusion possible.

The success of the Internet may seem to be merely fortuitous, however its importance cannot be understated especially when compared to the challenges that other government sponsored technologies have face in technology transfer and rapid diffusion. Greenstein argues that many (although not all) government sponsored technologies face substantial challenges in commercialization due to specific engineering specifications that non-commercial clients(DoD) demand, which limit some of the practical applications for a commercial market (Greenstein 2001, 5) and require extensive reengineering or the development of complimentary technologies to become commercially viable. The policy decisions and the project management style that the NSF employed, broad support for computer research and the founding of university based research centers, contributed to the development of a sufficiently incubated, flexible and robust technological system that was easily adapted to suit commercial purposes. Greenstein persuasively argues that a combination of beneficial social, economic, and technological conditions in the early 1990s and advantageous NSF policy decisions propelled the rapid and successful diffusion of the commercial Internet.

While the NSF managed to hit a home run with the of unanticipated aid of several conspiring outside factors, it is important to look at the influential policy decisions that Greenstein argues contributed significantly to the initial success of the Internet. To do so we must turn our attention to the history the NSF and the lessons of its first thirty years that shaped the Foundation's success in the 1980s and 1990s. The NSF's successful stewardship of the Internet from a government/military/academic network with a small community of specialized users to a fully commercialized information system by 1995 with long term social and economic impact has raised the bar for future NSF sponsored techno-scientific initiatives. Combining advances in such disparate fields as solid state engineering, software development, and telecommunications infrastructure, the Internet is an extremely successful example of the convergence of multiple, separately funded and administered, technology initiatives to create a large-scale technological system (Abbate, 1999). The NSF's role in the development and commercialization of the Internet demonstrated the Foundation's ability to successfully manage a network of interoperable systems predicated upon interdisciplinary cooperation, provide a substantial return on investment, and generate significant R&D advances in the strategic national interest of the US without having to exercise direct control of the entire R&D process.

Chapter Eight: The NSF and the Nanotechnology Frontier

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, science and technology 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.[18] 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 end of the Cold War produced a sense of disorientation for federal science and technology funding agencies accustomed competition with the Soviet Union determining strategic priorities and funding patterns from year to year. Rather than a logical transition from one frontier to the next, the end of the Cold War was a disruptive break in this continuum – the disappearance of a proxy frontier for science, and for the NSF. 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*,

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[18] LexisNexis Academic search 02/06/2008. LexisNexis Congressional Publications search on 02/06/2008.

> The Berlin Wall came down on September 11, 1989 [sic][19], 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 science and technology 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.

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[19] 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).

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" (1986, 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.

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, 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.

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 science and technology 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, 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[20].

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 Research (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

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

on ultra fast and ultra dense electronic devices and chips in the early 1990s (Department of Defense 2005, 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, 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, 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, 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, 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, 11), and completed a draft plan for the NNI, which Roco successfully pitched to the OSTP in March 1999 (Roco 2007, 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, 11). The Clinton administration elevated nanotechnology 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, 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, and 2007). Berube describes this rhetoric as "hyperbolic" and claims that Roco "seems to revel in fear appeals and nationalistic rhetorical flourishes" (2006, 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, 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, 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.

Nano-Bio-Info-Cogno Convergence

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 profound, paradigm-shifting, breakthroughs that the consortium involved in 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, 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, 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, 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, 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, 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.

The achievement of NBIC convergence rests on the innovative coupling of one or more of these technologies, or technological processes that they enable. Advances in the separate fields of Nano, Bio, Info, and Cognitive sciences need to be combined through the creation of interfaces that allow for the interoperability of these previously separate fields of research and development. The report points to the creation of and application of "systems approaches, mathematics, and computation in conjunction with NBIC" to create new fields of knowledge and

> "allow 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 (NBIC, ix)."

By emphasizing the natural and human worlds and scientific knowledge as interoperating components of a complex hierarchical system, the NSF/DoC report privileges a systems-based approach to understanding technological change, and is situated in a tradition that extends from the Second World War, through the Cold War, and the proliferation of Internet technology in the 1990s. There is also an extensive body of academic literature that examines this history, the development of complex technological systems, and the application of systems research to technological change.

The report lists a number of potential outcomes that may arise in the next ten to twenty years from NBIC convergence and become critical building blocks for wider societal change. These include:

> "improving work efficiency and learning, enhancing individual sensory and cognitive capabilities, revolutionary changes in healthcare, improving

> both individual and group creativity, highly effective communication techniques including brain-to-brain interaction, perfecting human-machine interfaces including neuromorphic engineering, sustainable and "intelligent" environments including neuro-ergonomics, enhancing human capabilities for defense purposes, reaching sustainable development using NBIC tools, and ameliorating the physical and cognitive decline (NBIC, ix)."

The report also makes clear that beyond shaping and controlling the physical future of the human body and mind, and managing technological change to achieve favorable societal outcomes that these potential technological advances need to be critically examined immediately in order to maximize their potential economic yield. NBIC convergence is being viewed with an eye toward ensuring a future return on investment and as a potential catalyst for national and international economic growth. In this regard NBIC convergence is reminiscent of the government, military, private industry, and academic cooperation that successfully married innovations in a number of scientific and engineering disciplines to create networked computing and communications. 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 network effects that could arise from NBIC convergence.

In order to achieve these potential benefits the NSF/DoC report identifies several strategies for the research, development, and implementation of NBIC technologies. Key among these strategies is preparing the major stakeholders in NBIC convergence, government agencies, the military, academic and private researchers and facilities, as well as potentially affected economic and societal sectors for the changes in store. To achieve this, the report advocates investing in multidisciplinary curriculum at all educational levels inside of an integrated and hierarchical system, to acclimate future researchers and users to NBIC technologies (NBIC, x). The result would be, in effect, to set the table for what the report dubs "a new renaissance, embodying a holistic view of technology based on transformative tools, the mathematics of complex systems, and unified cause-and-effect understanding of the physical world from the nanoscale to the planetary scale (NBIC, x)."

The report also identifies six overarching categories of NBIC convergence for special consideration, including three that are areas of interest for this dissertation due to their potential for profound effects on mass communication and enduring effects at the societal, national, and international levels (NBIC, xi). The three categories of interest are: enhancing group and societal outcomes, national security, and unifying science and education. Under the rubric of enhancing group and societal outcomes the report outlines a number of applications and services based upon the convergence of all four branches of NBIC technology at the nanoscale. The visionary project for this category is an experimental technology system named *The Communicator* that would be used to enhance the efficacy of persuasive communication by eliminating or compensating for language differences, cognitive disabilities, physical distance and knowledge differences (NBIC, xi). While the prospect of a technological system that enables near-universal communication and will facilitate understanding is appealing, the potential abuses of *The Communicator*, especially as a means of less than scrupulous persuasion or propaganda, should not be ignored.

The same optimism and caution should also be applied to the predicted emphasis on NBIC convergence as a means of improving or bolstering national security. Concerns range from individual privacy issues to a further accentuation of and dependence on virtual and artificial systems of security and warfare. The NSF/DoC report identifies seven areas in which NBIC convergence can enhance current US security regimes, including:

> "data linkage and threat anticipation; uninhabited combat vehicles; war fighter education and training; responses to chemical, biological, radiological and explosive threats; war fighter systems; non-drug treatments to enhance human performance; and applications of human-machine interfaces. (NBIC, xi)"

The application of NBIC technologies, rooted in a hierarchical system of natural, human, and technological interdependence, to national security challenges seems to be another step toward the total integration of individuals and human populations into a rationalized matrix of technology designed to mitigate contingency at the expense of privacy and civil liberties. Furthermore, despite good faith assurances from the authors of the NSF/DoC report that NBIC convergence research and development will require stringent ethical checks and balances before implementation, and that every effort will be made to ensure individual privacy, matters of national security are subject to wide-ranging classification that may preclude transparency and inhibit independent monitoring by civilian agencies via mechanisms such as the Freedom of Information Act. This is not merely alarmist rhetoric, especially in the post September 11th climate in the United States, as many of the privacy and civil liberties issues at hand take a back seat to more pressing security concerns.

The unification of science and education has the potential to transform the United States educational system, perhaps subtly, through educational policy agenda setting. The benefits of a comprehensive science education policy are manifold, and include preparing potential researchers and users (consumers) of NBIC technologies for the distinct possibility of a US-led global economy driven by the application of nanotechnology to an increasing array of consumer goods. The emphasis on a comprehensive education program also underscores the fact that NBIC convergence is a top governmental priority with a long developmental horizon and strong funding commitment from the network of governmental agencies that support it. By investing heavily in the education of a future generation researchers and users, the NBIC consortium is again making a strategic investment from which it aims to reap tremendous financial as well as societal benefits.

An additional area of priority that the NSF/DoC report emphasizes is the support and funding of a societal effects component of NBIC convergence to monitor and ensure the ethical implementation of research and development at all stages of development. The report calls for oversight of the entire NBIC convergence operation through a coordinating and oversight consortium consisting of the key governmental stakeholders (NBIC, xii). The goal of this consortium (it is unclear in the report whether this function is, or should be, carried out by the current National Nanotechnology Initiative) would be, in addition to promoting and funding NBIC convergence, to address the potential negative effects of this research and development program. The report states that,

> "Research on societal implications must be funded, and the risk of potential undesirable secondary effects must be monitored by a government organization in order to anticipate and take corrective action.

> Tools should be developed to anticipate scenarios for future technology development and applications (NBIC, xii)."

The importance of this recognition should not be dismissed simply as widow dressing, but rather should be seen as a well-considered strategic initiative.

The benefits of early self-regulation are twofold. First, it demonstrates the authors' understanding that self-regulation, and the perception of transparency, is an effective method for garnering public support for, and minimizing public criticism of, the NBIC convergence program. Additionally, it inoculates the NBIC initiative from unwanted outside investigation and oversight to some degree by providing the major stakeholders the ability to credibly claim that mechanisms are in place to ensure the promotion of ethical research. Proactive self-regulation is also an insurance policy that protects the project should it fall under congressional scrutiny. Secondly, self-regulation is a control mechanism that can be used as an effective tool by the consortium to set the national NBIC agenda and eliminate undesirable outcomes. It allows the NBIC consortium to reign in, or eliminate, controversial or unpopular research. This provides the consortium with the ability to carefully manage, steer, and influence the societal outcomes that NBIC research may produce.

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, 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, 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, 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 bi-directional 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.

<u>Science Fiction?</u>

The remarks of Phillip J. Bond, the former Undersecretary for Technology at the U.S. Department of Commerce, "Preparing the Path for Nanotechnology," presented in the "Introductory and Summary Comments" section of the NSF-sponsored report *Nanotechnology: Societal Implications – Maximizing Benefit for Humanity* (Roco and Bainbridge 2003, 16-21) are unusually strong in their evocation of scientific manifest destiny. Bond's nano-enthusiasm is unrestrained. He begins his presentation by describing the National Nanotechnology Initiative as "a bold, visionary effort to harness the extraordinary power of matter at the atomic level," and registers his wonder at "how far we've come in so short of time – lifting nanotechnology out of the genre of science fiction, into our academic and industrial laboratories, and more recently, into the marketplace" (2003, 16). While the enthusiasm for nanotechnology displayed in these statements is not unusual, the centrality of directed human agency that Bond emphasizes is worthy of note. To "lift" nanotechnology out of "science fiction" directly implies that without the conscious efforts of the coalition of actors assembled at the 2003 meeting – the "we" in Bond's statement – nanotechnology would remain nothing more than a realm of fanciful speculation. The agency that Bond describes is not the work of the scientists and engineers working at the nanoscale. Rather it is the top-down agency of those involved in the National Nanotechnology Initiative "lifting" nanotechnology out of the theoretical realm and placing it into academic and industrial labs and the marketplace. To paraphrase Alfred Chandler (1977), Bond is describing the very "visible hand" of the cadre of government officials, academic power brokers, and business leaders involved in making the nanotechnology "revolution" a reality, and specifically thanks "President Bush and bipartisan support in Congress" as well as "the NanoBusiness Alliance" (2003, 16) for the passage of the 21st Century Nanotechnology Research and Development Act. The Act put the NNI into law and committed a base federal investment of $3.7 billion over four years, excluding independent investments expected from the Departments of Defense, Homeland Security, and the National Institutes of Health, and establish the formal administrative infrastructure for the NNI.

Bonds remarks to the workshop are based upon ten "messages" about nanotechnology research and development, governance, and oversight. All ten messages will not be examined here, however several of his messages are particularly instructive examples of the nano-evangelism present in the highest reaches of the federal government, academic, and business communities and the rhetoric employed in support of nanotechnology funding and research and development. His "First Message" is his "ironclad belief" that "nanotechnology – with its myriad evolutionary and revolutionary applications – is coming and it can't be stopped" (2003, 17). Bond declares that nanotechnology is an "inevitability," and cautions against "some voices around the world [that] are calling for a slowdown or even outright moratorium on nanotechnology research and development" (2003, 17). Before moving any further into his "First Message" Bond simply announces that nanotechnology is inevitable and dismisses its critics first by referring to them as "voices" without ever naming a single person or group who may advocate a slowdown or moratorium. By refusing to name the critics of nanotechnology, Bond is able to both conflate all critics of nanotechnology into a single set of disembodied voices spread "around the world," as well as discount their critiques with a single sweeping statement that the desire of the "voices" to slow or stop research and development is pointless because nanotechnology is inevitable. Rather than acknowledge that some of these "voices" may have legitimate concerns, Bond instead advises them to "prepare for the inevitability of a world blessed with nanotechnology and nano-enabled products and services" (2003, 17). The quasi-religious use of "blessed" to describe the emergence of nanotechnology also serves to discredit critics that would sand in the way of the obvious gift of nanotechnology being bestowed upon them. Not only is nanotechnology inevitable, according to Bond, so too are the attendant blessings of a world transformed by nanotechnology. The utopianism and determinism of Bonds "message" are nonpareil. He states that "The economic promise, the societal potential, and the human desire for rolling back the frontiers of knowledge—to go where no one has gone before—are forces that cannot be held back" (2003, 17).

Outer Space and Inner Space

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 nano-terrain 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, 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, 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 21st century" (IWGN 1999, 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. Pertinent examples include,

> If I were asked for an area of science and engineering that will likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering. – Neal Lane, Assistant to President Clinton for Science and Technology (1999, 1)

> 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, 2)

> Nanotechnology is the way of ingeniously controlling the building of small and large structures, with intricate properties; it is the way of the future, a way of precise, controlled building, with incidentally,

> environmental benigness [sic] built in by design. – Roald Hoffmann, Cornell University, Chemistry Nobel Prize Winner (1999, 4)

Neal Lane, a former Director of the NSF, promises potential future breakthroughs by setting up nanoscale science and engineering as a frontier for exploration. The final quote by Hoffmann displays both the rhetorical optimism of future potential and the unfounded promise that manipulation of matter at the nanoscale carries with it an innate environmental "benigness," with little regard to potential unintended consequences. However, the Stormer quote represents one of the more interesting arguments for federal support of NSE, and directly references the Bacon/Cartesian model that ascribes dominion over nature to humanity and Bush's vision of an endless frontier. 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, 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, 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 or 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. Greenberg ([1967] 1999, 26) sees in technology an answer to the problems that proponents of basic science face:

> The predicament is that pure science is neither self-explanatory nor self-supporting. Its affiliate, technology, is both, and consequently has easily acquired a mass constituency, something on the order of the mass constituency that formerly gave allegiance to religion.

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.

One area for further study is the role that nanotechnology, the NNI, and NBIC convergence plays in post-9.11 U.S. security policy. A powerful economic and strategic shift from the “new economy” of the 1990s to the “Global War on Terror,“ marked by the bursting of the “Internet Bubble” and terrorist attacks of the United States in 2001, has produced wholesale changes in the generation of S&T policy. It stands to reason that in an era of heightened security concerns the management of large-scale science and technology projects will be subject to the pressures of shifting funding priorities and either respond and adapt or quickly fade away. The combined pressures of economic globalization and security vigilance should continue the trend of increasing glocalization and the implementation of neo-techno-nationalist policies (Yamada, 2002). Studying the evolution of US nanotechnology policy should provide both historical parallels to the formation of past S&T policy and unexpected trajectories arising from multiple streams of feedback.

Chapter Nine: Conclusion

The Theoretical Turn

The first chapter of French cultural theorist Paul Virilio's collection, "The Information Bomb," serves as a useful foil for contextualizing the NSF's involvement in nanoscale science and engineering and the NNI. Virilio's theoretical turn poses interesting questions about this endeavor and provides a philosophical lens through which it can be viewed. He writes,

> Science, after having been carried along for almost half a century in the arms race of the East-West deterrence era, has developed solely with a view to the pursuit of *limit-performances*, to the detriment of any effort to discover a coherent truth useful to humanity (emphasis original)(2005, 1).

This statement rings both true and false when the NNI is examined against it. The "race to the bottom," to paraphrase a term often used to describe the competitive pursuit of breakthroughs at the nanoscale, is itself a series of a *limit-performances*. Intervention at the nanoscale is fundamentally a transgression of limits. In order to manipulate the building blocks of life researchers must operate between 1 and 100 nanometers, roughly between the size of a single atom or molecule and a cluster of molecules. Roco, in a 2002 article explains why intervention at this scale is an object of intense research:

> Control of matter at the nanoscale means tailoring the fundamental structures, properties, processes and functions exactly at the scale where the basic properties are defined. Some structure and properties may be generated beyond what we have found in nature (Roco 2002, 488).

It is at the nanoscale that the fundamental properties and function of matter are defined. Obtaining control of matter at the nanoscale enables the manipulation of structures and the generation of new properties that exist outside of what is possible in nature. However, this is not to say that these structures and properties are unnatural. Rather, what Roco describes is more akin to nuclear fission, another revolutionary intervention at the limits of what is natural to create or unleash hitherto unknowable or uncontrollable properties. In this sense nanoscale science and engineering is a *limit-performance*; it occurs beyond the limit, boundary, and periphery of nature. Nanoscale science and engineering is therefore a frontier enterprise.

However, Virilio's statement that because science has been primarily concerned with *limit-performances* it has failed to discover any coherent truth that may benefit humanity is both a matter of conjecture and a matter of perspective. His argument focuses on the emphasis in (post)industrial societies on the promotion of science designed to provide demonstrable successes in the most literal sense, and is itself non-controversial. It is the second portion of his statement that is more problematic. While his contention that science has been distracted from discovering truths that would benefit society may be true to some degree, he fails to acknowledge that, at a minimum, the science he criticizes is claims to be a search for truth and socially beneficial. The tension between an ideal (proper) course of science and current (errant) course of science is nothing new.

This tension in the post-war U.S. science system has been explored in great depth by Greenberg ([1967] 1999; 2001) and Sarewitz (1996), and forms the basis for what both authors criticizes as the rhetorical excesses in U.S. science and technology policy. Nevertheless, members of the scientific community and federal science and technology bureaucracy regularly use rhetoric that proclaims in no uncertain terms that scientific research will both discover fundamental truths about the laws of nature and deliver great benefits to society. That this rhetoric often masks the uncertainty of outcomes from scientific research, especially basic research, highlights the interesting marriage of science and politics that lies at the heart of this dissertation. Basic science is engaged, ideally, in the objective pursuit of truth while politics is engaged in the pursuit and management of power. In order to maintain what Guston (2000) refers to as the post-war "social contract for science," government funding for science is secured through the promise of autonomy for the scientific community on one side and the production of research that enhances national well-being on the other. It is therefore useful for the scientific community, and its federal patrons, to demonstrate fidelity to the basic precepts of the contract. The difficulty of justifying expenditures on basic, undirected research has been elaborated upon earlier in this dissertation through Greenberg's ([1967] 1999) claim that because it is neither "neither self-explanatory nor self-supporting," basic research must claim a certainty of results, economic benefit, and societal enhancement when in fact this is impossible to prove. Therefore, rhetoric plays a significant role in the justification of federal funding of basic science, and masks the uncertainty of outcomes that may jeopardize the "social contract for science."

In a sense, Virilio's statement that science has been distracted from the "effort to discover a coherent truth useful to humanity" is turned on its head. Science is certainly not distracted from the fundamental importance of generating new scientific knowledge and demonstrating its importance to societal well-being. Rather, it appears all too preoccupied with demonstrating fidelity to these goals. The history of the NSF explored in this dissertation is rife with examples of the agency loudly proclaiming to support just what Virilio claims science doesn't. The problem lies in the fact that the range of true science that Virilio accepts does not extend far beyond the most fundamental, undirected, basic research. He does not recognize the legitimacy of applied research nor technological innovation. He argues that, "Modern science, having progressively become **techno-science** – the product of the fatal confusion between the *operational instrument* and *exploratory research* – has slipped its philosophical moorings and lost its way" (emphasis original)(2005, 1). Virilio decries the instrumentalization of exploratory, or basic, scientific research and firmly places applied science, engineering, and technology development outside of the boundaries of the acceptable. However, his statement is telling as it highlights the endurance of scientific elitism characterized by Vannevar Bush and Alan T. Waterman, two pivotal figures in the founding and early operation of the NSF. Both Bush and Waterman felt that basic research needed to be protected by clearly demarcating it from applied research and development, and developed, in Bush's case, and utilized, in Waterman's, a rhetorical strategy that linked investment in basic research to positive societal benefits. Yet even before the Sputnik launch in October 1957 refocused U.S. science policy on goal-oriented research, and therewith intensified the NSF need to link basic research to positive downstream outcomes and focus more intensely on funding research infrastructure, the boundaries between basic science, applied research, and technology development were fuzzy at best, especially when viewed in a political context that places a premium on demonstrable results. An example of this is the NSF's involvement in the Vanguard Satellite project as part of the 1957-58 International Geophysical Year. Although the satellite was designed to carry out some basic research experiments while in space, the project as a whole was overwhelmingly based upon applied research and technology development that NSF's funding subsidized. Additionally, cooperation with the Naval Research Laboratory on Vanguard demonstrates (at least partially) the overlapping scientific and political interests of the NSF and the military in the messy world of Washington politics.

Which leads us back to Virilio and his criticism of the instrumentalization of science producing the bastard form that he refers to as techno-science. He wants to decouple, or at least weaken the bonds between, techne and episteme. Although he decries instrumentalization, Virilio does not make a direct objection to the use of tools – microscopes, laboratories, Petri dishes – per se, but attacks what can be described as techno-scientific systems. These systems, like the NSFNET or the Network for Computational Nanotechnology discussed in this dissertation, simultaneously act as both the object and subject of research. Virilio is alarmed that the "technical instrument" and the "truth of scientific thought" are fused without regard to the fact that they are "two fundamentally distinct aspects of knowledge," leading science to be more concerned with "effectiveness" than "truth" (2005, 2). He regards the merger of the tools of research with the knowledge produced as dangerously elevating operational technology to the status of objective scientific truth. For Virilio, danger lies allowing the operational knowledge characteristic of techno-science to obscure more fundamental knowledge about the laws of nature. His argument focuses on the perceived disappearance of universal scientific Truth in favor of truths based on the internal logic of socio-technological systems, in which the process of knowledge generation and the knowledge produced are indistinguishable. He decries this process as "generalized virtualization," "post-scientific extremism," "science of excess," and "extreme science," and charges that the knowledge produced "is not so much encyclopedic as cybernetic, a knowledge which denies all objective reality" (2005, 2-3). Virilio wants to purify the frontier and return it to an Eden-like status – Eden before the apple was eaten.

Virilio's concern is the "*acceleration of reality*" through the virtualization of science through technology, specifically information and communication technologies (emphasis original)(2005, 3). He writes,

> Thus, after having largely contributed to the speeding up the various means for the representation of the world, with optics, electro-optics, and even the recent establishment of virtual reality, contemporary sciences are engaging, *a contrario*, in the eclipsing of the real, in the aesthetics of scientific disappearance (emphasis original)(2005, 3).

Virilio's concerns about information and communication technologies are nothing new and mirror the myriad concerns that have accompanied many of the technological advances in this field. The fact that his concerns rest so heavily on these technologies only serves to highlight the importance of information and information technologies to scientific research. This dissertation, in large part, has been about this importance. The NSF has been intimately involved in the information revolution in science; carving out a niche in the federal science funding and science policy apparatus as the agency that supports the development of information and communications infrastructure, information management, virtual simulation, and at the most fundamental level, raw information in the form of new scientific knowledge. If, as Chandler and Cortada (2002) claim, the United States is truly a "nation shaped by information," then the NSF's focus on information infrastructure since its inception in 1950 is both significant for the changes to science that Virilio decries, and to the shape of the political life of the nation. This dissertation has examined the influence of external feedback upon the NSF, encouraging it to adopt a rhetorical strategy that focuses on the positive social outcomes that arise from investment in science and technology, and an operational strategy of support for infrastructure projects that make the conduct of research, the education of scientists and engineers, and the development of tools for research possible. In responding to these external pressures, one recurring trope for the NSF was the frontier: the NSF reached back into its pre-existence and anchored itself to the nation it served by summoning the powerful imagery of Turner and Bush. Through these pressures and practices, the NSF indelibly shaped the course of science and technology in the United States and helped build the infrastructure that enables what Virilio describes as techno-science. The NSF has made destiny manifest by becoming an agency dedicated to building the infrastructure to support the generation of new knowledge on the scientific frontier, at the margins of the possible. By creating virtual spaces, as well as human and digital research networks, the NSF makes itself indispensable to the operation of research the relies upon this information infrastructure. Furthermore, the Foundation's involvement in building and supporting virtual frontiers for science – information management and control systems, supercomputing centers, the NSFNET backbone, or Network for Computational Nanotechnology – not only enables the expansion of U.S. science into hitherto unexplored spaces but helps ensure the survival of the NSF.

It seems somewhat paradoxical then that the "aesthetics of scientific disappearance" that Virilio describes is exactly what makes a great deal of nanoscale science and engineering research possible. In other words, the tools associated with nanoscale science and engineering, from the scanning tunnel microscope to advanced computer simulation environments, make the nanoscale appear. Without these technologies the nanoscale would remain impenetrable. In a sense then, nanoscale science and engineering is a techno-scientific enterprise. The tools cannot be divorced from the knowledge generated any less than the network of physical infrastructure that spread across the North American continent in the preceding four centuries can be separated from the eventual establishment of the nation. This is not an attempt to elevate scientific knowledge and technology development to level of the establishment of a state, with its attendant social, political, and economic practices and institutions, but rather to acknowledge the role that open, and non-proprietary infrastructure plays in enabling scientific research and technological innovation. That the NSF plays such a prominent role in the establishment and support of these networks is no accident, but a conscious strategy employed by the Foundation to fulfill its broad mission to support both science and general well-being of the nation, as well as ensure its own perpetuation. Vannevar Bush's rhetorical re-imagination of science as the heir to the long-settled Western frontier, and the adoption of this concept by the NSF, has served the Foundation well. Beyond providing the justification for NSF support to even the most esoteric, yet scientifically valid, basic research with no plausible expectation of showing a near-term return on investment, it has also provided a philosophical temple for the Foundation to act as the consummate infrastructure agency producing the networked infrastructure the enables the exploration of new frontiers.

The settlement of frontiers is about the conquest of space, both literally and figuratively. Space must be colonized in order to become useful in the exercising of liberty and power, and networks of infrastructure must be established in order to first exploit, and then bind, the periphery to the core where power resides. Sovereignty must be established if full benefit is to be extracted from the colonization of frontiers. The NSF, as an agency of the U.S. federal government that derives its funding from tax-payer funded congressional appropriations, is embedded in the political context in which it exists and is obligated to uphold its legislated mission to support the national interest. It is therefore reasonable to view the Foundation's infrastructural activities, in part, as an attempt to establish sovereignty over the frontiers of science. The tremendous concern over the role that science and technology play in national economic competitiveness, and the full fledged acknowledgement of this reality by the start of the Clinton administration discussed earlier, lend credence to this claim. However, it is worth noting that scientific discovery and technological innovation are based on the sharing data and information across national and regional boundaries. Innovation has become a global enterprise. Yet concerns over national interest remains the prime motivator for national agencies tasked with supporting scientific research and technological development. Bruno Latour addresses this seeming contradiction through his discussion of networks in his book *We Have Never Been Modern* (2002, 118).

> Technological networks, as the name indicates, are nets thrown over spaces, and they retain only a few scattered elements of those spaces. They are connected lines, not surfaces. They are by no means comprehensive, global or systematic, even though they embrace surfaces without covering them, and extend a very long way... Every branching, every alignment, every connection can be documented, since it generates tracers, and every one of them has a cost. It can be extended almost everywhere; it can spread out in time as well as in space, yet without filling time and space.
>
> ...
>
> [I]f we had had only telephones and television, railroads and sewers, Western domination would have never appeared as anything but the provisional and fragile extension of some frail and tenuous networks. But

> there is science, which always renews and totalizes and fills in the gaping holes left by the networks in order to turn them into sleek, unified surfaces that are absolutely universal.

For Latour, science, or knowledge generated from its pursuit, fills in the blanks between the physical traces of infrastructure that stretch across space. If we extend the definition of scientific knowledge to include ideology, or the systematic organization of ideas, as Latour hints at by mentioning Western domination, then networked infrastructure is influential in the establishment of sovereignty over space. The lines and channels of infrastructure turn the empty spaces between nodes of a network into semiotic space made sovereign by the extension of ideology. Hodge and Kress (1988, 3) describe this phenomenon as the construction of ideological complexes, in which "dominant groups attempt to represent the world in forms that reflect their own interests, the interests of their power." However, when extending the idea of ideological complexes to the establishment of sovereignty over the empty lands of the scientific frontier one must confront the contradictory impulses of national interest and the universality of fundamental knowledge.

There are two avenues to overcome this contradiction. The first is a kernel of truth in Virilio's denunciation of techno-science. In a system that fuses technology with universal knowledge it is possible to extend dominion over at least part of the universal through the development of proprietary systems and/or physical infrastructure that allow the builder the ability to enclose the spaces in which this knowledge is acted upon for goal-oriented purposes. Even open, global systems extend dominion into spaces that extend beyond the political borders of nations through localized infrastructure and technology. At the turn of the millennium over half of the world's Internet traffic flowed through information infrastructure in the Northern Virginia suburbs of Washington, DC, only miles from the offices of the CIA, Pentagon, DARPA and the NSF (Ceruzzi 2008). It is unsurprising that the conglomeration of information and communication technology firms, Internet service providers, and government information systems should occur so close to the federal patrons for computer networking, yet the fact that half of the global volume of data on the Internet passes through infrastructure in the Washington suburbs allows the U.S. government a great degree of sovereignty over this seemingly global and unruly cyberspace. Gertrude Stein's phrase "there is no there there," has often been used to describe cyberspace, but falls flat when examined against the historical development of great portions of the technical infrastructure and operating protocols of the Internet by U.S.-based, and federally funded, researchers and engineers, and the reality of where the physical infrastructure is located. Infrastructure matters. Therefore the examination of the operational ideology, political reality, and institutional history of the NSF is an important aspect of the story.

The second avenue to overcome the contradiction between national interest and universal truths is through the prism of "discursive infrastructure" as put forward by Paul Edwards in *The Closed World: Computers and the Politics of Discourse in Cold War America* (1997). His concept of "discursive infrastructure" helps elaborate how the space between the physical traces of networked infrastructure that Latour discusses are made sovereign by describing discourse as a form of bricolage. Edwards writes:

> A discourse, then, is a self-elaborating "heterogeneous ensemble" that combines techniques and technologies, metaphors, language, practices, and fragments of other discourses around a support or supports. It produces both power and knowledge: individual and institutional behavior, facts, logic, and the authority that reinforces it. It does this in part by continually maintaining and elaborating "supports," developing what amounts to a discursive infrastructure. It also continually expands its own scope, occupying and integrating conceptual space in a kind of discursive imperialism.
>
> ...
>
> The models, metaphors, research programs, and standards of explanation that make up a scientific paradigm are assembled piece by piece from all kinds of heterogeneous materials. To see science and engineering as tinkering – as discourse – is to blur and twist the sharp, neat lines of often drawn between them and the knowledges and practices that constitute

other human endeavors such as politics, commerce – or war (1997, 40-41).

Edwards' discursive infrastructure encompasses both the tangible and intangible, and treats both information and the system used to carry it as indistinguishable from one another. The "heterogeneous ensemble" he describes both creates space and enables its colonization. His model reconciles the contradiction of power and knowledge discussed above. It is possible for networked infrastructure to reflect the conditions of power in which it was built, yet also embody universal truths. Following the logic of the frontier metaphor, discursive infrastructure has a representative, as well as practical, function. Like the isolated frontier fort in the American West, discursive infrastructure serves a practical purpose and also represents a statement of intent and projection of power. Thus, infrastructure, no matter how open, replicates, to some extent the political, social, cultural, and economic conditions in which it is produced. It is important to remember that these technical systems are the product of social shaping (Mackenzie and Wajcman 1985) and encompass the myriad personal and institutional choices and technical possibilities available to the network of actors involved in their production. This dissertation has focused on the context in which the NSF operates, choices made based upon internal and external feedback, and the series of political, economic, and social enablements and constraints that have shaped the Foundation's infrastructural programs. Therefore, the history of the NSF and its operational reality are inscribed in the networks that it has supported. This means that the frontier rhetoric of Turner and

Bush – the logic that dictates that physical, virtual, and scientific frontiers must be made safe for pioneering, and that national interest must be served – are replicated in their construction. The frontier model and the service of national interest ensures that, like Edwards' discursive infrastructure, the NSF's infrastructural program must continually expand its own scope and integrate and establish sovereignty in the spaces that it inhabits. This infrastructure is not and cannot be a "bridge to nowhere," to borrow a phrase from recent debates over federally funded infrastructure. The NSF must establish for itself and its external audiences that there is “a there there.”

However, any discussion of infrastructure as promoting sovereignty, dominion, or discursive imperialism should not be viewed through a strictly determinist lens. The outcomes engendered by the construction of infrastructure are the product of social shaping. Uses of technology are neither stable nor set in stone, rather individuals and groups play a significant role in determining how tools are used and to what effect, within the set technological constraints that each object presents. Returning to tension between objects and ideas discussed above, the NSF's networked infrastructure is only as good as the combined value of the material improvements and the knowledge that they help generate and transmit. The NSF does not produce the knowledge at the frontiers of science; instead it either creates frontiers or makes existing frontiers safe for others, often supported by Foundation grants, to do pioneering research. It helps establish the realm of the possible. However, without pioneers to generate the raw resource of knowledge the value of this infrastructure in the frontier enterprise is negligible. A frontier with infrastructure, but without pioneers and settlers, remains little more than empty space. Therefore, the great value of the NSF is encapsulated in its strategic priority areas of Ideas, People, and Tools that developed in response to the conditions of the Foundation's history and the political and economic context in which it is situated. The NSF not only supports the opening of frontiers through building and supporting infrastructure, but also through grants to researchers and the training of the next wave of pioneers. By providing support at critical and overlapping stages and junctures of the frontier enterprise, the NSF simultaneously fulfills its mission and creates lasting infrastructural traces that establish sovereignty over space and enables the generation of fundamental knowledge that undergirds, at least rhetorically, the linear model of innovation that shapes post-war science and technology policy in the United States.

Disciplinary Conversations

This dissertation engages both the field of Science and Technology Studies (STS), broadly conceived, and the field of Communication Studies. However, this dissertation is situated somewhere in the gray area between both fields, and is not a traditional synthesis of STS and Communication Studies that focuses on either the history of a specific communication technology or system, or the influence of communication practices and technologies upon scientific research and development. These traditional approaches combining STS and Communication Studies are neither invalid nor outdated, but were inadequate alone to deeply analyze the impact of the National Science Foundation on the development of U.S. information infrastructure. Rather, the subject matter of this dissertation was best explored utilizing both aforementioned approaches, plus methods from political science, rhetoric, institutional history and critical theory to tell this story. The dissertation is positioned therefore, in a strictly academic sense, in what could be considered as a territory between disciplines. However, my intention was to research the relationship between a complex institution and complex information and communication systems, a task that, in my opinion, cannot be deeply explored if one is strictly constrained by rigid disciplinary orthodoxy. Both the institution and the systems explored are multifaceted, complicated, and the product of a set of messy historical, political, and social circumstances, some intended and others unforeseen. This is not to say that either the NSF or any of the information or communication technologies discussed here are unruly or so complex as to be beyond exploration, but that understanding the relationship between the institution and the systems that it supports must include observation and analysis of the political and social contexts in which both arise. Additionally, it is important to recognize the utility of the language and power of the metaphors used in and around the NSF to motivate and engage both policy machinery in Washington and the research agendas of bench scientists at academic institutions across the nation into alignment with the NSF's interpretation of "the national interest." Both context and language therefore play a significant role in shaping the establishment and trajectory of critical information and communication infrastructure projects.

The contribution of this dissertation to both STS and Communication Studies disciplines as well as public policy and institutional history resides, I feel, in two observations – that language, rhetoric, and discourse all matter a great deal to the generation of science and technology policy and that the NSF should be primarily considered an infrastructure organization. It seems obvious to state that language matters in the generation of policy. After all, laws, position papers, meeting memos, executive and management orders, and even press accounts of policy decisions all employ language that influence policy outcomes. However, this dissertation looks specifically at the important role that the metaphor of the American frontier has played not only in allowing a nascent, and weak, NSF to anchor itself to one of the more powerful and symbolic U.S. myths-of-origin, but also how the adoption of the frontier metaphor was then used to explain to constituents both inside the federal government and in the wider scientific community how and why the mission of the NSF was critically important to the health of the United States as a whole. The frontier metaphor also provided convenient cover – or put another way, a malleable sound bite – for the NSF and its supporters when dealing with the tricky notion of justifying costly support for basic science when no causal link can be established between investment in undirected research and positive societal outcomes. The power of the frontier metaphor is that it can so readily be applied to scientific endeavor where so little is known beyond the point of departure except for the certainty that the journey will be expensive and positive results are not guaranteed. Yet the application of the frontier metaphor seeks to ameliorate any chilling effect of these potential negatives by not only describing the frontier as the crucible of the nation and the font from which American exceptionalism springs, but also by describing the high cost and risky exploration of frontiers as fundamentally American and something not to be feared.

By connecting science to the concept of American exceptionalism via Vannevar Bush and Frederick Jackson Turner, the NSF, as previously stated in this dissertation, reached back into its pre-history to couple its fate to that of the nation as a whole. Not only was this a brilliant rhetorical strategy to justify the appropriation of federal funds to a young agency with a potentially risky mission, it also provided an operational template for the NSF to follow; a template that I argue defines the NSF as an infrastructure organization. The importance of recognizing that the NSF operates as an infrastructure organization, or as the agency that *builds the laboratory in which U.S. science takes place*, is that behind the exploration and settlement of both the frontiers of the American West and U.S. science is a massive and indispensable infrastructural enterprise that enables the conquest of physical and metaphorical space. By recasting the NSF in this light, I am providing a distinct frame through which the Foundation can be understood.

This should be of interest to STS scholars generally, and particularly in the sub-disciplines of history of technology and history of science, because recasting the operational strategy of the NSF in this light may provide new insight into what it funds and why. This is a critical question, as the NSF is, in my opinion, a much-misunderstood agency, with a mission so broad as to be nebulous, and a mandate to support basic research that Greenberg ([1967] 1999, 33) describes as "being neither self-explanatory nor self-supporting." Many studies have seized on the long history of rhetorical contortions employed by the NSF to explain support for basic research and justify expenditures in order to critique the nature of science and technology policy and funding in the U.S., and rightly so. However, this is only part of the story. While it is critical to examine and expose the excesses and foibles of an imperfect institution embedded in an imperfect system, it is equally necessary to recognize that the NSF has invented a role for itself as an infrastructure organization in spite of the weaknesses so aptly described by its critics. Out of the dual necessity of securing its own existence in the first few decades of its history and the need to demonstrate tangible results to its constituents, the NSF began to place an operational emphasis on infrastructure, including physical improvements, human capital, and intellectual property. The justification for this emphasis was also found in the writings of Turner and Bush, who both specifically make mention of the infrastructural support of the federal government as critical to the exploration and settlement of frontiers. It is my argument therefore, that the NSF cannot be adequately understood without combining both the critiques of STS scholars on the Foundation's sometimes strained attempts to justify support for basic research and a discursive analysis built from Communication Studies that promotes an understanding of the NSF that extends into concepts such as the frontier metaphor. This combination of approaches promotes a vision of the NSF as a complex organization shaped by its history and the context in which it operates, that emphasizes both the creation of discourse and infrastructure as critical to the health of the U.S. science and technology enterprise.

The relevance of this research to Communication Studies scholars resides not only in the aforementioned discursive analysis of NSF rhetoric and communication, but also in the examination of an often-overlooked federal agency that has had a direct influence on the development of many advanced information and communication technologies and systems of interest to the discipline. These technologies are of particular interest to communications scholars who examine various media as well as the flow of information and the communication practices that they enable. However, Communication Studies research dedicated to NSF itself is scant, although the agency does receive some attention for its role in the development and commercialization of the Internet, in addition to a handful of very specific information and communication programs. Much of the research on the development of the Internet, however, treats the Foundation simply as one historical actor among many others, only briefly addressing the NSF's role in funding the research of early Internet pioneers, the development of the NSFNET backbone, and the subsequent commercialization of the Internet. While this research provides an excellent foundation upon which to build a greater understanding of the importance of the NSF to the development of post-World War II information and communications technologies, a deeper examination of the NSF as a federal agency and its institutional practices is often absent. This dissertation builds upon the research in Communication Studies and STS that addresses the role of the NSF as a historical actor in the development of advanced information and communication technologies and couples it with an examination of the institutional, political, and discursive history of the Foundation to produce a study that provides a deep analysis of the impact of the NSF on the development of U.S. information infrastructure.

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