Testimony of
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Before the
House Committee on Science

September 21, 2006

Fundamental Nanotechnology Research: The Key to Finding the Promise and Minimizing the Peril

Chairman Boehlert, Ranking Member Gordon, and distinguished members of the Committee, I am delighted to be with you once again to speak on behalf of the National Science Foundation. NSF is an extraordinary agency, with an equally extraordinary mission of enabling discovery, supporting education, and driving innovation – all in service to society and the nation.

The past several months have been particularly exciting for the NSF and the U.S. research community. As you are well aware, the National Science Foundation is an integral part of the President's American Competitiveness Initiative (ACI). The President's request for an 8% increase at NSF this year represents the first step in the Administration's commitment to doubling the budgets of the ACI research agencies over the next 10 years.

The ACI encompasses investments across NSF's research and education portfolio. NSF's investments in discovery, learning, and innovation have a longstanding and proven track record of boosting the nation's economic vitality and competitive strength. This level of commitment is recognition of the urgent and ongoing need to invest in our nation's future through fundamental research and innovation.

Frontier research is NSF's unique task in pursuing the Administration's research priorities within the larger federal research and development effort. Over the years, NSF has advanced the frontier with support for pioneering research that has spawned new concepts and even new disciplines. NSF provides strong support in fundamental research for activities coordinated by the National Science and Technology Council (NSTC), including our role as a lead federal agency in the multi-agency National Nanotechnology Initiative (NNI).

But before I begin, let me thank this committee for its historic and ongoing support of NSF. I also want to extend special thanks – on behalf of everyone associated with the National Science Foundation – to Representative Boehlert for his many years of leadership as Chairman of the House Science Committee. The science and engineering community appreciates all that you have done as a champion for our nation's quest for knowledge.

Nanotechnology – First Steps and Demand for Fundamental Principles

Ten years ago, predicting the state of nanotechnology research today would have been a fruitless gesture. In the 1990s, NSF and other research entities around the globe were just beginning to apply nanoscale concepts to the frontiers of science and engineering.

Though some visionary researchers certainly recognized the vast potential of skillful atomic and molecular manipulation, no one could have predicted the enormous impact of these early steps into a new realm of discovery. One reason for this lack of prescience is our limited understanding of the physical principles that come into play on the nanoscale.

The research community's first vision for nanotechnology was based on our understanding of the macro world, where the same laws and physical properties of our everyday experience hold sway, regardless of size or scale. We now know that this simplistic view was woefully inaccurate. The world of nanotechnology – it turns out – is an often topsy-turvy world where familiar physical properties disappear and new capabilities emerge.

Consider something with which we are all familiar – ordinary gold. Whether in a ring, shielding sensitive electronics in space, or kept as a trusted investment for a rainy day, gold behaves in the same predictable ways. It has a certain color, luster, hardness, and melting point. This is true for an ounce or a metric ton. But something remarkable happens when we study the vanishingly small bits of gold called nanodots. On the nanoscale, gold no longer behaves the same as it does in our day-to-day lives. Its color changes to a striking red (as ancient stained-glass artists learned), and it's no longer the inert metal used in home and biological appliances. Rather, under certain circumstances, gold nanoparticles may be very reactive, may penetrate the blood/brain barrier, or may enter into cells.

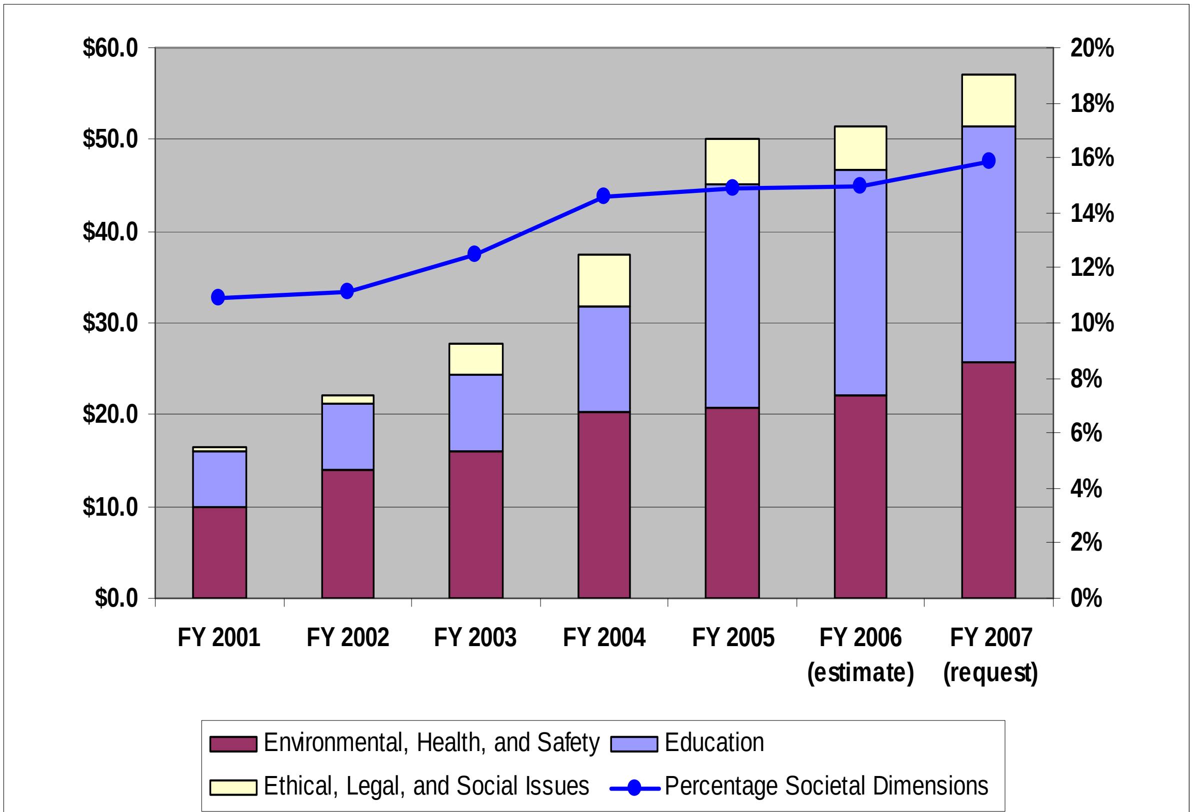
So we have to ask ourselves: as the NSF funds fundamental nanoscale research, how should we address the societal issues associated with the development and use of nanotechnology, and in particular engineered nanoscale materials.

Societal Dimensions

We typically refer to the impact of nanotechnology on the environment, humans, cultures, and societal relationships as the "societal dimensions" of nanotechnology. NSF characterizes research in this area into three main groups:

- Environment, Health, and Safety
- Education, and
- Ethical, Legal, and other Social Issues.

Each pillar of this triumvirate is indispensable, and removing one would weaken the stability of our efforts to effectively and safely exploit nanotechnology's vast potential, which is why NSF's support of fundamental research is so critical. Of the total 2007 NSF Request within the National Nanotechnology Initiative of $373.2 million, $59 million – or 16 percent – is directed toward societal dimensions.[1] This is a $7.5 million (15 percent) increase over the FY 2006 estimated funding of $51.5 million.



NSF fundamental research investments in the societal dimensions of nanotechnology*

Because of NSF's critical impact on building a fundamental body of knowledge, specialized facilities, and qualified people, NSF funds a large fraction of the overall National Nanotechnology Initiative (NNI) investment in Societal Dimensions: $59 million of $82.1 million in the FY 2007 Request, and $51.5 million of $71.7 million in the FY 2006 estimate.

NSF dedicates about 7 percent of its NNI budget to projects that focus primarily on fundamental aspects of environmental, health, and safety implications and applications of nanomaterials, and basic research that assesses the risk of these implications. This comes to $25.7 million or 6.9 percent of the total FY 2007 NNI/NSF Request, or $3.6 million over the FY 2006 estimate.

[1] NSTC/NSET, July 2006

* FY 2001 – 2004 data retrospectively collected based upon FY 2005 OMB guidance.

Setting a Research Agenda

NSF sets annual priorities for nanoscale science and engineering research. Input for these priorities comes from the NSF's Nanoscale Science and Engineering Working Group; the NNI strategic plan; other national, international, and industry perspectives; as well as from grassroots sources such as the general public, annual grantees meetings, and other non-governmental sources.

Another important input in developing the NSF's NNI-related research and education activities is through participation in the Nanoscale Science, Engineering and Technology Subcommittee (NSET) of the National Science and Technology Council (NSTC) Committee on Technology. NSF participates in all NNI workshops, research directions and planning meetings, and is coordinating its programs with the work done by other agencies in the general context of R&D, infrastructure, and education needs. NSF is also part of the NSET Subcommittee's Nanotechnology Environmental and Health Implications Working Group (NEHI), through which it has systematic interactions with other agencies supporting research and regulatory activities. NSF also has co-organized grantees meetings with the Environmental Protection Agency (EPA), the National Institute for Occupational Safety and Health (NIOSH), and other agencies to ensure open lines of communication, cross-fertilization of ideas, funding of complementary projects, and leveraging. Since FY 2001, the results from these meetings, and nanoscale science and engineering awards and solicitations, have been placed on NSF's dedicated nanotechnology website: www.nsf.gov/nano.

NSF also receives input from industry on the impact of this research agenda, ensuring that it is both deep and broad, and one that will serve the fundamental research needs of the entire community.

NSF Focus on Environmental, Health, and Safety Research

As stated earlier, NSF – through its proven system of merit review – seeks to advance the central body of knowledge on nanotechnology and corresponding infrastructure by support for fundamental research, not including clinical testing, and other activities that address broad societal dimensions. We do not fund product development or late-stage innovation: the research necessary to move a product into a commercial market.

NSF research addresses a variety of nanoparticles and nanostructured materials in different environmental settings (air, water, soil, biosystems, and working environment), as well as the non-clinical biological implications. These topics are supported through programs in all the NSF research directorates.

There are several priority areas for environmental, health, and safety research at NSF. These key EHS priority research areas are:

- new measurement methods and instrumentation for nanoparticle characterization and nanotoxicity,
- transport phenomena of nanoscale aerosols and colloids, interaction of nanomaterials with cells and living tissues,

- safety in nanomanufacturing, physico-chemical-biological processes of nanostructures dispersed in the environment,
- separation of nanoparticles from fluids,
- development of user facilities, and
- educational programs supporting EHS issues.

For example, the NSF is funding research on the safety of manufacturing nanoparticles through four Nanoscale Science and Engineering Centers (NSECs) and one Network:

- The NSEC at Rice University in Houston is investigating the evolution of manufacturing nanoparticles in the wet environment;
- The NSEC at Northeastern University in Boston is looking into occupational safety during nanomanufacturing;
- The University of Pennsylvania's NSEC is exploring the complex behavior and interactions between nanomaterials and cells; and,
- The NSEC at University of Wisconsin, Madison, is looking broadly at the effects of nanostructured polymers on Environmental Health and Safety.
- The National Nanotechnology Infrastructure Network is also exploring societal dimensions through nanoparticle characterization centers at the University of Minnesota and Arizona State University.

Additionally, about twenty interdisciplinary research teams (NIRTs) were funded in the EHS area since FY 2001.[2] Research through these teams has covered such diverse topics as:

- Theoretical and experimental methods of describing the formation and transformation of carbon nanoparticles in the atmosphere.
- The effect on human cells of exposure to single-wall carbon nanotubes. Research at the Houston Advanced Research Center has indicated that these nanotubes have less toxicity than carbon black and silica. However, research results on toxicity depend on many factors and more knowledge is needed before a final conclusion can be reached.
- NSF also is looking into the robust large-scale manufacturing of nanoparticles and their toxicology. This project will involve an academic–government–industrial partnership, encompassing chemistry, chemical and mechanical engineering, and medicine. Extensive tests will be performed on toxicology. Mechanisms of particle/cell interactions will also be evaluated, and the potential adverse and beneficial effects will be determined.
- An NSF-supported Nanoscale Interdisciplinary Research team is investigating ceramic membranes for filtration of nanoparticles, which is relevant in control technology for manufacturing processes involving aqueous nanoparticles.
- An NSF-supported Nanoscale Interdisciplinary Research team is developing solvent-free techniques, using supercritical carbon dioxide, for the deagglomeration of nanoparticles. This will enable environmentally benign manufacturing of high-surface-area nanostructured composites.

[2] NSF 2001-2006

In addition to the Center and NIRT awards, single investigator and small group awards provides creative ideas and innovation across all directorates in NSF. Several examples are:

- Several NSF awardees are developing instrumentation for monitoring nanoparticles which could be useful for ensuring the proper operation of control technology in factories. Examples include instrumentation for:
  - in-situ, real-time, high-resolution measurements of nanoparticle size distributions
  - chemical composition of nanoscale aerosols
  - size-resolved measurements of surface tension, critical supersaturation, and chemical composition of nanoscale cloud condensation nuclei, which will help elucidate the role of organic materials in environment
- Laser Doppler Velocimetry (LDV) in synchronous AC electric and acoustic fields, to determine the size and charge of nanoparticles. These technologies could also be used to monitor nanoparticle emissions in the environment, providing critical information for the design and implementation of mitigation strategies where needed.
- An NSF Nanoscale Exploratory Research project is developing risk scenarios for the full life-cycles of three types of nanoparticles currently manufactured in multiton quantities: endohedral metallo-fullerenes, titania nanoparticles, and carbon nanotubes. The project's broad interdisciplinary approach, including toxicity studies, life-cycle analysis, hierarchical holographic modeling, and assessment of the existing regulatory framework, will serve as a model for to identifying environmental impacts and risks of nanomaterials.

Since FY 2002, NSF has had a Nanotechnology Undergraduate Education program. The program is currently sponsoring an effort to introduce research-based environmental nanotechnology experiences into the undergraduate curricula. Research-based hands-on laboratory modules will introduce students to the effects of nanomaterials on the environment and the potential use of nanomaterials for removal of environmental pollutants.

We also support fundamental research on decision making, risk, and uncertainty as part of our Human and Social Dynamics portfolio. This research will yield insight into decision-making processes, loss and mitigation models, and risk perception that are widely applicable to managing the risks and general governance associated with emerging technologies including nanotechnology.

NSF has also released a number of solicitations that deal directly with the societal impacts of nanotechnology. These include an NSF-wide solicitation in FY 2001 to FY 2005 that had two major research and education themes: nanoscale processes in the environment, and societal implications of nanotechnology. There also was a solicitation in FY 2006 and FY 2007 on active nanostructures and nano-devices.

Research to Enable Risk Assessment and Risk Management

What sort of research is necessary to enable sound risk assessment and risk management of nanotechnology? And what is the role of NSF in supporting that research? NSF's unique expertise and strength of its human and administrative resources is in fundamental research. This research will add to the overall body of knowledge on nanotechnology, will prove essential to the regulatory mission agencies' abilities to develop science-based standards, and complements the more applied approach of EPA, toxicity studies by the National Institutes of Health, and regulatory activities by the Food and Drug Administration and NIOSH.

By creating the strong foundation of fundamental research, NSF catalyses the development of trained researchers, the future workforce, and the laboratory infrastructure that is needed for the mission specific research and development in the regulatory agencies.

As with any new technology, the benefits and risks of nanotechnology need to be evaluated from the beginning; nanotechnology has been exemplary in this regard. But research to understand the benefits and risks cannot advance without the combination of fundamental research, domain specific research, and technology and product specific research. This is where a balanced approach ensures the best results. Without these three components, the successful long-term commercialization of new products is at risk.

This foundation for commercialization is of great concern to industry, and NSF activity integrates their input and concerns into its research agenda. NSF receives input from industry through the Collaborative Boards for Advancing Nanotechnology, which was established by NNI with the electronic industry, the chemical industry, and other businesses and organizations.

NSF, therefore, does have an important role to play in enabling the acceptance of nanotechnology-based goods in the marketplace. Primarily, this is through fundamental research and the development of the necessary infrastructure – education, physical infrastructure for nanomaterials research, and more comprehensive topics such as nomenclature, metrology, and patent-evaluation framework. NSF also develops the institutional capability for R&D, production, information dissemination, safe use and regulations, and commercialization of nanotechnology. Above all, NSF supports the long-term R&D for new generations of nanoproducts. NSF research is most effective when targeted at long-term results and broad impacts that cut across the entire research landscape.

The Public and Nanotechnology

NSF supports a host of education-related activities to communicate the state and future direction of nanotechnology research. This includes developing materials for schools, curriculum development for nanoscience and engineering, development of new teaching tools, and K-12 and public outreach. Three networks for nanotechnology education and societal dimensions with national outreach have been established:

- The Nanotechnology Center for Learning and Teaching, with the main node at the Northwestern University, will reach 1 million students in high school and undergraduate education in all 50 states in the next 5 years;
- The Nanoscale Informal Science Education, focused at the Museum of Science in Boston will address innovative science learning approaches, supplement K-12 education, and engage adult audiences; and
- The Network for Nanotechnology in Society will address both short-term and long-term societal implications of nanotechnology, as well as public engagement.

The success of these efforts, however, hinges on a firm foundation of research across all areas and considering all implications. That outcome can only be achieved with the fundamental, broad-based research supported by NSF.

Conclusion

For many years, NSF has used the slogan "Where Discoveries Begin" to welcome people to our website. That phrase, however, did not come from a focus group or a marketing guru: it came from our mission – our mission of research and discovery. The same is true for nanotechnology. NSF ***is*** where the discoveries begin.

Mr. Chairman, I hope that this brief overview conveys to you NSF's continued commitment to advance science and technology in the national interest. If there is one thing that I would want to leave you with is that the vital, critical, and highly visible regulatory decisions that will need to be made will be based on the equally vital, critical, yet – by and large – unseen fundamental research that is NSF's hallmark.

I appreciate your – and your Subcommittee's – longstanding support of NSF. I would be pleased to answer any questions that you may have.

Thank you.