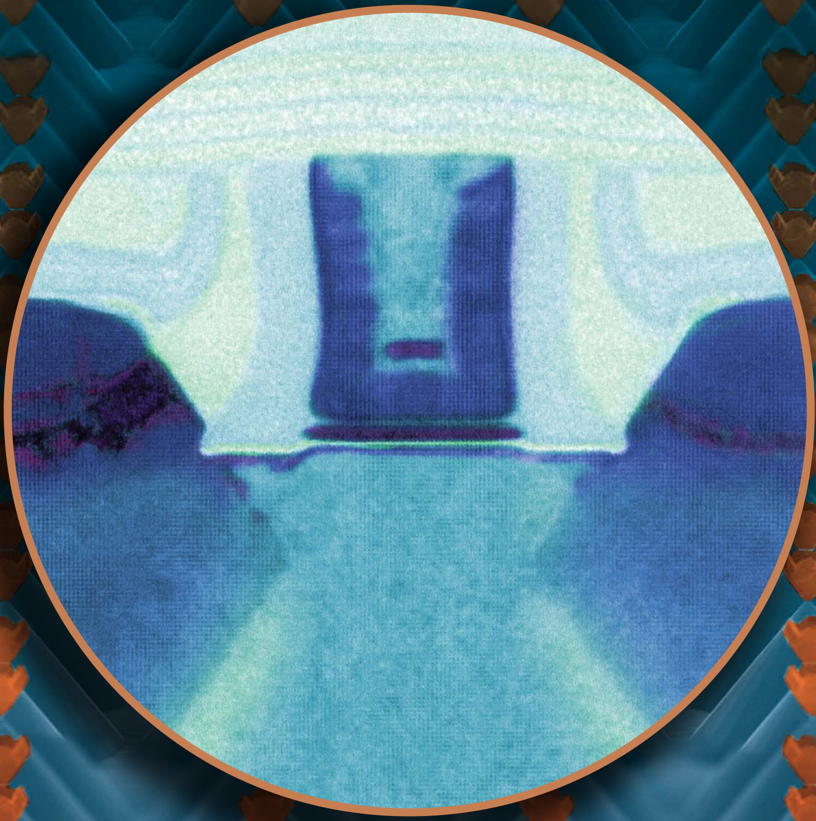
THE NATIONAL NANOTECHNOLOGY INITIATIVE



Final Report

Strategic Planning Stakeholder Workshop

July 13-14, 2010

About the Nanoscale Science, Engineering, and Technology Subcommittee

The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee is the interagency body responsible for coordinating, planning, implementing, and reviewing the National Nanotechnology Initiative (NNI). The NSET is a subcommittee of the Committee on Technology of the National Science and Technology Council (NSTC), which is one of the principal means by which the President coordinates science and technology policies across the Federal Government. The National Nanotechnology Coordination Office (NNCO) provides technical and administrative support to the NSET Subcommittee and its working groups in the preparation of multiagency planning, budget, and assessment documents, including this report. More information is available at http://www.nano.gov.

About the National Nanotechnology Initiative

The National Nanotechnology Initiative is the Federal nanotechnology R&D program established in 2000 to coordinate Federal nanotechnology research, development, and deployment. The NNI consists of the individual and cooperative nanotechnology-related activities of 25 Federal agencies that have a range of research and regulatory roles and responsibilities. The goals of the NNI are fourfold: (1) to advance a world-class nanotechnology research and development program; (2) to foster the transfer of new technologies into products for commercial and public benefit; (3) to develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and (4) to support responsible development of nanotechnology.

About this Report

This document is the report of a workshop held July 13–14, 2010. The goal of this workshop was to obtain input from stakeholders—both those new to nanoscale science, engineering, and technology and those already familiar with these fields and with the NNI—regarding the goals and objectives of an updated NNI Strategic Plan that was under development at the time of the workshop. This report was designed, assembled, and edited by NNCO staff. This report is not a consensus document, but rather is intended to reflect the diverse views, expertise, and deliberations of the workshop participants.

About the Report Cover

Report cover design is by N.R. Fuller, Sayo-Art LLC.

Foreground image: False-color rendering of a transmission electron microscope cross-sectional image of an Intel 45 nm transistor, manufactured with Intel's high-k, metal gate process technology. The hafnium-based high-k material in the gate dielectric is formed using an atomic layer deposition technique and is combined with electrodes that use a combination of different metal materials. These transistors feature a 160 nm gate pitch and a 35 nm physical gate length. The use of the hafnium-based high-k gate dielectric material results in an equivalent oxide thickness of 1.0 nm. The dual work function metal gate electrodes are used in combination with other innovative technologies such as enhanced channel strain, ultra shallow junctions, and nickel silicide to enable the continuation of "Moore's Law" scaling to these smaller dimensions. This technology was first used in high-volume manufacturing in late 2007. Since 2009 Intel's leading-edge high-volume manufacturing is based on a significantly smaller 32 nm transistor technology (courtesy of Intel Corporation, Santa Clara, California).

Background image: False-color scanning electron microscopy image of gold nanopyramids situated on silicon pedestals as they are formed using high-resolution lithography; the spacing of the pedestals is about two micrometers. This image demonstrates how anisotropic particles made by nanofabrication methods are highly uniform in size and can be three-dimensional in shape. The method also enables selective functionalization of the nanoparticle surfaces (work funded by NSF; courtesy of Teri W. Odom).

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National Nanotechnology Initiative

Strategic Planning Stakeholder Workshop

July 13–14, 2010, Arlington, Virginia

FINAL REPORT

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Committee on Technology
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Acknowledgments

The many individuals listed below dedicated considerable time and expertise to make the National Nanotechnology Initiative (NNI) Strategic Planning Stakeholder Workshop a reality and to write and produce this report.

Workshop Organizing Committee:

- Co-chair: Janet Carter – Department of Labor/Occupational Safety and Health Administration
- Co-chair: Michael Gorman – National Science Foundation
- Co-chair: Elizabeth Nesbitt – U.S. International Trade Commission
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- Nora Savage – Environmental Protection Agency
- Sally Tinkle – National Institutes of Health
- Clayton Teague – National Nanotechnology Coordination Office

The committee planned, organized, and ran this workshop, and helped to write and review the report.

Discussion Leaders:

- Richard Canady – International Life Science Institute/Research Foundation
- John Cowie – American Forest and Paper Association
- James Murday – University of Southern California
- Norman Scott – Cornell University

The discussion leaders led the deliberations of the workshop's four brainstorming breakout sessions and prepared summaries of the comments and suggestions from the participants in those sessions, which constitute the body of this report.

Workshop Plenary Speakers: Clayton Teague, Travis Earles, Courtney Smoot, Mihail Roco, George Thompson, Rosalyn Berne, Kevin Ausman, Vincent Caprio, Robert Hwang, William Kojola, James Murday, Robert "Skip" Rung, Fran Schrotter, Norman Scott, Rep. Daniel Lipinski, Paul Alivisatos, and James Heath (see Appendix B for affiliations). The plenary speakers shared their expert perspectives with workshop participants on what has been accomplished during the first ten years of the U.S. Government's National Nanotechnology Initiative, and where they think it should be going in the future. Each of the breakout sessions at the workshop included several additional prepared presentations; see agenda (Appendix A) for a list. Credit is due to all of the workshop participants for contributing to the discussions and sharing their insights.

Support Staff: Staff members of the National Nanotechnology Coordination Office (NNCO) assisted in planning and organizing the workshop and in producing the report. In particular, Diana Petreski and Halyna Paikoush supported the organizing committee and handled workshop logistics. The report was edited by Geoff Holdridge and Pat Johnson and formatted by Kristin Roy.

The Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council's Committee on Technology sponsored this workshop through the National Nanotechnology Coordination Office. Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and workshop participants and do not necessarily reflect the views of the United States Government or the authors' parent institutions. This report is not a consensus document, but rather is intended to reflect the diverse views, expertise, and deliberations of the workshop participants.

Preface

One of the greatest strengths of the U.S. Government's National Nanotechnology Initiative (NNI) is that it has been driven from its inception by long-term goals based on broad community and stakeholder input, received in part through workshops such as the July 2010 NNI Strategic Planning Stakeholder Workshop. The original NNI proposal formulated in 1999 called for periodic external input to and evaluation of the initiative. The proposal itself was to a large extent the distillation of the recommendations of a January 1999 workshop convened by the National Science and Technology Council (NSTC) to gather input for the proposed initiative from a broad range of stakeholders external to the Government, including senior representatives of academia, industry, and national laboratories.[1]

Since the inception of the NNI, it has been evaluated three times by the President's Council of Advisors on Science and Technology (PCAST) and three times by the National Academies. During the same period, the NSTC's Nanoscale Science, Engineering, and Technology (NSET) Subcommittee has organized over 20 official NNI workshops to continually gather input on the initiative from the research community, industry, and other stakeholders. The NNI participating agencies have organized many more workshops that were affiliated with or supportive of the initiative. As a result of this external input, and additional internal deliberations among NNI agencies, the long-term NNI Strategic Plan has been updated twice since its inception—in 2004 and in 2007. In 2008, the NSET Subcommittee also separately published the *NNI Strategy for Nanotechnology-Related Environmental, Health, and Safety (EHS) Research*.

As called for by the 21st Century Nanotechnology R&D Act of 2003, the NNI began updating its strategic plan again in 2009–2010. As in the past, the 2010 update to the NNI Strategic Plan (completed in February 2011) is based in part on extensive external input. In early 2009 the National Academies completed a review of the NNI EHS strategy that included a number of recommended changes. PCAST completed a review of the NNI in March 2010; its recommendations include sustaining support for fundamental research while increasing the NNI's emphasis on commercialization, technology transfer, and nanomanufacturing activities, as well as on EHS research. In 2009 and 2010, the NSET Subcommittee sponsored a series of EHS workshops, a workshop on nanotechnology-enabled sensing, and one on regional, state, and local nanotechnology initiatives. Other sources of external input for the new plan include a portal website (http://strategy.nano.gov) and a formal Request for Information (RFI) posted in the *Federal Register.* The July 13–14, 2010, NNI Strategic Planning Stakeholder Workshop was aimed at helping the NNI agencies synthesize all of this input, and in particular, to focus on developing specific objectives that the new NNI Strategic Plan should include to help achieve the NNI vision and goals.

On behalf of the NSET Subcommittee, we thank Janet Carter, Michael Gorman, and Elizabeth Nesbitt for co-chairing the workshop, and Richard Canady, John Cowie, James Murday, and Norman Scott for leading the breakout session discussions. We also thank all the speakers and other participants for their contributions to the workshop and to this report. Their generous sharing of time and expertise made the workshop a valuable reference for the NNI, following in the tradition of interdisciplinary and cross-sector engagement that has marked the NNI from the beginning.

Sally S. Tinkle
Co-Chair
NSET Subcommittee

Travis M. Earles
Co-Chair
NSET Subcommittee

E. Clayton Teague
Director
NNCO

1 See the report from that workshop: *Nanotechnology Research Directions: Vision for Nanotechnology R&D in the Next Decade* (NSTC/IWGN, Washington, DC, September, 1999; http://wtec.org/loyola/nano/IWGN.Research.Directions/IWGN_rd.pdf).

About the Workshop and this Report

This report is the outcome of the National Nanotechnology Initiative (NNI) Strategic Planning Stakeholder Workshop held in July 2010. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council's Committee on Technology sponsored this workshop to obtain input from outside the U.S. Government on the future directions of the NNI. This is one in a series of such workshops that support the NSET Subcommittee's long-range planning efforts for the NNI, the multiagency Federal nanotechnology R&D program. The recommendations of the workshop provided input to the NSET Subcommittee in the development of its 2010 update of the NNI Strategic Plan (completed in February 2011).

In this workshop, experts from academia, nongovernmental organizations, and industry were asked to help the NSET Subcommittee formulate specific objectives to be included in the new NNI Strategic Plan under each of the four overarching NNI goals. The NSET Subcommittee developed a draft list of such objectives in advance of the workshop, for consideration and discussion at the workshop (see Appendix C). Participants were also invited to suggest new objectives not on the draft list, and to suggest implementation strategies for the recommended objectives. Suggestions were also made concerning the priority order and the wording of the four overarching NNI goals as laid out in the previous (2007) NNI Strategic Plan. The NSET Subcommittee decided prior to the workshop not to revise the goals for the 2010 update of the NNI Strategic Plan or the NNI vision or the eight program component areas (PCAs) set out in the 2007 plan, so these were not a major topic at the workshop.

Each day of the workshop began with a series of plenary lectures in which subject matter experts shared their insights and discussed the status of specific nanotechnology research areas and application domains. Parallel breakout sessions followed covering each of the four overarching NNI goals: (1) Advance a world-class nanotechnology research and development program; (2) Foster the transfer of new technologies into products for commercial and public benefit; (3) Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and (4) Support responsible development of nanotechnology. The aim of the workshop breakout sessions was to gather input from the participants on three basic questions: (a) With respect to each individual goal, what has the NNI done right and what should it continue doing? (b) With respect to each individual goal, where has the NNI headed down the wrong path? and (c) What can the NNI do in the future to address each specific goal? Some breakout sessions also addressed additional questions more specific to individual goals. Finally, each breakout group was asked to review the draft objectives proposed by the NSET Subcommittee for each goal, suggest changes to them, prioritize them, and suggest any new objectives that the participants thought would help address the goals. Each of the breakout sessions met twice (on both July 13 and July 14) to allow participants to consider overnight the discussions from the first day, leading to a more conclusive discussion the second day. This report summarizes the comments and suggestions of the workshop participants.

Chapters 1–4 of this report summarize comments and suggestions from the breakout sessions for NNI Goals 1–4, respectively; each of these chapters includes the revised list of objectives for that goal that emerged from the breakout session discussions. Chapter 5 includes abstracts of each of the plenary talks. Appendix A is the workshop agenda. Appendix B is a list of workshop participants. Appendix C is the list of draft objectives for each of the four NNI goals that were prepared by the NSET Subcommittee's Strategic Planning Task Force as a starting point for discussion at the workshop; this appendix begins with some guidance that the task force offered to workshop participants in terms of how they might evaluate the proposed objectives. Appendix D is a glossary of abbreviations and acronyms used in this report.

This report is not a consensus document but rather is intended to reflect the diverse views, expertise, and deliberations of the workshop participants.

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Executive Summary

The goal of the July 13–14, 2010, National Nanotechnology Initiative (NNI) Strategic Planning Stakeholder Workshop was to obtain input from stakeholders—both those new to nanoscale science, engineering, and technology and those already familiar with these fields and with the NNI—regarding the goals and objectives of an updated NNI Strategic Plan that was under development at the time of the workshop. The NSET Subcommittee decided prior to the workshop not to revise the NNI goals in the 2010 update of the NNI Strategic Plan (completed and published in February 2011), or the vision, or the eight program component areas (PCAs) set out in the 2007 plan, so these were not a major topic at the workshop. The main focus of the workshop was on four two-day breakout sessions organized around the four overarching NNI goals, with the aim of obtaining input from NNI stakeholders on specific objectives to be included in the 2010 update to the NNI Strategic Plan under each of the goals. The NNI Strategic Planning Task Force prepared a draft list of proposed objectives for each of the goals in advance of the workshop. These were discussed, revised, and prioritized by participants in the breakout sessions. Each session was also asked to address a number of questions asking about the NNI's past performance and soliciting suggestions for how the NNI could do better in the future. The following is a brief summary of some of the highlights of the comments and suggestions that emerged from each of the breakout sessions. The synthesis of the workshop is a list of revised, prioritized objectives suggested by the workshop participants for each of the goals; these are shown at the end of each of Chapters 1–4, corresponding to NNI Goals 1–4, respectively. Some of the proposed objectives were characterized as near-term or long-term efforts, in keeping with the 3–10-year outlook of the updated NNI Strategic Plan.

Goal 1: Advance a world-class nanotechnology research and development program

Highlights of comments and suggestions from breakout session participants include the following:

- The wording of Goal 1 should be more "aspirational" and "attractive for funders." The group proposed rewording the goal as follows: *Advance a leading, world-class nanotechnology research and development program.*
- The NNI should have efforts across the full range of basic and applied research and development. Overall the nanotechnology community is moving more from pure discovery to application/use-inspired research.
- Future priorities should include new instrument development and computational methods.
- There should be an interagency/commercial sector forum to facilitate cooperation.
- Some component of future NNI research should be addressed towards "grand challenges" with specific targets.
- The NNI has not marketed itself well outside the research community.
- Nanotechnology is maturing in some industries more than others—for example, applications of nanotechnology to medicine are more mature compared to use of nanotechnology in the transportation infrastructure.

- Participants in this breakout session proposed a number of significant changes to the NNI's draft objectives for Goal 1, along with several new or consolidated objectives.

Goal 2: Foster the transfer of new technologies into products for commercial and public benefit

Highlights of comments and suggestions from breakout session participants include the following:

- The NNI has had success at greatly incentivizing multidisciplinary R&D for nanotechnology.
- The NNI has made commercialization and economic development outcomes a goal from its beginning and has been successful at creating industry partnerships.
- The NNI has also been successful in creating nanotechnology R&D infrastructure; it should maintain the successful Nanoscale Science and Engineering Centers (NSECs, NSF activities) and potentially institutionalize them.
- Some state and local nanotechnology-based economic development initiatives that were begun in the last decade have now disappeared, perhaps due in part to lack of Federal support. Perhaps Federal support with 50% matching funds could be provided to help state and local programs, which in turn will help business.
- The NNI has not adequately defined "nanomanufacturing," per se.
- Some participants recommended that 5% of NNI funding be set aside for interagency projects.
- Prototyping centers should be established by the NNI for "proofs of concept" so developers can understand the potential products and refine fabrication and eventual manufacturing technologies.
- More "get-to-the-moon" projects or programs should be funded.
- There should be more "prizes" programs like the ones that DARPA and NASA have funded.
- One idea was to fund companies to cooperate with universities, rather than the reverse.
- The NNI could fund entrepreneurs-in-residence programs at NNI-funded universities.
- The NNI should provide a searchable database of all NNI-funded R&D projects.
- The Government should take full advantage of the opportunity to play the role of "first customer" for nanotechnology-enabled innovations.
- Consider creating an organization modeled on SEMATECH for government/industry cooperative support of precompetitive research in nanomanufacturing.
- Along similar lines, the group agreed with the draft objective proposed by the NSET Subcommittee (also recommended previously by PCAST), that the NNI should launch government-industry-university partnerships using models such as the Nanoelectronics Research Initiative (NRI), to increase emphasis on commercialization.
- Regulatory uncertainty inhibits investment.
- The group proposed a new objective calling for the NNI to work with industry to develop technology roadmaps.

Goal 3: Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology

Highlights of comments and suggestions from breakout session participants include the following:

- The draft objectives proposed by the NNI Strategic Planning Task Force were framed so broadly that it was difficult to appraise them in the SMARTER[1] context; a number of more focused objectives and sub-objectives were suggested.
- R&D infrastructure, education, and workforce topics were sufficiently unique to warrant their individual attention; the breakout session

1 "Specific, measurable, acceptable, realistic, timeframe, extending, rewarding"; see Appendix C.

organized the remainder of its comments accordingly.

R&D Infrastructure

- Nanoscale user facilities have experienced significant advances in the past decade.
- Four of the objectives from the list proposed by the NNI Strategic Planning Task Force in advance of the workshop were considered relevant to the R&D infrastructure subtopic. The group agreed with all of the NNI's proposed infrastructure-related objectives, but suggested adding nongovernmental organizations (NGOs) and Federal, state and local governments to the list of users of the facilities information. The group also prioritized the infrastructure objectives and suggested those that were likely to be near-term or long-term priorities, as indicated in Chapter 3 of this report.

Educational Infrastructure

- Nanoscale science and engineering is largely transdisciplinary. It challenges the traditional science and engineering education taxonomies.
- The nanoscale holds sufficient novelty to attract student interest in science, technology, engineering, and mathematics (STEM).
- The attention that the National Science Foundation (NSF) and other institutions have paid to education at the nanoscale is resulting in the development and dissemination of a wealth of new instructional materials.
- Those interested in "NanoEducation" believe it is time to: (a) broaden the nanoscale education efforts to include all of the many stakeholder groups and communities; (b) establish an enduring infrastructure beyond the NSF-sponsored Nanoscale Science and Engineering Education (NSEE) workshops; and most importantly, (c) develop partnerships toward meeting the challenges and identifying the opportunities provided by global advances at the nanoscale.
- The participants proposed a new high-level objective under this topic, under the heading "NanoEducation Ecology." This includes creating an NSET Subcommittee Nanotechnology Education and Workforce working group and an education and workforce consultative board for outreach to external stakeholders.
- Participants proposed a number of edits to the draft objectives proposed under this topic by the NNI Strategic Planning Task Force, and suggested some new sub-bullets. One key new sub-bullet suggested was to identify and assist U.S. K–12 common core educational efforts to appropriately include nanoscience. Another was to sponsor the creation of new degree programs in nanotechnology at doctoral, master's, and vocational college levels.

Workforce

- Many countries have followed the U.S. lead and established nanotechnology initiatives; these tend to be more focused on targeted technology development than are the NNI programs. Consequently, there will likely be strong global competition for nanotechnology-trained people.
- The Department of Labor needs to work with industry groups and with professional science and engineering societies to develop accurate assessments of domestic workforce needs.
- The breakout group recommended leaving the workforce objective as originally worded, but also suggested an additional sub-bullet to develop programs specifically addressing displaced and unemployed workers.

Goal 4: Support responsible development of nanotechnology

Highlights of comments and suggestions from breakout session participants include the following:

- Some participants expressed the view that the order of the four overarching NNI goals implies priority order, and that Goal 4 should become Goal 1 to indicate that it is the highest-priority goal. NNI representatives noted that the goals are not listed in any particular priority order, and that the numbering is only for convenience in referring to the goals.
- Addressing potential environmental, health, and safety (EHS) issues is not the only component

to responsible development of nanotechnology, however, the expertise of the participants in this breakout session was heavily weighted towards EHS, so other aspects of responsible development may not have been discussed as extensively.

- NNI agencies have provided nanotechnology EHS research funding across many different sectors and disciplines and have provided the vision for integrating EHS and ethical, legal, and other societal implications (ELSI) issues into research.
- Several participants expressed the sentiment that the NNI has not necessarily headed down the wrong path but perhaps has not gone far enough in addressing potential EHS issues.
- Another view was that the NNI has not made, but should make, societal dimensions considerations a priority and encourage mission-oriented agencies to fund this type of research.
- With many NNI research projects reaching maturity, there is no clear vision for how to integrate the data generated from these research projects (e.g., characterization, toxicology, EHS, societal) in theoretically sound and experimentally practical ways. This should be addressed at the genesis of a project.
- The NNI can play a pivotal role in advancing several issues related to "data," e.g., provide data conversion resources from EHS studies into usable risk management concepts; promote data-sharing across repositories, including "failed" or no-results studies; and provide a single access point to risk-related data from available Federal, academic, international, and possibly industry sources.
- A prevailing approach to risk communication for nanomaterials seems to be avoidance of some of the failures in public acceptance that occurred for agricultural biotechnology; however, the NNI should instead focus on successful risk communication models for technology introduction/use.
- The NNI should explore strategies outside of the risk paradigm, e.g., "safety by design" or qualitative and/or scenario-based approaches.
- The NNI should set a benchmark for the share of NNI resources to be dedicated to societal research (e.g., the National Human Genome Research Initiative's 3% minimum) and should strongly encourage all NNI agencies, centers, and networks to contribute to meeting this goal.
- The NNI can encourage societal research and other activities that seek comparative leverage between nanotechnologies and other emerging technologies, e.g., synthetic biology or geo-engineering.
- The NNI could convene a "nanotechnology best practices" summit to discuss and disseminate models for integrative research, training, and outreach activities.
- The NNI should implement a new public engagement strategy that emphasizes ongoing, substantive, two-way dialogues between the nanoscale science and engineering (NSE) research community and public stakeholders.
- There are various opinions on the reliability and sensitivity of predictive models. Research in this area should be continued, but there needs to be agreement that the science is not "there" yet, and more emphasis needs to be placed on modeling research.
- A careful and thoughtful approach should be developed for extrapolating *in vitro* studies to *in vivo* models.
- The United States needs to be engaged in global initiatives (e.g., global regulatory harmonization frameworks).
- The objectives related to ELSI issues need the kind of specificity found in the other objectives under Goal 4.
- The participants proposed three new objectives for Goal 4: providing a portal to existing EHS and ELSI databases, convening a scientific advisory board on comparative risk assessments, and developing a prioritized list of nanomaterials for EHS investigation.

1. Goal 1: Advance a World-Class Nanotechnology Research and Development Program

Norm Scott, Discussion Leader

Introduction

The first day of the Goal 1 breakout session began with introductory presentations by George Adams (Network for Computational Nanotechnology, "The Role of Computational Nanotechnology in the NNI") and Vinothan Manoharan (Harvard University, "Nano as Seen from Micro [and Macro]").[1] Norm Scott then led an open brainstorming session during which there was considerable discussion of the wording of the goal itself. Ensuing discussion concerned the general questions that were asked of all four breakout sessions:

- With respect to this goal, what has the NNI done right and what should it continue doing?
- With respect to this goal, where has the NNI headed down the wrong path?
- What can the NNI do in the future to address this goal?

In addition, the Goal 1 breakout was asked to consider the question, "Where should NNI research be distributed on Pasteur's Quadrant (i.e., what is the appropriate mix of basic and applied research)?"[2]

The second day of this breakout session focused on a detailed review of the proposed objectives for Goal 1, which resulted in a revised list of objectives as proposed by the members of this breakout session.

Introductory Presentations

Brief summaries follow of the two brief invited presentations that were made at the outset of this breakout session.

George Adams, Network for Computational Nanotechnology, Purdue University

Dr. Adams spoke about the use of computational modeling methods in support of nanotechnology R&D. He began by describing how vitally important computer modeling has been in the development of the semiconductor industry, and how it will be even more important in the future for a wide range of related industries as they evolve into the nanoscale range. He then described a number of integrated, online computational modeling environments that are now being used for nanotechnology applications, such as VEDA (VErsatile Data Analyst) and nanoHUB. In particular, such distributed modeling resources are very valuable for providing advanced knowledge and research tools to a wide array of educational and workforce development entities such as community colleges, which can directly impact U.S. economic development activities in the future.

1 Presentations are available at http://www.nano.gov/html/meetings/NNISPWorkshop/presentations.html.

2 *Editor's note:* The reference is to a 4-quadrant matrix proposed by Donald Stokes (*Pasteur's Quadrant – Basic Science and Technological Innovation,* Brookings Institution Press, 1997) cross-categorizing fundamental and use-inspired scientific research. In this chart, the Bohr quadrant represents pure scientific and theoretical research; the Edison quadrant represents purely applications-driven, empirical research; and the Pasteur quadrant represents a combination of the two. (The fourth quadrant is null in both categories.)

Vinothan Manoharan, Harvard University

Prof. Manoharan talked about the interface between nanoscale structures and processes and those at larger length scales. A main point was that future applications will require that designer materials can be built that have large physical dimensions, and that a very promising route to this is “bottom-up” self-assembly. However, such techniques require insights and methods from a variety of disciplines (biology, physics, computational modeling), and hence, multidisciplinary approaches are vital. The NNI should therefore put an emphasis on multidisciplinary research, for example, in supporting small interdisciplinary research teams focused on particular problem areas. One problem with funding such research is that the topics often fall between the cracks of the “stovepiped” research programs within individual agencies.

Summary of Comments and Suggestions

What follows is a synthesis of the comments and suggestions of the Goal 1 breakout session participants as they emerged from both days of breakout sessions. This is divided below into two sections: (1) suggestions concerning the wording of the Goal 1 statement itself, and (2) responses to the general questions that were posed to all four breakout sessions. The final section of this chapter is a list of suggested revised objectives for NNI Goal 1.

Suggested Revisions to Wording of Goal 1

Some participants expressed the view that the wording of Goal 1 should be more “aspirational” and “attractive for funders.” Specific suggestions for wording changes included the following:

- Replace the phrase, “world-class,” with “excellent” or “world-leading”
- Include “the best possible;” change to “a leading world-class...”
- Add “ for societal benefit” or “for human well-being”

After additional discussion, the final recommended rewording of Goal 1 was, “Advance a leading, world-class nanotechnology research and development program.”

Responses to Questions

With respect to this goal, what has the NNI done right and what should it continue doing?

- Public engagement and ethical issues
- Development of specific goals

With respect to this goal, where has the NNI headed down the wrong path?

- The NNI has not marketed itself well outside the research community.

What can the NNI do in the future to address this goal?

A wide variety of comments were offered in response to this question:

- “Nano” applied to large-scale engineering applications: Nanotechnology is maturing in some industries more than others—for example, more mature application of nanotechnology to medicine compared to use of nanotechnology in the transportation infrastructure.
- What is NNI? Is it too big? What is the scope of the goals? Should there be agency-by-agency objectives? What about efforts that are already underway within agencies; who gets credit for doing the nanotechnology, etc.?
- In context of the opening presentations: Should the NNI be focusing more on the “valley of death,”[1] and how would it do that organizationally? General sentiment: yes, addressing this valley issue is important—but we don’t know how much government can do.
- NNI-funded research should span all three of the valid “quadrants” in the matrix of basic and applied research described by Donald Stokes in his 1997 book, *Pasteur’s Quadrant,* but what is the appropriate distribution among those quadrants? Stakeholders seemed to agree that the NNI needs to have efforts in all of Stokes’ quadrants

1 “Valley of death” is a colloquial business term used to describe an early “make or break” commercialization phase where, due to insufficient capital, many promising new advanced technological developments fail to transition from research prototype and low-volume production to cost-effective high-volume production and market viability. Some states and organizations provide some kind of “gap” funding to help startup businesses survive the arduous commercialization passage.

(except the low-fundamental-understanding/low-use-inspired quadrant, which does not seem to be a very exciting place to be). There is some sense that, overall, the nanotechnology research community is moving from pure discovery to more applications/use-inspired research (i.e., from upper left to upper right, from Bohr's quadrant towards Pasteur's quadrant).

- Focus areas for nanotechology R&D could include the following:
  - Gathering requirements for instrument development to accelerate discovery; metrology and standards development is critical.
  - Collecting and sharing fundamental constants to create a stable, essential platform to perform science.
  - Providing more funding for computational methods and informatics.
- Maybe there could be an interagency/commercial sector forum to facilitate cooperation.
- Grand challenges with specific targets are needed—add public–private partnerships to signature initiatives? (This is captured in objectives below.)
- Interagency coordination needs to have more structured, more fluid processes.
- Better understanding is needed of the management of funding under NNI—who contributes what?

Suggested Revised, Prioritized Objectives for Goal 1[1]

The Goal 1 breakout group was asked to review, revise, and prioritize specific objectives proposed for inclusion in the 2011 NNI Strategic Plan, as developed in advance of the workshop by the NNI Strategic Planning Task Force (see Appendix C). The breakout group proposed a number of significant changes to these draft objectives, along with several new or consolidated objectives. Listed below are the revised objectives recommended by this breakout group, roughly in priority order—although all were considered to be very important. Revised Objective A below would replace the task force's proposed Objectives A, B, C, and H. Proposed Objectives D, E, F, G, and I were rewritten. Objectives B and F are new.

A. Explore novel approaches for transformative cross-disciplinary research to foster discovery and innovation.

   i. Develop at least five broad interdisciplinary nanotechnology initiatives ("Signature Initiatives") over the next 3–5 years that substantially engage and draw funding support, adequate to achieve stated initiative goals, from 3 or more NNI member agencies—presumably, $20 million or more annually.

   (As these activities progress, industry may be an important player in realizing success in these initiatives. In some cases, industry may already be engaged, and where this is happening, this information should be conveyed appropriately.)

   ii. Expand the boundaries of knowledge in fields of science, engineering, and technology relevant to nanotechnology by focusing the funding on at least five suggested R&D topics, selected by an interagency working group, that were not called out substantially in the 2007 NNI Strategic Plan.

   iii. Fund R&D at the frontiers and intersections of many disciplines, including biology, chemistry, engineering, geology, materials science, medicine, physics, and social sciences (as called for in the 2007 NNI Strategic Plan) by maintaining funding specifically set aside for multi- and interdisciplinary research centers, programs, and projects.

   iv. Maintain a balanced funding portfolio specifically for multi- and interdisciplinary research centers, programs, and projects.

   v. Develop and support interagency pilot programs that explore novel approaches for transformative, cross-disciplinary research to foster discovery and innovation and integrate

1 For purposes of comparison, see the original draft objectives submitted for consideration in advance of the workshop by the NNI Strategic Planning Task Force, Appendix C.

peer review and program management across agencies.

B. Incentivize industry to form consortia with one or more NNI agencies by offering matching funds to jointly support university research that addresses barriers to nanotechnology transition into commercial applications.

C. Develop an understanding of how the U.S. nanotechnology R&D program stands in the world.

  i. Define quantitative and qualitative measures for comparing the U.S. nanotechnology R&D program to that of other major economies of the world and obtain data on the metrics to quantify the comparison (cf. PCAST 2010). (Suggestion: By having an NNI workshop bringing together specialists in the relevant fields of scientiometrics, bibliometrics, etc.; develop a publicly accessible database of these metrics for the quantitative comparison.)

D. Strengthen support for the NNI throughout the Federal Government from the Executive Office to the NNI member agencies to the individual researchers at Federal agencies.

  i. Monitor and improve alignment between NNI and member agencies' priorities and national priorities, e.g., by creating a concept map.

  ii. NNI leadership should meet annually with top-level management of each NNI member agency (especially those contributing funding to the NNI budget). (Note that stakeholders didn't feel strongly about this item.)

E. Set research and education priorities by establishing an ongoing dialogue with diverse stakeholder groups (e.g., industry, NGOs, academia). (Examples could include inviting speakers to NSET Subcommittee meetings, use of webinars, use of NNI strategy portal Web 2.0 interface).

F. Incentivize the development of a shared nanoscale materials properties database to advance goals, including developing the understanding necessary to define acceptable practices in the EHS area, for example, to expand Material Safety Data Sheets to include scale effects, support design of green chemistry processes, and accelerate fundamental research that depends on knowledge of nanoscale material properties.

G. Foster international collaboration in nanotechnology research and development between government, academia, industry, and other stakeholders. This should include fostering relationships with developing countries and economies in transition.

2. Goal 2: Foster the Transfer of New Technologies into Products for Commercial and Public Benefit

John Cowie, Discussion Leader

Introduction

The first day of the Goal 2 breakout session began with introductory presentations by Shaun Clancy (Evonik, "NNI and Gaining Public Benefits from Nanotechnology"); Sean Murdock (NanoBusiness Alliance, "Improving Nanotechnology Commercialization"); and John Randall (Zyvex, "Atomically Precise Nanomanufacturing").[1] John Cowie then led an open brainstorming session during which much of the discussion concerned the specific questions that the introductory presenters had been asked to address in their talks:

- Are there new forms of public–private partnerships that you could recommend to improve commercialization?
- What do you think the NNI should do in regard to improving/fostering technology transfer and commercialization?
- What U.S. Government policies (or lack thereof) are helping or hindering commercialization of nanotechnology in the United States, and how should those be changed?

Discussion then turned to the draft objectives for Goal 2 proposed in advance of the workshop by the NSET Subcommittee (see Appendix C). A wide range of comments were offered on each of the draft objectives.

On the second day of the breakout session, the initial discussion focused on the general questions that were asked of all four breakout sessions:

- With respect to this goal, what has the NNI done right and what should it continue doing?
- With respect to this goal, where has the NNI headed down the wrong path?
- What can the NNI do in the future to address this goal?

The session ended with a detailed review of the proposed objectives for Goal 2, which resulted in a revised list of objectives as proposed by the members of this breakout session.

Introductory Presentations

Brief summaries follow of each of the three brief invited presentations that were made at the outset of this breakout session.

Shaun Clancy, Evonik

Dr. Clancy began by stating that his perspective was shaped by his employment at a large chemical company as well as participation in policy groups such as the Working Party on Manufactured Nanomaterials (WPMN) of the Organisation for Economic Cooperation and Development (OECD) and the American National Standards Institute (ANSI) Nanotechnology Technical Committee. He then pointed out several important areas that impact nanotechnology commercialization, including hazard information collection, which could be improved by development of some common methodologies

1 Presentations are available at http://www.nano.gov/html/meetings/NNISPWorkshop/presentations.html.

such as rapid screening methods and computational toxicology; development of economical methods and measuring instruments for personal exposure; much better methods to detect nanomaterials in the environment; better and more consistent methods to characterize nanomaterials, including size and shape; and agreement on a common terminology across disparate fields working in nanotechnology. He concluded by stressing that better communication with the public about what nanotechnology is and can do is vital, since members of the public will ultimately be the consumers [of nanotechnology-enabled products], and their health could be affected. Uncertainty in the regulatory environment, and the inability [of some scientists] to communicate with the public, result in increased perceived risk and ultimately less investment.

Sean Murdock, Nanosonix, NanoBusiness Alliance

Mr. Murdock began by presenting some context for U.S. investment in nanotechnology: Over roughly the last decade, total U.S. nanotechnology R&D investment has been less than $30 billion, compared to a total U.S. R&D investment of almost $2 trillion, and a U.S. GDP of almost $13 trillion. Moreover, the fraction of venture capital (VC) investment in nanotechnology has also been comparatively small. He argued that this is a considerable underinvestment, given how revolutionary nanotechnology will likely become. A second main point he presented was the changing long-term dynamics of the U.S. "innovation ecosystem," in which he presented data (from the Information Technology and Innovation Foundation) showing the steady decline of R&D investment by large corporations, and consequently the need to increase R&D investment from Federal sources. In particular, the Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs have become increasingly important for generating new technology innovations. Additionally, VC investments, which are always critical to technology commercialization, have been in decline since 2006. An interesting fact was that there was an increase in nanotechnology investment when the 21st Century Nanotechnology R&D Act was passed in 2003, due to increased confidence in nanotechnology in the private sector, and so it is important that the proposed NNI reauthorization legislation be passed. Mr. Murdock concluded with several recommendations for strengthening the U.S. innovation ecosystem with respect to nanotechnology, including significantly increasing R&D funding and an increase in "patient capital," extending R&D tax credits, developing more public–private partnerships (PPPs), fostering virtual research networks, and creating additional gap funds.

John Randall, Zyvex

Dr. John Randall, Vice President of Research at Zyvex Corp., began his talk by mentioning that ten years ago, 80% of Federal applied research funding went to companies, whereas today 80% goes to universities. He observed that this shift may be a poor strategy from a product commercialization standpoint. He stated that most nanotechnology research today is evolutionary, not revolutionary, and that the United States is not investing much in potentially game-changing technologies. He gave the example of research to improve manufacturing precision, which facilitates a very wide range of developments, and which directly impacts the ability of the United States to capture product markets. He discussed the Atomically Precise Manufacturing Consortium (APMC), a broad PPP in Texas, which is an effort to develop a general manufacturing process with greatly improved precision. This program may create a manufacturing process capable of creating products that are atomically identical (e.g., quantum dots), which would be truly revolutionary. APCM is making progress toward making this process scalable, which will have profound consequences for many industries such as electronics, where it may make commercial quantum computers realizable, as well as communications and biomedical advancements. More generally, the NNI should take this lesson and invest in more revolutionary research, as well as promoting regional innovation centers, PPPs, and metrology and infrastructure.

Summary of Comments and Suggestions

The intent of extending the breakout sessions over two days was to allow participants to consider the discussions from the first day overnight, leading to a more conclusive discussion the second day. What follows is a synthesis of the comments and suggestions of the Goal 2 breakout session participants as they emerged at the end of the second day. This is divided below into two sections: (1) responses to the general questions that were posed to all four breakout sessions, and (2) responses to the specific questions posed to this breakout session. The final section of this chapter is a list of suggested revised and prioritized objectives for NNI Goal 2.

Responses to General Questions

With respect to this goal, what has the NNI done right and what should it continue doing?

The NNI has had success in greatly incentivizing multidisciplinary R&D for nanotechnology. In addition, the NNI has made commercialization and economic development outcomes a goal from its beginning and has been successful at creating industry partnerships. The NNI has made the development of nanotechnology the goal of more agencies and has been instrumental in developing nanotechnology-focused SBIR programs. The NNI has also been successful in creating nanotechnology R&D infrastructure (e.g., user facilities, research centers), as well as a nanocharacterization lab at the National Cancer Institute (NCI). The NNI website (http://www.nano.gov) and the NNI publications have been very useful to the scientific community as well as to those outside the scientific community. The NNI should maintain the successful Nanoscale Science and Engineering Centers (NSECs, NSF activities) and potentially institutionalize them. Other NNI and agency programs that were suggested as possible models for future activities include the Grant Opportunities for Academic Liaison with Industry (GOALI) Program and the Industry/University Cooperative Research Centers (I/UCRC) Program (both of which are NSF programs).

The NNI has been able to influence investment by driving down the initial costs for large- and medium-sized enterprises and small- and medium-sized enterprises. NSECs have been phenomenally successful in helping startups and getting political support at the state and local levels that otherwise might not have happened.

With respect to this goal, where has the NNI headed down the wrong path?

Some suggested that the NNI has emphasized a safer path (more in the middle). Stronger commercialization efforts are needed on one hand, and more funding is needed for high-risk/high-payoff research to enable major discoveries, on the other hand. Several participants suggested that the NNI's commercialization efforts could be stronger; however, one senior industry participant noted that, as a research initiative, the NNI cannot create the "market pull" that is a key element of commercialization. (Nonetheless, NNI-enabled discoveries do create opportunities for private markets to exploit.) Some state and local nanotechnology-based economic development initiatives that were begun in the last decade have now disappeared, perhaps due in part to lack of Federal support. Perhaps Federal support could be provided to help state and local programs "blossom," which in turn will help business. Other comments in response to this question included the observation that the NNI has not adequately defined "nanomanufacturing," per se; the group recommended increased emphasis on three related topics: (1) hierarchical self-assembly, (2) high-throughput top-down nanomanufacturing (e.g., through parallelism), and (3) deterministic control over position and orientation in bottom-up nanomanufacturing. Finally, some participants observed that the NNI agencies have been unable to truly work together as much as they should; the corresponding suggestion was that 5% of total R&D be set aside for interagency projects.

What can the NNI do in the future to address this goal?

Several options were discussed among participants: (1) Provide prototyping centers for "proof of concept" so developers can understand the potential products and refine fabrication and eventual manufacturing technologies for making them; (2) have more "get-to-the-moon" projects or programs coming out of Goal 1; (3) do more "prizes" programs like the ones that DARPA and NASA have done in the past (with specific challenges like producing the longest carbon nanotube, $1/peak Watt photovoltaic devices, etc.); and (4) move technology offices to marketing/business development offices so companies can envision how nanotechnology can become a solution that spurs industry growth, products, and problem-solving. The NNI could also help address the nanotechnology "risk" issue with insurance—create a "one-stop shopping" site for all information (e.g., both state and Federal regulatory structures, export controls, etc.). Other suggestions were to develop regional technology transfer offices that would work as a continuum through to the business development side, strategically focusing all SBIR and STTR projects to aim for strategic impacts; and to create a "gap" fund that will help fill-in the "valley of death" for broader impact. One final suggestion was to consider the development of a process capability to develop tools that can in turn be used to make other nanoscale parts and tools.

Responses to Questions Specific to Goal 2

The Goal 2 breakout group was also asked to address a number of questions more specific to this goal, as follows:

Are there new forms of public/private partnerships that you could recommend to improve commercialization?

In response to this, a number of models were suggested by the breakout participants:

- State model (e.g., Oklahoma, Oregon).
- SBIR model, where the National Institute of Standards and Technology (NIST) has some special intellectual property (IP) provisions.
- Defense Advanced Research Projects Agency (DARPA) model.
- VC models (work better in some sectors than others).
- Fund companies to cooperate with universities, rather than the reverse, which is typical of current U.S. Government funding.

What do you think the NNI should do in regard to improving/fostering technology transfer and commercialization?

Many suggestions were offered in response:

- Add a commercialization component to university R&D grants.
- Establish entrepreneurs-in-residence programs at NNI-funded universities.
- Task the National Nanotechnology Coordination Office (NNCO) with assisting in commercialization outreach to agencies and companies.
- Provide a searchable database of all NNI-funded projects (i.e., R&D dashboard).
- Evaluate and consider increased funding for existing programs, e.g., GOALI; enhanced SBIR Phase II and III; ATP, TIP (Advanced Technology Program and Technology Innovation Program: former and current NIST programs), etc.
- Make sure that technology transfer is actually a priority for the individual agencies.
- Take full advantage of the Federal Government as a potential first customer for nanotechnology innovations, e.g., as the Minuteman ICBM program helped to stimulate technology maturation and demand for the newly invented integrated circuit in the early 1960s.
- Consider creating an organization modeled on SEMATECH for government–industry cooperative support of precompetitive research in nanomanufacturing.

What U.S. Government policies (or lack thereof) are helping or hindering commercialization of nanotechnology in the United States, and how should those be changed?

Comments and suggestions by breakout participants included the following:

- Universities have a disincentive for commercialization.
- Regulatory uncertainty inhibits investment.
- The government is giving too much R&D funding to universities; perhaps it should only fund commercial companies (EU Framework model)

or require universities to partner with industrial companies.

- U.S. tax policy rewards consumption and punishes investment (not nanotechnology-specific); do not tax companies.
- Review panels evaluating research proposals don't look at broader implications.

Suggested Revised, Prioritized Objectives for Goal 2[1]

The Goal 2 breakout group was asked to review, revise, and prioritize specific objectives proposed for inclusion in the 2010 update to the NNI Strategic Plan, as developed in advance of the workshop by the NNI Strategic Planning Task Force (see Appendix C). Overall, the group agreed with the objectives that were proposed by the Task Force for Goal 2. Objectives A, B, and C were not revised, though changes to sub-bullets of C were suggested. One of the proposed sub-bullets under C was moved to a separate objective, prioritized as D. Objective D (international environment) as proposed by the Task Force was moved to E. Finally, the group proposed a new Objective F. The group also commented that Objective A needs more specifics. The resulting revised (and reprioritized) list of objectives under Goal 2, as proposed by this group, is as follows:

A. Increase emphasis by NNI member agencies on manufacturing of nanotechnology-based products by doubling the funding devoted to nanomanufacturing, for those agencies that have nanomanufacturing as part of their programs. (cf. PCAST's *2010 Report to the President and Congress on the Third Assessment of the National Nanotechnology,* e.g., pp. x–xi):[2]

   i. Identify technologies for which additional investments in nanomanufacturing are needed to promote commercialization.

   ii. Address barriers for commercialization.

   iii. Create some "gap" funding.

1 For purposes of comparison, see the original draft objectives submitted for consideration in advance of the workshop by the NNI Strategic Planning Task Force, Appendix C.

2 http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nni-report.pdf.

B. Increase emphasis by NNI member agencies on commercialization of nanotechnology-based products by launching at least five government-industry-university partnerships using successful models such as the Nanoelectronics Research Initiative (NRI) (cf. PCAST 2010, p. xiv).

   i. U.S. companies should get first access to IP.

C. Establish at least three self-sustaining hubs that have the primary goal of transferring newly developed concepts into commercial products—possibly transitioning some existing NNI centers into such technology transfer centers or prototyping centers or foundries analogous to the foundries developed for microelectromechanical systems (MEMS):

   i. The NNI should offer 1:1 matching for regional nanotechnology-oriented gap funds that are VC-partner-advised and that have as their specific objectives and measures of success to form new companies and attract at least 10x leverage VC capital to them within three years.

   ii. Develop a "fab-less" nanoscale foundry offering a wide range of process and fabrication capabilities, along the lines of the DARPA MEMS Exchange, geared to business prototyping, to provide economical access to state-of-the-art tools and processes, expertise, and training, with an option for remote use.

   iii. Create Federal–state government–industrial sector partnerships to facilitate the transition of new research discoveries to regional, state, and local nanotechnology initiatives and then into commercialization.

   iv. Create an IP auction so that large firms can get access to IP, to incentivize firms sitting on IP to sell it (vs. compulsory licensing). Hold workshops to facilitate technology transfer along the lines of the NASA Tech Briefs® program—but possibly broader.

D. Develop informational materials to assist small businesses in understanding the regulatory issues (e.g., environmental, health, and safety regulations as well as national security and international trafficking in arms export controls and regulations) that are relevant to and particular to nanotechnology-related products and businesses.

E. Improve the international environment for commercialization, technology transfer, and innovation related to nanotechnology:

   i. Increase engagement from the NNI member agencies and encourage participation from other U.S. and international stakeholder organizations in international forums such as the OECD Working Party on Nanotechnology (WPN) and Working Party on Manufactured Nanomaterials (WPMN).

   ii. Secure consistent interagency support of the documentary standards development necessary to facilitate nanotechnology innovation.

F. Reenergize U.S. manufacturing by asking agencies to propose, identify, and fund platforms and/or transformational nanomanufacturing technologies that are high risk and high reward:

   i. Develop “roadmaps” using the International Technology Roadmap for Semiconductors (ITRS) model. Technologies and industry sectors that could be covered include:

      a. Harvesting and storage of energy (e.g., thermoelectric technology)
      b. Nanocellulose crystals for strengthening packaging and composites, windows, surfaces, structural materials, HVAC systems
      c. Nanosensors (wide variety of applications)
      d. Water filtration/purification
      e. Pharmaceuticals and medical devices
      f. Supercomputing
      g. High-strength fibers—impacting aerospace, transportation, buildings, etc.

3. Goal 3: Develop and Sustain Educational Resources, a Skilled Workforce, and the Supporting Infrastructure and Tools to Advance Nanotechnology

James Murday, Discussion Leader

Introduction

The first day of the Goal 3 breakout session began with introductory presentations by Vincent Caprio (NanoBusiness Alliance, "NanoBusiness Alliance Members' Use of NNI Infrastructure"); Stephen Fonash (Pennsylvania State University, "An Assessment of NNI's Educational and Outreach Efforts"), and Charles Gause (Luna Innovations).[1] James Murday then led an open brainstorming session during which the primary topic of discussion was the draft objectives proposed by the NNI Strategic Planning Task Force in advance of the meeting. Objectives proposed by the task force were assigned a priority rating and a likely timeframe. A number of new objectives were also proposed.

Introductory Presentations

Brief summaries follow of each of the three brief invited presentations that were made at the outset of this breakout session.

Vincent Caprio, NanoBusiness Alliance

Vince Caprio, Executive Director of the NanoBusiness Alliance (NBA), began with a quick overview of the NanoBusiness Alliance, a large and diverse network of commercial nanotechnology entities. Mr. Caprio then discussed the topic of shared nanotechnology infrastructure facilities, and in particular the National Nanotechnology Infrastructure Network (NNIN), as well as some of the barriers to their use that companies currently face. For example, while use of NNIN facilities provides great value, supporting costs such as staff training and travel can be a burden, particularly on small companies. Mr. Caprio suggested that the NNI should consider direct grant programs to offset these costs and make it easier for businesses to participate. He pointed to a statistic that shows only about 4% of nanoHUB users are businesses and asked whether the new strategic plan will include mechanisms to help increase the number of industrial users. He suggested that an increase in industry-targeted informational outreach might be one mechanism to educate the commercial sector about the value offered by these shared facilities.

Stephen Fonash, Pennsylvania State University

Prof. Fonash focused on some of the NNI's educational and outreach programs. Specifically, he covered the activities of Penn State's Nanotechnology Applications and Career Knowledge (NACK) Center, an NSF-funded program that focuses on developing educational and job training resources in nanotechnology for K–12, 2-year colleges, universities, and graduate programs. Dr. Fonash explained that numerous barriers exist to developing nanotechnology educational programs, such as lack of expertise in nanotechnology, school budgets, and disparities in standards for curricula nationwide. The NACK Center attempts to provide solutions to these issues by helping develop educational materials and courses, developing partnership opportunities with

1 Presentations are available at http://www.nano.gov/html/meetings/NNISPWorkshop/presentations.html.

research universities to provide practical student experience, helping create minors in nanotechnology within other disciplines, educating leadership on the economic and societal benefits of nanotechnology, and creating public outreach programs in nanotechnology, including a catalogue of online resources. The long-term goal of NACK is to foster a more technically literate workforce and a scientific community with a nanotechnology background that can address future opportunities in the area.

Charles Gause, Luna Innovations, Inc.

Dr. Gause gave an overview of the activities of Luna nanoWorks (LnW), a division of Luna focusing on nanotechnology products. LnW conducts a broad spectrum of research activities, from basic research into nanomaterials to developing new processes for nanomanufacturing, and it has developed several profitable nanotechnology products in the medical and solar energy arenas. LnW has also developed a strong EHS research effort to characterize the effects of its nanotechnology products. Finally, Dr. Gause discussed the economic effects of LnW's success. He showed statistics for the significant economic improvement that Danville, Virginia, has experienced since LnW was founded there, and how LnW is now helping Danville Community College develop a 2-year technician program in the Manufacturing Engineering Technology Program focused on training a future workforce in the field of nanotechnology.

Summary of Comments and Suggestions

Although interrelated, the R&D infrastructure, education, and workforce topics for Goal 3 were sufficiently unique to warrant their individual attention and are so organized in what follows. The original draft objectives proposed by the NNI Strategic Planning Task Force are shown in italics font. Comments, suggested changes, and proposed new objectives are shown in normal font. The task force's proposed objectives were framed so broadly that it was difficult to appraise them in the "SMARTER" context. A number of more focused objectives and sub-objectives were suggested instead.

R&D Infrastructure

Research and development at the nanoscale requires instrumentation—to make, measure, and manipulate—that can be expensive both to acquire and to operate. Expert operators must be available. User facilities are required to meet this need. While new analytical and fabrication tool development over the past twenty years has provided many impressive new capabilities, a number of recent workshops point to the importance of ongoing development. As nanotechnologies become ever more sophisticated, the equipment needed to make, measure, and manipulate will also grow in complexity and cost. When these tools are either expensive and/or difficult to operate, they must be made available at user facilities. International and industrial partnerships should be fostered as a means of sharing the cost of these new capabilities.

NNI accomplishments with respect to R&D infrastructure

Nanoscale user facilities have experienced significant advances in the past decade, in the United States and around the world. In a 2003 NSF competition, the National Nanotechnology Infrastructure Network was created with 14 participating sites distributed across the country. The NNIN provides extensive support in nanoscale fabrication, synthesis, characterization, modeling, design, computation, and hands-on training in an open, hands-on environment available to all qualified users. The Network for Computational Nanotechnology, with Purdue as lead university, was created in 2002 to design, construct, deploy, and operate a cyber-resource for nanotechnology theory, modeling, and simulation. The U.S. Department of Energy (DOE) and NIST also opened user facilities in the 2007–2008 timeframe. The National Institutes of Health (NIH), in collaboration with the U.S. Food and Drug Administration (FDA) and NIST, opened the Nanotechnology Characterization Laboratory in 2008 to meet the special needs for characterizing nanostructure interactions with living systems.

Beyond the user facilities, there are a large number of nanoscale science/engineering centers at U.S. universities that provide and maintain instrumentation for their faculty (for more information see http://www.nano.gov).

R&D infrastructure objectives

Objectives A, E, F, and G from the list proposed by the NNI Strategic Planning Task Force in advance of the workshop (see Appendix C) were considered relevant to the R&D infrastructure subtopic. None of the objectives were eliminated. For Objective A, the group suggested adding *NGOs and Federal, state and local governments* to the list of users of the facilities information. Two additional sub-bullets were added to Objective F. Objectives A and G were deemed high-priority; Objective A was considered to be a near-term priority and Objective F a longer-term one. Objectives E and F were rated as mid-priority, long-term efforts. Detailed comments on each of these objectives were offered, as follows (with the original proposed language in italics):

A. *Accelerate innovative nanotechnology discoveries by developing, maintaining, and publicizing information on nanotechnology facilities, including those supported by states, that are accessible for use by individuals from academic institutions and industry. This information may include the facility location, contact information, terms and conditions for use, and a description of the equipment available for use.*

Comments: This is a high-priority, near-term effort. A search engine should be available to search by needed function (e.g., TEM with specific capabilities) and by geographic location. The information should be readily available on the NNI website. To the extent possible it should include information on facilities in other countries. The InterNano website (http://www.internano.org/) being developed for the National Nanomanufacturing Network would be a logical place to implement this idea.

E. *Develop and implement informatics tools that will advance the understanding and utility of nanomaterials.*

Comments: This is a mid-priority, long-term effort. Nanoinformatics will involve the development of effective mechanisms for collecting, sharing, visualizing, modeling, and analyzing information relevant to the nanoscale science and engineering community. It also involves the utilization of information and communication technologies that help to launch and support efficient communities of practice. Nanoinformatics is necessary for comparative characterization of nanomaterials, for design and use of nanodevices and nanosystems, and for instrumentation development and manufacturing processes. Nanoinformatics also fosters efficient scientific discovery and learning through data mining and machine learning techniques. Both NIH and NSF have strong efforts in informatics. The nanoinformatics effort should leverage those programs. The InterNano and/or nanoHUB (http://www.nanohub.org/) websites may be mechanisms to provide access to any tools emanating from this effort.

F. *Support infrastructure and tools development to advance nanotechnology innovation.*

   i. *Develop new tools for imaging, displaying, measuring, and manipulating matter at the nanoscale.*

   ii. *Develop advanced methods and hardware capabilities for modeling and simulating nanoscale materials, phenomena, and processes.*

   iii. *Develop advanced methods for high-throughput analysis of the physico-chemical properties of nano-objects and nanostructured materials.*

Suggested additional sub-bullets for Objective F

Two additional sub-bullets were suggested for this objective:

   iv. Develop user-friendly, reliable remote access for use by school (K–12, community/technical colleges, undergraduates) students and museum projects.

   v. Develop manufacturing user facilities that provide the capability to make and assess devices/systems.

Comments: This is a mid-priority, long-term effort. Since manufacturing at the nanoscale has many facets, there will necessarily be more than one manufacturing user facility. The Albany NanoCenter presently provides capability for information technology devices. Workshop participants suggested that one or more of the existing Federally supported user facilities might be morphed into a manufacturing user facility. While some equipment at NNI user facilities is designed for remote user access, many tools are not. Efforts to date to develop that capability have met with limited success.

G. *Create and maintain programs that will facilitate sustained and expanded investments in NNI interdisciplinary research centers, user facilities, and networks; continuously update/upgrade equipment at those facilities, and sustain staffing levels, to maintain cutting-edge research capabilities.*

Comments: This is a high-priority, long-term effort. Because centers/user facilities are unique and capable of providing services unavailable elsewhere, there is a need for sustained funding. The NSF NSECs and other agency center programs should be sustained, and strong efforts should be made to transition graduating centers to state/local/industrial funding. If the number of NSECs is reduced, it will be difficult for the NNI to meet this objective.

Educational Infrastructure

Nanoscale education is a fundamental tenet of the NNI and its constituent agencies. A technically accurate understanding of nanotechnology (benefits, challenges, impacts, etc.) is essential for every American. However, the breadth and depth of that knowledge and the institutions or programs that support that education are varied and depend upon the specific segment of the U.S. population to which the educational content is being addressed.

The current U.S. interest in, planning for, and activity toward reinvigorating science, technology, engineering, and mathematics (STEM) education provides programmatic opportunities for innovation. With the disruptive discoveries already realized through nanoscale science and engineering research, it is essential to examine what impact the nanoscale might impose on approaches to revamping STEM education:

- Nanostructures can have new physical, chemical, and biological properties. This new knowledge should be incorporated into the educational corpus.
- Nanoscale science and engineering is largely transdisciplinary. It challenges the traditional science and engineering education taxonomies.
- The nanoscale holds sufficient novelty to attract student interest in STEM.
- As nanostructures become materials' building blocks and directed self-assembly becomes a viable manufacturing process, there will be a need for an informed, skilled workforce.
- Workers and members of the general public may be in contact with nanomaterials in various forms during manufacture or in products, and they should be sufficiently knowledgeable to understand the benefits and risks.
- The attention that NSF and other institutions have paid to education at the nanoscale ("NanoEducation") is resulting in the development and dissemination of a wealth of new instructional materials, some of which are available as cyberinfrastructure resources.

Those interested in NanoEducation believe it is time to: (a) broaden the nanoscale education efforts to include the many stakeholder groups and communities, (b) establish an enduring infrastructure beyond the NSF-sponsored Nanoscale Science and Engineering Education (NSEE) workshops, and most importantly, (c) develop partnerships toward meeting the challenges and identifying the opportunities provided by global advances at the nanoscale.[1] This is consistent with the Carnegie Opportunity Equation report that calls for a national mobilization in education exploiting partnerships.[2] A partnership approach is also reflected in the proposed NNI reauthorization bills.[3]

NNI accomplishments with respect to educational infrastructure

The Nanoscale Informal Science Education Network (NISE Net) was established in 2005 for the purpose of creating a national infrastructure of informal science education institutions, in partnership with nanoscale research centers, aimed at raising public awareness, understanding, and engagement with nanoscale science, engineering, and technology.

1 J.S. Murday, *Partnership for Nanotechnology Education Workshop Report,* UCLA 26-28 April 2009 (NSF, Arlington, VA, 2010; http://www.nsf.gov/crssprgm/nano/reports/nsfnnireports.jsp).

2 *The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy* (Carnegie Corporation of New York and Institute for Advanced Study, 2009; http://www.OpportunityEquation.org).

3 H.R. 554, http://www.opencongress.org/bill/111-h554/show; S.1482, http://www.opencongress.org/bill/111-s1482/show.

Most research-intensive universities now have nanotechnology-related science and engineering courses, many have centers or institutes focused on the nanoscale, and several have nanoscience/nanotechnology-oriented departments and colleges. As an example of the latter, the new campus of the College of Nanoscale Science and Engineering at SUNY Albany is seamlessly integrated with micro- and nanoelectronics companies.[1]

Several nanotechnology-oriented NSF-Advanced Technological Education[2] (ATE) programs at community/technical colleges focus on training future nanoscale technicians (see http://www.nano.gov for more information).

The pre-college level is where efforts can begin to prepare nanotechnology-literate citizens, train future nanotechnology technicians and engineers, and use nanoscale concepts to pique student interest in STEM. There are K–12 nanotechnology education and outreach components:[3]

- The Northwestern National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT).
- Many NSE research centers with funding from NSF, DOE, and other agencies are charged with transferring these concepts into U.S. classrooms. Examples are the NSF NSECs and the DOE Nanoscale Science Research Centers (NSRCs).
- Other programs such as the NSF Materials Research Science and Engineering Centers (MRSECs), Engineering Research Centers (ERCs), and Science and Technology Centers (STCs) have also developed nanoscale science and engineering components. Activities vary among centers but may include classroom outreach, content development, and teacher professional development, often with funding from the NSF Research Experiences for Teachers (RET) program.
- Other nanotechnology-specific projects have been funded under existing education programs. For example, NSF has funded nanotechnology-specific learning research by organizations such as BSCS, Nanoteach, and McREL.

Educational infrastructure objectives

Proposed new objective

The group proposed a new, high-level objective under this topic, as follows:

NanoEducation Ecology:

i. Create an NSET Subcommittee Nanotechnology Education and Workforce working group that will support agency efforts toward addressing education and workforce issues.

ii. An education and workforce-focused consultative board to the NSET Subcommittee should also be created, comprising the various principal stakeholders.

iii. Develop a hand-off process/mechanism between NSF (which is the initiator for much of the nanotechnology education and workforce training material) and the Department of Education (which is the agency with responsibility for sustaining the developed educational content).

Comments: There are numerous groups around the world addressing STEM education, NanoEducation, nanoscale science and engineering research, and nanotechnologies. There is an immediate challenge to integrate these various communities. A focal point is needed to identify, validate, and integrate the many NanoEducation capabilities that presently exist and to assess what is additionally needed. Principal stakeholders include: The Executive Office of the President, including the Office of Science and Technology Policy (OSTP) and the National Science and Technology Council (NSTC); the NNI participating Federal agencies; the National Education Association (NEA); the National Science Teachers Association (NSTA); professional science and engineering organizations (e.g., the American Chemical Society, the American Institute of Physics,

1 http://cnse.albany.edu/about_cnse.html.

2 NSF Advanced Technology Education Centers, http://www.atecenters.org/.

3 Table 1 in *Partnership for Nanotechnology Education Workshop Report*.

the Society of Manufacturing Engineers, etc.); the NanoBusiness Alliance; and the STEM Education Coalition.

Review of Objective B

Objective B from the list proposed by the NNI Strategic Planning Task Force in advance of the workshop (see Appendix C) was considered most directly relevant to the educational infrastructure subtopic. The proposed objective as originally worded is as follows:

B. *Develop effective mechanisms to communicate to K–12, undergraduate students, and the public an understanding of nanotechnology and the broad opportunities for nanotechnology-related careers:*

   i. *Leverage Science, Technology, Engineering, and Mathematics (STEM) educational initiatives being sponsored by NNI member agencies to equip future nanotechnology researchers and developers.*

   ii. *Create programs to support the development and implementation of outreach programs such as workshops, public forums, or mobile nanotechnology demonstrations. Benchmark these programs by identifying and comparing them with international best practices.*

   iii. *Survey existing mechanisms for international collaboration on issues of education and workforce development.*

   iv. *Establish a national network for developing and implementing education and training courses for stimulating nanotechnology innovation.*

   v. *Sustain outreach and education programs currently supported at the NNI agencies, and increase efforts to disseminate and use the best ideas developed.*

Suggested edits to Objective B: The last phrase of the objective should be reworded to read, "…communicate nanoscience and nanoengineering fundamentals to all constituents." The end of sub-bullet (i) should be reworded to read, "…nanotechnology researchers and developers and to extend the reach to non-scientific community constituents." Sub-bullet (ii) should be reworded as follows: "Continue to create and fund projects to support the development and implementation of outreach programs such as workshops, public forums, or mobile nanotechnology demonstrations. Encourage education outreach programs that make use of modern communication tools such as webcasts, podcasts, social media forums, etc. Benchmark these programs by identifying and comparing them with international best practices and implementing additional best-practice approaches for continuous improvement of communication." Sub-bullet (iii) should have the following phrase added to the end: "…and utilize them to improve U.S. capabilities."

Comments: This is a high-priority, long-term effort. The constituents include students and educators in K–12, undergraduate programs, community colleges, and 4-year institutions. The audience also includes future, incumbent, and displaced workers who may require training, and manufacturers, laborers, and incumbent workers who may use or be exposed to nanomaterials during the course of their job execution and require a fundamental understanding of nanotechnology materials and processes. The general public is also included because communication about nanotechnology is necessary to create informed citizens regarding policy, legislation, and regulation. The content of this communication includes a general understanding of nanotechnology and the broad opportunities for nanotechnology-related careers. What fundamental knowledge needs to be known and understood by the group of constituents listed above? That is, what is the depth and breadth of nanoscience information that is required? What is the appropriate method for communication—forums, online, face-to-face, etc.? Appreciation for nanoscience can be enhanced by presenting ideas and applications with a "wow" factor, something that will affect the lives of individuals or change the way people live. Opportunities for these learning communications need to be regular and periodic, either addressing new issues or reviewing and reinforcing understanding of nanoscience concepts. Sub-bullet (iii) above is mid-priority, requiring a sustained effort over the long term.

Suggested additional sub-bullets for Objective B: The group concluded that some of the draft objectives originally proposed by the NNI Strategic Planning Task Force needed to be more specific and actionable in order to meet the "SMARTER" criteria (see first page of Appendix C). It therefore formulated a number of additional sub-bullets under Objective B, with those criteria in mind, as follows:

vi. Identify and assist U.S. K–12 common core educational efforts to appropriately include nanoscience.

   a. Work with the National Governors Association (NGA), the Council of Chief State School Officers (CCSSO), and Achieve, Inc., to appropriately introduce the nanoscale into the common core physical science standards. Present an international benchmark for inclusion.

   b. Encourage participants in the many U.S. nanoscale science, engineering, and technology centers ("NanoCenters") to work with their own state education departments toward revising science learning standards.

   c. Provide funding to develop coherent nanoscale science and engineering contributions to the curricula addressing the common core standards.

Comments: This is a high-priority topic requiring a short-term start date and a long-term sustained effort. Funding should be provided for the design, development, testing, and implementation of a coherent curriculum that would allow 7- to 18-year-old students to develop an integrated understanding of core science ideas that underpin nanoscale science and engineering. Such a curriculum would focus on helping students develop progressively deeper understanding of core ideas. Such a process calls for change in the standards that focus on teaching big ideas, with a focus on developing a deeper understanding of these ideas. Assessment and standardized testing must also be addressed.

vii. Establish links between museums (NISE Net) and the national and international research communities for new exhibit development.

Comments: This is a high-priority, long-term effort. Beyond NSF, other Federal funding agencies and industry representatives must also be contributors, since they will be engaged in the translational efforts that lead to technology impact. This is an element of public outreach, not a stand-alone item.

viii. Create a centralized website that provides ready access to vetted K–12 education materials.

Comments: This is a mid-priority, long-term effort. There is a significant amount of content that has been developed by NSF and other projects. The NSTA should serve as the evaluator for quality control to ensure that website materials are of high quality, are in a format readily utilized by K–12 teachers, are carefully indexed to the various state learning standards, and can be readily accessed from the NSTA website. Additional well-designed, highly interactive, media-rich, online learning tools should continue to be developed.

ix. NSF, DOEd [Department of Education], and other agencies with relevant missions should foster nanotechnology curricula development and evaluation that is appropriate for community colleges and ensure meaningful collaborations between the community colleges and the NanoCenters.

Comments: This is a mid-priority, long-term effort. The Department of Education's College and Career Transitions Program addressing articulation should include nanotechnology.

x. Update and expand continually the Wikipedia entries on nanotechnology.

Comments: Wikipedia is the de facto encyclopedia of the world. As such it is a worldwide resource that deserves closer attention. The present entries addressing nanotechnology leave much to be desired. This task might be best accomplished by mobilizing the variety of talent and expertise at the various NanoCenters. K–12 science teachers should be involved to ensure that the information is structured in ways that can be readily absorbed at the various grade levels.

xi. Better publicize nanoscale science and engineering education resources.

Comments: "Nano"-enabled technologies will enable us to alter our world and provide advances in standards of living. With the decline in the number of science journalists, there is an opportunity for the NNCO, university and industrial programs, and other stakeholder groups to develop a continuing stream of information that can inform technical and nontechnical educators and learners of the benefits and risks emanating from progress at the nanoscale. NanoHUB, NNIN, NSF Nanoscience Education Centers, and other infrastructure resources focused on nanotechnology need to be better publicized regarding accessibility, available educational content, targeted user levels, customizability both in terms of targeted audiences and user interface, interoperability with other systems, and service and training offerings.

xii. Mobilize NanoCenter undergraduate and graduate students to assist in K–12 education at the nanoscale.

Comments: Federal funding agencies must provide an adequate budget allowance for this work. Universities must recognize the faculty supervisory efforts in tenure and promotion decisions.

xiii. Establish a Nanoscale Science and Engineering Education forum to share best practices wherein all Federally funded NanoCenters and other interested parties should participate, not just those funded by NSF.

xiv. Utilize modern communications means in all education efforts.

Comments: The rapid growth in information technologies is creating new interaction paradigms that might be exploited using electronic media (e.g., Wikipedia, FaceBook, Second Life, YouTube, Nook, and Kindle) that are being adopted by young and IT-literate learners.

Review of Objective C

The breakout session participants left Objective C unchanged, as originally proposed by the Strategic Planning Task Force:

C. *Sponsor the creation of educational and training programs to advance nanotechnology innovation, such as science and engineering doctorate degrees in nanotechnology, professional science master's degree programs, and two-year programs for training in proficient use of all the tools and instrumentation of nanotechnology.*

Comments: This is a high-priority, long-term effort. There are many degree/certificate experiments underway that should be watched and evaluated for their success and subsequent employment rate. If nanoscale science and technology is to be fully institutionalized, at some point the issue of accreditation needs to be addressed.

Workforce

Preparation for employment is an important aspect of the educational process. In our rapidly evolving world, the needs of industry are fluid due to changing technologies and growing global competition. Nanoscale science will be instrumental in technological change. Many countries have followed the U.S. lead and established nanotechnology initiatives. Moreover, those initiatives tend to be more focused on targeted technology development than is the United States. Consequently, there will likely be strong global competition for nanotechnology-trained people. The Department of Labor needs to work with industry groups and with professional science and engineering societies to develop accurate assessments of domestic workforce needs, including the effects of growing education and job opportunities in other countries. These needs must be factored into the educational system.

NNI accomplishments with respect to workforce issues

The Departments of Labor and Education are now actively participating in the NSET Subcommittee. Several nanotechnology-oriented NSF Advanced Technological Education (ATE) programs focus on training future nanoscale technicians. Students participating in these programs acquire classroom knowledge and high-technology industrial lab experiences. The National ATE Center for Nanotechnology Applications and Career Knowledge, created at Penn State University in 2008 with funding from NSF, is charged with augmenting and further developing nanotechnology education at two-year degree institutions across the United States. NACK offers nanotechnology courses that may be attended or viewed on the web, course units on the web, state-of-the art equipment utilization experiences that may be attended or utilized on the web, web access to characterization equipment, and workshops on teaching nanotechnology.

Workforce objectives

Objective D from the list of draft objectives prepared in advance of the workshop by the NNI Strategic Planning Task Force was deemed most relevant to workforce development issues. The breakout group recommended leaving the objective as originally worded:

D. Institute effective mechanisms for educating, training, and sustaining a skilled workforce in nanotechnology:

- *i. Design and distribute communication tools such as videos/presentations/slide shows that workers and employers can use to promote good product stewardship in the manufacture and production of nanomaterials.*
- *ii. Develop educational and training materials for best safety practices in manufacture and production of nanomaterials for integration into overall training programs.*
- *iii. Develop statistical data on nanotechnology-related workforce opportunities and potential career pathways.*

Suggested additional sub-bullet for Objective D

The group recommended adding one additional sub-bullet to Objective D:

- iv. Develop programs specifically addressing displaced and unemployed workers.

Comments: This is a high-priority, short-term effort. Quantifiable data is needed to support the claim that nanotechnology is a driver toward U.S. economic recovery. States have money to retrain workers but have no idea what nanotechnology is, which makes it impossible to get funding for these training programs. Preparation for employment is an important aspect of the educational process.

Suggested Revised, Prioritized Objectives for Goal 3[1]

The resulting final revised (and reordered, prioritized) list of objectives under Goal 3, as proposed by participants in this breakout session, is as follows:

I. R&D Infrastructure Objectives

A. Accelerate innovative nanotechnology discoveries by developing, maintaining, and publicizing information on nanotechnology facilities, including those supported by states, that are accessible for use by individuals from academic institutions, NGOs, Federal, state, and local governments, and industry. This information may include the facility location, contact information, terms and conditions for use, and a description of the equipment available for use.

B. Create and maintain programs that will facilitate sustained and expanded investments in NNI interdisciplinary research centers, user facilities, and networks; continuously update/upgrade equipment at those facilities, and sustain staffing levels, to maintain cutting-edge research capabilities.

C. Develop and implement informatics tools that will advance the understanding and utility of nanomaterials.

D. Support infrastructure and tools development to advance nanotechnology innovation.

- i. Develop new tools for imaging, displaying, measuring, and manipulating matter at the nanoscale.
- ii. Develop advanced methods and hardware capabilities for modeling and simulating nanoscale materials, phenomena, and processes.
- iii. Develop advanced methods for high-throughput analysis of the physico-chemical properties of nano-objects and nanostructured materials.
- iv. Develop user-friendly, reliable, remote access for use by school (K–12, community/technical

1 For purposes of comparison, see Appendix C for the original draft objectives submitted for consideration in advance of the workshop by the NNI Strategic Planning Task Force.

colleges, undergraduates) students and museum projects.

v. Develop manufacturing user facilities that provide capability to make and assess devices/systems.

II. Educational Infrastructure Objectives

E. NanoEducation Ecology:

i. Create an NSET Subcommittee Nanotechnology Education and Workforce working group that will support agency efforts toward addressing education and workforce issues.

ii. An education and workforce-focused consultative board to the NSET Subcommittee should also be created, comprising the various principal stakeholders.

iii. Develop a hand-off process/mechanism between NSF (which is the initiator for much of the nanotechnology education and workforce training material) and the Department of Education (which is the agency with responsibility for sustaining the developed educational content).

F. Develop effective mechanisms to communicate nanoscience and nanoengineering fundamentals to all constituents.

i. Identify and assist U.S. K–12 common core educational efforts to appropriately include nanoscience.

a. Work with the National Governors Association (NGA), the Council of Chief State School Officers (CCSSO), and Achieve, Inc., to appropriately introduce the nanoscale into the common core physical science standards. Present an international benchmark for inclusion.

b. Encourage participants in the many U.S. nanoscale science, engineering, and technology centers ("NanoCenters") to work with their own state education departments toward revising science learning standards.

c. Provide funding to develop coherent nanoscale contributions to the curricula addressing the common core standards.

ii. Leverage science, technology, engineering, and mathematics (STEM) educational initiatives being sponsored by NNI member agencies to equip future nanotechnology researchers and developers and to extend the outreach to nonscientific community constituents.

iii. Continue to create and fund projects to support the development and implementation of outreach programs such as workshops, public forums, or mobile nanotechnology demonstrations. Encourage education outreach programs that make use of modern communication tools such as webcasts, podcasts, social media forums, etc. Benchmark these programs by identifying and comparing them with international best practices and implementing additional best practice approaches for continuous improvement of communication.

iv. Survey existing mechanisms for international collaboration on issues of education and workforce development and utilize them to improve U.S. capabilities.

v. Establish a national network for developing and implementing education and training courses for stimulating nanotechnology innovation.

vi. Sustain outreach and education programs currently supported at the NNI agencies, and increase efforts to disseminate and use the best ideas developed.

vii. Establish links between museums (NISE Net) and the national and international research communities for new exhibit development.

viii. Create a centralized website that provides ready access to vetted K–12 education materials.

ix. NSF, DOEd, and other agencies with relevant missions should foster nanotechnology curricula development and evaluation that is appropriate for community colleges and ensure meaningful collaborations between the community colleges and the NanoCenters.

x. Update and expand continually the Wikipedia entries on nanotechnology.

xi. Better publicize nanoscale science and engineering education resources.

xii. Mobilize NanoCenter undergraduate and graduate students to assist in K–12 education at the nanoscale.

xiii. Establish a Nanoscale Science and Engineering Education forum to share best practices wherein all Federally funded NanoCenters and other interested parties should participate, not just those funded by NSF.

xiv. Utilize modern communications means in all education efforts.

G. Sponsor the creation of educational and training programs to advance nanotechnology innovation, such as science and engineering doctorate degrees in nanotechnology, professional science master's degree programs, and two-year programs for training in proficient use of all the tools and instrumentation of nanotechnology.

III. Workforce Objectives

H. Institute effective mechanisms for educating, training, and sustaining a skilled workforce in nanotechnology:

i. Design and distribute communication tools such as videos/presentations/slide shows that workers and employers can use to promote good product stewardship in the manufacture and production of nanomaterials.

ii. Develop educational and training materials for best safety practices in manufacture and production of nanomaterials for integration into overall training programs.

iii. Develop statistical data on nanotechnology-related workforce opportunities and potential career pathways.

iv. Develop programs specifically addressing displaced and unemployed workers.

4. Goal 4: Support Responsible Development of Nanotechnology

Richard Canady, Discussion Leader

Introduction

The first day of the Goal 4 breakout session began with introductory presentations by Alison Elder (University of Rochester), Amy Jones (Applied NanoStructured Solutions), Pat Mooney (ETC), and Dietram Schuefele (University of Minnesota, via video feed).[1] Richard Canady then led an open brainstorming session that began with examination of the overarching questions that were posed to all four breakout groups:

- With respect to this goal, what has the NNI done right and what should it continue doing?
- With respect to this goal, where has the NNI headed down the wrong path?
- What can the NNI do in the future to address this goal?

Discussion then turned to the specific questions that were posed for the Goal 4 breakout session:

- How do we develop appropriate risk analyses to ensure maximum benefit for society?
- How do we engage stakeholders in both anticipatory and participatory governance (in the context of the NNI) regarding the future of nanotechnology?
- What do you think the NNI should do to more effectively address potential environmental, health, and safety issues associated with nanotechnology?
- How can the NNI agencies better communicate and explain what they are doing to various stakeholders (e.g., Congress, NGOs, industry, and the public)?

During the course of this discussion, a number of suggestions were made concerning the objectives to be included in the 2010 update to the NNI Strategic Plan (completed in February 2011) under Goal 4. These suggestions were refined into a revised list of objectives during the second day of the breakout session.

Introductory Presentations

Brief summaries follow of each of the four brief invited presentations that were made at the outset of this breakout session.

Alison Elder, University of Rochester

Dr. Elder began her talk by citing a few examples of toxicological studies that indicated serious adverse effects of certain nanomaterials. She then rephrased one of the session questions as, "How can the benefits (of nanotechnology) be maximized and risks minimized?" Achieving this goal would require gaining detailed knowledge about the physico-chemical properties of nanomaterials, the target organ dose and effects, and the mechanisms of toxicological response. She then argued that detailed risk analyses of nanomaterial effects required exposure characterization, rigorous testing

1 Presentations are available at: http://www.nano.gov/html/meetings/NNISPWorkshop/presentations.html.

of the predictive qualities of hazard bioassays, and a focus on realistic exposures. Finally, she stated that engaging stakeholders in this process required clear communication about the importance of nanotechnology and realistic statements about risk and safety, a focus on basic issues such as what should be expected from the risk assessment process for nanomaterials, and what specifically could be done to manage risks.

Amy Jones, Applied NanoStructured Solutions

Dr. Jones presented a conceptual model for EHS risk management in nanomaterial product development. Dr. Jones's strategy involved five main steps. The first is the "idea build" step, where the product development team initially identifies potential risks and develops a plan to systematically reduce overall risk. The second step is the viability assessment, where a strategy is developed to manage total risk over the product life cycle. The third step is the prototyping stage, which involved issues such as optimizing the manufacturing process, finalizing material substitutions, and product stewardship review. The fourth step is the transfer to manufacturing and the assurance that all previously identified risks have been eliminated. The final stage is the product launch, where product performance and life cycle data is collected about EHS factors.

Pat Mooney, ETC

Patrick Mooney, Executive Director of the ETC Group, began his talk by saying that the NNI has done an excellent job so far of demonstrating interagency collaboration and addressing interdisciplinary issues, and that the NNI model was instructive for other interagency programs. However, he also said that many opportunities had been lost over the last decade. Specifically, the NNI's focus on EHS issues was perhaps too narrow, and also it had not dealt fully with IP issues, competition policy, and industrial policy. Moreover, the NNI has not dealt with many things happening that could affect nanotechnology, such as other emerging technologies, broader multistakeholder approaches, and international trends and activities. He stated that we need to get the economics right, not just the technology, for example by understanding what the implications of nanotechnology are for commodities and for developing countries. He ended by saying that the United States has probably not engaged globally on nanotechnology as well as it should have and is not currently demonstrating the leadership it could be.

Dietram Schuefele, University of Minnesota

Prof. Dietram Scheufele, from the Department of Life Sciences Communication at the University of Wisconsin-Madison, did not attend in person; however, a video was shown of his presentation, which dealt with public communication of NNI activities. He began by saying that the NNI has done "a lot right" in recent years, including paying attention to ELSI issues early on and supporting development of risk management strategies. He then went on to say that the NNI has done some things less well, including having an overly simplistic focus on public perceptions of the risks of nanotechnology, and putting too little effort into exploring nanotechnology-specific policy options. He then showed data indicating that NNI public outreach seemed to be reaching highly educated people but largely missing less educated members of the public. Finally, he made several recommendations for the future, including a systematic reevaluation of NNI public outreach efforts and the compilation of data on NNI public communication. He suggested that useful mechanisms for achieving these goals included relying on institutional partners in industry and academia, online and social media tools, and perhaps creation of small interagency grants to study inherently transdisciplinary challenges that may arise over the next ten years.

Summary of Comments and Suggestions

What follows is a summary of the comments and suggestions that were offered during the Goal 4 breakout session as they emerged at the end of the second day. This is divided below into four sections: (1) responses to the general questions that were posed to all four breakout sessions; (2) responses to the specific questions posed to this breakout session; (3) additional comments and suggestions not keyed to questions; and (4) comments and suggestions for Goal 4 objectives. This leads into the final section of this chapter, the resulting list of suggested revised, prioritized objectives for NNI Goal 4.

In addition, some participants in the Goal 4 breakout session expressed the view that the order of the four overarching NNI goals implies priority order, and that Goal 4 should become Goal 1 to indicate that it is the highest-priority goal.

Responses to General Questions

Participants discussed and recognized that EHS is not the only component of responsible nanotechnology development. However, as some participants noted, because the expertise of those in this brainstorming session was heavily weighted towards EHS, other aspects of responsible development were less emphasized. However, Goal 4 is still very broad in scope.

With respect to this goal, what has the NNI done right and what should it continue doing?

Over the past 10 years, the NNI has provided visibility and a framework for nanotechnology with respect to EHS issues nationally and across multiple agencies. The NNI agencies have provided nanotechnology EHS research funding across many different sectors and disciplines and have provided the vision for integrating EHS and ELSI into research. As a coordinating body, the NNI has been a focal point for regulatory and risk management discussions. The NNI has helped establish national characterization labs in order to generate good, standardized, high-quality data while rapidly promoting the adoption of best practices from other industries.

With respect to this goal, where has the NNI headed down the wrong path?

Several participants expressed the sentiment that the NNI has not necessarily headed down the wrong path but perhaps has not gone far enough in addressing potential EHS issues. Another sentiment expressed was that the NNI has not placed responsible development as its primary goal and has potentially allowed investments to move ahead of the agencies' abilities to regulate for some regulatory environments (but not all). The point was also made that there are adequate regulations in some cases, especially when considering other "new" technologies. However, some participants expressed the view that the NNI should be clear that its primary goal is "responsible development," and that therefore this should be Goal 1, not Goal 4.

Some expressed the view that the NNI sees public engagement in instrumental terms: to gain public support for research funding and the adoption of nanotechnology products, rather than as "the right thing to do" in order to engender support or take advantage of expertise among diverse user communities. One comment was that in its strategic planning, the NNI has tended to collapse responsible government down to risk management and risk management down to EHS without assessing the need for addressing societal dimensions. Another was that the NNI has not, but should, make societal dimensions a priority and encourage mission-oriented agencies to fund this type of research.

The NNI has reached the 10-year milestone with many research projects reaching maturity. However, while the research has matured, some participants expressed the view that there is no clear vision for how to integrate the data generated from these research projects (e.g., characterization, toxicology, EHS, societal) in theoretically sound and experimentally practical ways. This should be addressed at the genesis of a project.

What can the NNI do in the future to address this goal?

Participants expressed the view that the NNI can play a pivotal role in advancing several issues related to "data": provide data conversion resources from EHS studies into usable risk management concepts; promote data-sharing across repositories, including "failed" or non-results studies; provide a single access point to risk-related data from available Federal, academic, international, and possibly industry sources. In addition, the NNI should focus on successful risk communication models for the introduction and use of other technologies for insights on what can be used to communicate successfully about nanotechnology. The NNI could also reframe its goals to be within a larger framework for promoting well-being rather than just promoting the United States as the best in nanotechnology.

Responses to Questions Specific to Goal 4

The Goal 4 breakout group was also asked to address a number of questions more specific to this goal (which are listed on the first page of this chapter). Rather than answering each question individually, the group offered the following comments and suggestions in response:

- The NNI should explore strategies outside of the risk paradigm, which could range from "safety by design" to qualitative and/or scenario-based approaches, to envisioning and managing potential environmental and occupational health and safety implications of nanotechnologies. We need to be able to understand the capacities of existing knowledge systems for identifying and integrating EHS knowledge about nanotechnology into policy decision making. EHS and sustainability issues should also be integrated across other areas of nanoscale science and engineering (NSE) such that these concerns are taken fully into account in other strategic goals.
- The NNI should set a benchmark for the share of NNI resources to be dedicated to societal research, e.g., the National Human Genome Research Initiative's 3% minimum, and should strongly encourage all NNI agencies, centers, and networks to contribute to meeting this goal. This could be done by appointing an ad hoc working group to help participating agencies make a thorough review of existing societal dimensions research and identify new opportunities relevant to their own portfolios. The NNI could require participating agencies that identify a primary or secondary priority in the NNI Program Component Area (PCA) 8 (Education and Societal Dimensions) to develop a three-year plan to describe the development of their societal research portfolios. PCA 8 should be split into distinct component areas for societal dimensions research and for education. In addition, the NNI should ensure that agencies funding societal research have appropriate research solicitations, charges to panels, review processes, and expertise for the solicitation, peer review, and support of such projects.
- The NNI should encourage research and other activities that seek comparative leverage between nanotechnologies and other emerging technologies, e.g., synthetic biology or geo-engineering, which have relevance and at times overlapping applications and societal concerns across NNI agencies. Ensure that funds are significantly (but not exclusively) available for societal dimensions research at the scale of centers, teams, and large research ensembles so that such work can move ahead in conjunction with other NSE groups. Actively (but not exclusively) pursue the integration of social science and humanities research with NSE research.

Additional Comments and Suggestions Not Keyed to Questions

Beyond the input listed above in response to the questions asked of this breakout session, the Goal 4 group offered the following suggestions:

- Convene a "best practices" summit to discuss and disseminate models for integrative research, training, and outreach activities and their review and funding among participating agencies, researchers, and publics.
- Implement a new public engagement strategy that replaces an emphasis on public support for NSE research and the adoption of nanotechnologies with one on ongoing, substantive, two-way dialogues between NSE researchers and public stakeholders.
- Conduct a follow-up meeting to the 2006 NNI public participation workshop that reviews U.S. and international progress on public engagement with nanotechnology (and other emerging technologies), importantly including the activities of the Centers for Nanotechnology in Society as well as NISE Net.
- Convene at least one major nanotechnology activity every year among participating agencies that will reach a variety of stakeholder audiences, including those least educated and those least dependent on Internet sources.
- Work with NNI-sponsored and other groups conducting public engagement activities on

nanotechnology to gain access to experts and policymakers who might serve both as informants to such processes and targets for the dissemination of their results.

- Encourage interactions between societal dimensions research and nanoscale science and engineering education in formal and informal settings.
- Focus the NNI's strategic, policy, and communication agenda around important aspects of societal research for responsible development of nanotechnology.
- Conduct foresight/scenario development workshops that are integrated with other NNI goals, e.g., strategic planning and/or statements of the status and future of particular nanotechnology fields, and communication planning.

Comments on and Suggestions for Goal 4 Objectives

Before addressing the draft objectives for Goal 4 proposed by the NNI Strategic Planning Task Force (see Appendix C), the participants discussed the gaps in the current and proposed EHS strategy. In the course of this discussion the session participants proposed a number of new objectives for the updated NNI Strategic Plan.

New proposed objectives for Goal 4

A. Provide a public single point of access or portal to existing databases relevant to the responsible development of EHS and ELSI. This portal should provide the ability to query identified sources of data:

   i. Create a portal to a series of databases with the appropriate meta data. Responsibility for curation lies with individual database maintainers (e.g., National Libraries of Medicine).

   ii. Look to existing efforts.

   iii. Consider the need for an NNI-directed effort to meet this database need.

   iv. Allow for a mix of public/private data to allow companies to collaborate where possible.

      a. Establish better mechanisms for collaboration/data-sharing than [the current] agency-by-agency agreements. Mechanisms could include enabling public–private partnerships to go forward by facilitating data collaboration.

      b. Establish pilot study program(s) (e.g., the National Institute for Occupational Safety and Health [NIOSH] and the National Toxicology Program [NTP]) to demonstrate what can be done. This would be an iterative process, with user feedback, including modeling.

Comments: In order to achieve this objective, the NNI should establish an initiative for public database search capability, as noted above, catalogue existing efforts, and provide positive feedback to attract submissions to databases (e.g., require data submittal as part of grant reporting requirements). A proposed timeline for this new objective follows:

- No later than March 2011, form a multistakeholder initiative specific to this objective that includes entities with data (private, international, public) and stakeholders relevant to responsible development of nanotechnology. The group or groups formed through this initiative will
  - Within 6 months establish a catalogue of existing databases and data sources relevant to responsible development of nanotechnology.
  - Within 12 months evaluate the feasibility of creating appropriate database techniques to permit a single query to access data, data structures, original data, or meta data, specific to particular classes of nanomaterials, nested or tiered with respect to components of a life cycle analysis or responsible development framework.
  - Within 18 months establish proposals, programs, agreements, or other mechanisms for implementing an ontology to permit query of the identified databases from a common access point.
  - Within 24 months establish a report of the above outcomes of the initiative that provides a roadmap for further efforts toward database development or use.

The group also proposed a number of measurable outcomes from this new objective:

- Establish a multistakeholder initiative specific to this objective.
- Construct a catalogue of databases:
  - Query the 25 NNI agencies regarding existing databases.
  - Use existing science and technology agreements or other cooperative agreements to identify databases in other nations or international organizations.
  - Issue requests for information for relevant data sources.
- Develop a feasibility report for combined (federated) datasets.
- Develop recommendations for or promulgate curation rules and access rules.
- Implement data-sharing programs that produce publicly accessible federated databases relevant to responsible development of nanotechnology.
- Provide monitoring reports of the use and effectiveness of the data-sharing in promoting responsible development of nanotechnology that include actionable and specific recommendations for improvement.

Two additional new Goal 4 objectives were also proposed (without as much discussion or detailed recommendations for implementation strategies/timeline), as follows:

B. Provide a center of gravity to the concept of plausible risk assessment in order to gain broader acceptance in the science, science policy, and public arenas. Specific tasks include the following:

   i. Scientific Advisory Board (SAB) report on comparative risk assessments into priority materials

   ii. Workshops with states and local governments

   iii. Survey and public engagement exercises

   iv. Report results to Congress

   v. International joint effort to calibrate against similar efforts at the national level

C. Develop and publicize to the research community a prioritized list of nanomaterials for EHS investigation. This list should be strategically chosen with multistakeholder input to address:

   i. Current and near-term commercial, societal, and environmental relevance of target nanomaterials

   ii. Relevance of target nanomaterials to developing a broad general understanding of the EHS trends for engineered nanomaterials

Comments on NNI-proposed draft objectives for Goal 4

Of the draft objectives proposed by the NNI Strategic Planning Task Force, the participants considered Objectives A, B, G, H, and I as higher priorities for purposes of the breakout session discussion, while Objectives C, D, E, and F were not discussed in the session. Several changes to the objectives selected for discussion were suggested, including the addition of a new sub-bullet for Objective A.

Environmental, health, and safety objectives

The breakout group offered a number of specific comments and suggestions for individual EHS objectives in the original NNI draft list. In each case, the original proposed draft objective or sub-bullet is shown below in italics font; explanatory comments and suggestions are interspersed with those draft objectives as appropriate, in normal font. EHS objectives or sub-bullets of objectives on which no comments were offered by the breakout group are not reproduced below. See Appendix C for a complete list of the original draft objectives proposed by the NNI Strategic Planning Task Force.

A. Develop tools to monitor and control handling, manufacture, and production of nanomaterials by:

   i. Developing measurement tools (defined as protocols, standards, models, data, and instruments) to assess the physico-chemical properties of engineered nanoscale materials (ENMs) and toxicity in the environment and human health.

   ii. Identify, characterize, and quantify exposures of workers, the general public, and the environment to specific nanomaterials in order *of priority based on risk assessments across the nanotechnology-enabled product life cycle.*

iii. *Develop exposure-specific engineering controls and nanomaterials-specific exposure measurement tools.*

Comments: Participants suggested the following addition to this objective:

iv. Develop a forum for gathering user requirements across all sectors. Current tools are inadequate for research, so there is a need for manufacturers to be involved early to develop tools for field experiments (e.g., terahertz spectroscopy, low energy electromagnetic radiation). Need to inform manufacturers of the needs in order to get the quality and items desired, build the link between needs and tools.

In proposing this additional bullet for Objective A, participants noted that material characteristics are important. In environmental monitoring, there are hosts of different kinds of nanomaterials, which are not necessarily specific to engineered materials or anticipated risks. It is important to make certain that tools are available to monitor for the broader aspects of these materials. To do this, the NNI should have those who create the objectives for tools talk to ecological, human, and environmental health scientists about their needs in the field for greatest diversity of measurement capabilities. Another comment was that instrument/tool developers need to talk to users of the instruments and also to users of the data in risk management decision making. Collaborative mechanisms are needed to ensure that different points along the risk management paradigm are linked to each other.

B. *Develop risk assessment models and surveillance models for engineered nanomaterials, both for the general population and for susceptible populations.*

i. *Risk Assessment Models*

Comments: The NNI should develop plausible risk assessment methods (based on the 2010 PCAST recommendations regarding "plausible risk"):

- Characterize and identify the health outcomes among exposed populations, especially in occupational settings.
- Monitor exposures to determine safe levels of exposures.

a. *Provide data to understand the relationship of physico-chemical properties of ENMs to* in vivo *physico-chemical properties and biological response.*

Comments: The NNI should develop research programs to understand functional relationships. In addition:

- Does this objective and sub-objective "d" fit better under health surveillance?
- Develop approaches and criteria for structure–function/activity relationship (SFAR) evaluations for discrete categories of materials or in specific contexts like clearance or transport across barriers, while recognizing that single models of everything are not likely to be developed—the broad array of information at present does not lend itself to an understanding of how surface characteristics, charge, size, distribution, etc., relate to toxicity. (Some participants voiced opposing views—quantitative structure/activity relationship (QSAR) or SFAR analyses may be a bit far-fetched in total, given the current data sets.)
- A major gap, based on a literature review, is bridging from *in vitro* data toward *in vivo* extrapolation.
- If the goal is to bridge the gap between physico-chemical effects, chemists or materials scientists (for example, those who are familiar with particle chemistry) should be collaborating on projects with environmental scientists and toxicologists (interdisciplinary research teams).
    - Measurable objective: encourage/require materials scientists to be included in the grants/papers with the people doing the impact research (toxicologists and so forth). The data are not necessarily trustworthy if, for example, materials scientists are imputing health effects and vice versa, due to their areas of expertise.

- Use a multiagency granting process, e.g., EPA and NIH together with NIST, so that nanomanufacturing research is funded under joint grants to clearly integrate expertise.
- *In vitro* and *in vivo* testing: there is a tremendous divergence in amount of relative emphasis from one person to the next across viewpoints of stakeholders. How should this balance go forward?

c. *Develop specific standardized predictive methodologies and protocols that are broadly applicable to predict human health and ecological effects and fate for newer classes of manufactured nanoparticles.*

Comments:

- Microsoft and IBM hire anthropologists to study the use of their products. Perhaps responsible development of nanomaterials in products should be considered similarly, to gain a better understanding of exposure potential and other use-related implications of the materials.
- There are various opinions on the reliability and sensitivity of predictive models. Research in this area should be continued, but there needs to be agreement that the science is not there yet and more emphasis needs to be placed on research in this area.
- As in many other areas of biological science, a careful and thoughtful approach should be developed for extrapolating *in vitro* studies to *in vivo* models.
    - Is *in vitro* not relevant to *in vivo* for nanomaterials in general?
    - There is a mix of disciplines to help integrate *in vitro* and *in vivo*.
    - This is not an either/or. One informs the other. *In vitr*o works for screening but cannot be relied upon for *in vivo* predictions. However, because *in vivo* is expensive, it is tempting to say *in vivo* or *in vitro*.
    - *In vivo* and *in vitro* tests are conducted in controlled environments; in ecology there are a host of variables that will change results.
- *In vitro* methods can supplement research until validated results are available.
- There aren't enough *in vitro* methods that are validated today to replace *in vivo*.
- Should this be an opportunity/objective? The combination of *in vitro* and *in silico* methods could be used to get a lot more information than in the past, even if they are not substitutes. This might be an opportunity to take these methods forward because of the wide range of questions posed by nanotechnology.
- Reiterate the importance of validating *in silico* and *in vitro tests*, e.g., a reactivity matrix for metal oxides, elegant from a chemical perspective.

d. *Transition from absolute to comparative risk assessment using tools of decision analysis, value of information analysis and life cycle analysis for risk management.*

Comments:

- Does this mean "plausible"? Is "absolute" a component of "comparative"? Is this a trade-off or add-on? One interpretation is to slot-in new chemicals, and compare the risk of the new item versus the old one.
- Comparative risk assessment needs to be defined within the objective.

"Societal" objectives

For Objectives F, G, H, and I (in the draft NNI list under both the category on "Public and International Outreach/Engagement" and the category on "Ethical, Legal, and other Societal Implications"), the discussion was more generalized under the heading of "societal." The synopsis of this discussion is included below. Unlike in the section above on environmental, health, and safety objectives, where there were comments from this breakout group on individual objectives and sub-bullets, the original draft "societal" objectives proposed by the NNI Strategic Planning Task Force are not reproduced here; see Appendix C.

General comments on societal objectives:

- The NNI needs to get the scope of technology right. A solitary focus on nanotechnology creates artificial boundaries and silos, and ignores overlaps and synergies. For example, technology is necessary to move away from a carbon-based economy, and so climate change and fuels for relevant technologies should be emphasized rather than pushing one technology. Nanotechnology spreads into synthetic biology, geo-engineering, carbon sequestration, and solar radiation management.

  - The NNI perspective is too narrow. Risks and opportunities exist now that blur boundaries; there are fundamental problems in fencing off a set of technologies.
  - How does/should the NNI work with other science initiatives?

- The geography incorporated is too narrow: the United States needs to be engaged in global initiatives, global regulatory frameworks. The United States needs to engage with the United Nations (UN) or other multilateral cooperative mechanisms, in addition to OECD countries.
- Economic and societal implications: Nanotechnology could profoundly affect resources used here and abroad in the future. For example, the current issue of platinum demand and its effects on markets and the environment mirrors that of many commodities. For some markets, it is not clear how supply will meet demand in 20 years. Responsible development of nanotechnology should be considered in the context of broad societal needs such as this.
  - It is more productive to know whether societal and ELSI should follow the same trajectory as EHS?
  - If, according to the original framing, objectives should be phrased as, "the NNI should," there should be an objective, "The NNI should encourage agencies to prioritize along these lines."
  - Referencing a March 2010 NSF-sponsored nanotechnology retrospective and research directions workshop,[1] it took the insights of a political scientist to point out the link between nanotechnology and geo-engineering to the scientists present, because the research is conducted in separate silos.
  - It is difficult to find good matches between the research interests of social scientists and, say, chemists. It would be very valuable to figure out how to better incorporate social science research into physical and material sciences research.
- The ELSI objectives section needs the kind of specificity found in the other objectives under Goal 4:
  - Introduce more social scientists into NNI activities. Its work needs to be expanded with the input of social scientists and from society as well.
  - Foster better communication and collaborations among toxicologists and fate and transport and measurement scientists, as well as foster integration among the science and technology and EHS communities, including the general public.
  - Coordinate on a global level the U.S. Government's EHS programs with those of other governments. Foster transatlantic consumer dialogue—this needs to have a greater status.
  - Establish an interagency working group to discuss some of the issues beyond EHS (for example, to include ELSI), and discuss them within the context of sustainability and meeting compelling challenges such as climate change. Sustainability is more than just EHS, and the NNI should be more broadly engaged than on just EHS for responsible development of nanotechnology.
  - Participate actively in the UN Commission on Sustainable Development, Rio Plus 20 summit.

Comments on objectives relating to stakeholder engagement:

- Adopt clear demonstrations of public engagement activities.
- Engage with state governments and state entities.

1 See http://www.wtec.org/nano2/.

- Support and inform state and local governments to take actions on nanotechnology as part of the NNI's public engagement activities.

Comments on priorities:

- The NNI should establish and communicate more specific priorities:
  - Clearly articulate priorities for agencies even if they have no money to disperse.
  - Identify priority nanomaterials on which EHS research should focus, based on volume of production, use data, etc., in order to enhance benefit while reducing risk.
  - Address questions that are relevant to risk management needs; adopt a precautionary approach for truly risky materials.
  - Provide case studies of successful adaptation of risk assessment to nanomaterials based on analyses done, for example, for liposome-based drugs or colloidal solutions or other particle-based products that have gone through extensive review or have a long history of use.
  - Emphasize the overlaps among nanotechnology, synthetic biology, and informatics.
  - Emphasize prevention of risk around production of nanomaterials or prevention of risk by limiting exposures.
  - Sponsor guidance on data sources, data collection, data mining, and "connecting dots."

Suggested Revised, Prioritized Objectives for Goal 4[1]

The resulting final revised (and reordered/prioritized) list of objectives under Goal 4, as derived from the discussions by the participants in this breakout session, is as follows:

1 For purposes of comparison, see the original draft objectives submitted for consideration in advance of the workshop by the NNI Strategic Planning Task Force, Appendix C.

I. Environmental, Health, and Safety Objectives from Original NNI List, High Priority

A. Develop tools to monitor and control handling, manufacture, and production of nanomaterials:

   i. Develop measurement tools (defined as protocols, standards, models, data, and instruments) to assess the physico-chemical properties of engineered nanoscale materials (ENMs) and toxicity in the environment and human health.

   ii. Identify, characterize, and quantify exposures of workers, the general public, and the environment to specific nanomaterials in order of priority based on risk assessments across the nanotechnology-enabled product life cycle.

   iii. Develop exposure-specific engineering controls and nanomaterials-specific exposure measurement tools.

   iv. Develop a forum for gathering user requirements across all sectors. Current tools are inadequate for research, so there is a need for manufacturers to be involved early to develop tools for field experiments (e.g., terahertz spectroscopy, low energy electromagnetics). Inform manufacturers of the needs in order to get the quality and items desired, and to build the link between needs and tools.

B. Develop risk assessment models and surveillance models for engineered nanomaterials, both for the general population and for susceptible populations.

   i. Risk Assessment Models

      a. Provide data to understand the relationship of physico-chemical properties of ENMs to *in vivo* physico-chemical properties and biological response.

      b. Understand the ecological effects and environmental fate of commercial ENMs that offer the highest potential for exposure and/or hazard.

c. Develop specific standardized predictive methodologies and protocols that are broadly applicable to predict human health and ecological effects and fate for newer classes of manufactured nanoparticles.

d. Transition from absolute to comparative risk assessment using tools of decision analysis, value-of-information analysis, and life cycle analysis for risk management.

e. Integrate life cycle considerations and tools into risk assessment and management, including ELSI considerations such as stakeholder values, environmental justice.

f. Develop information feedback loops between physical scientists, risk managers and assessors, and social scientists to inform each others' studies and decisions.

ii. Health Surveillance Models

a. Characterize and identify the health outcomes among exposed populations, especially occupational settings.

b. Monitor exposures to determine safe levels of exposures.

c. Develop a stored blood repository as part of the health surveillance programs for future evaluation of exposure and health consequence.

II. Environmental, Health, and Safety Objectives from Original NNI List, Low Priority

C. Increase research that would inform definitions, standards, and protocols relevant to interagency regulations development and implementation.

D. Create an information system for all stakeholders to find in real time the nanotechnology-related EHS research results.

III. Societal Objectives from Original NNI List, High Priority

E. (originally G) Increase U.S. involvement in international organizations (e.g., OECD, UNEP/SAICM, UNITAR) that focus on issues of specific relevance to developing countries and economies in transition to ensure a proper balance of the benefits of nanotechnologies and nanomaterials with their potential risks.

F. (originally H) Develop robust interactive public engagement program to solicit the views of the general public and various stakeholder groups.

G. (originally I) Create and monitor collaborations among social scientists, regulators, ethicists, and scientists and engineers specializing in nanotechnology to explore possible futures together. The engagement should include workshops and conversations, but should go beyond to actual collaborations.

IV. Societal Objectives from Original NNI List, Low Priority

H. (originally E) Continue monitoring public awareness of, and concerns and hopes about, future developments in nanotechnology.

i. Provide ongoing assessment of stakeholder awareness of, and concerns and hopes about, future developments in nanotechnology. Multiple efforts under way include surveys, focus groups, and citizens' panels.

ii. Startups and larger companies should be included in order to determine what they regard as the market, how they are protecting against potential risks, and whether current workforce training is adequate to meet their needs.

I. (originally F) Increase joint solicitations with target countries on environmental, health, and safety research related to nanomaterials, and where appropriate, convene workshops.

V. New Objectives Suggested by Goal 4 Breakout Group

J. Provide a public single point of access/portal to existing databases relevant to the responsible development of EHS and ELSI. This portal should provide the ability to query identified sources of data:

   i. Create a portal to a series of databases with the appropriate meta data. Responsibility for curation lies with individual database maintainers. (e.g., National Libraries of Medicine).

   ii. Look to existing efforts.

   iii. Consider the need for an NNI-directed effort to meet this database need.

   iv. Allow for a mix of public/private data to allow companies for collaboration where possible.

      a. Establish better mechanisms for collaboration and/or data-sharing than [the current] agency-by-agency agreements. Mechanisms could include enabling public–private partnerships to go forward by facilitating data collaboration.

      b. Establish pilot study program(s) (e.g., NIOSH, NTP) to demonstrate what can be done. This would be an iterative process, with user feedback, including modeling.

K. Provide a center of gravity to the concept of plausible risk assessment in order to gain broader acceptance in the science, science policy, and public arenas. Specific tasks include the following:

   i. Scientific Advisory Board (SAB) report on comparative risk assessments into priority materials

   ii. Workshops with states and local governments

   iii. Survey and public engagement exercises

   iv. Report results to Congress

   v. International joint effort to calibrate against similar efforts at the national level

L. Develop and publicize to the research community a prioritized list of nanomaterials for EHS investigation. This list should be strategically chosen with multistakeholder input to address:

   i. Current and near-term commercial, societal, and environmental relevance of target nanomaterials

   ii. Relevance of target nanomaterials to developing a broad general understanding of the EHS trends for engineered nanomaterials

5. Abstracts of Plenary Presentations

Introduction

The introductory remarks by NNI representatives and the keynote presentations by leading nanotechnology researchers set the tone for this workshop. Keynote presenters also included a number of specific suggestions to the NNI in their talks. Each of the plenary presentations at the workshop is summarized briefly below.[1]

Clayton Teague, National Nanotechnology Coordination Office (NNCO)

The NNI Strategic Plan Stakeholder Workshop was convened to solicit input from various stakeholder communities that will be used to prepare the 2010 triennial update of the NNI Strategic Plan [completed in February 2011]. As voluntary participation in the NNI has grown from eight agencies in 2001 to 25 today, the NNI's roles and responsibilities have grown to encompass a wide range of research, industry, trade, education, and regulatory activities. Starting in fiscal year (FY) 2011, 15 participating agencies will have budgets devoted exclusively to nanotechnology R&D, totaling over $1.8 billion. In the past decade, member agencies have established an extensive infrastructure consisting of 64 centers, networks, and facilities and 4,500 research programs throughout the country. At the same time, education programs train over 10,000 students and teachers annually.

1 Speakers' presentations are available at http://nano.gov/html/meetings/NNISPWorkshop/presentations.html.

In terms of the structure and operations of the NNI, the Executive Office of the President oversees management, while the NSET Subcommittee is responsible for interagency coordination and the NNCO manages daily operations and reporting through the NNI website (http://www.nano.gov) and an ongoing series of published reports. Four NSET Subcommittee working groups promote effective interagency communication and coordination and enable the subcommittee to operate more efficiently. The NNI's publications go back to the *Research Directions I* report of 1999, which guided the NNI's initial plans. Despite the extensive reviews, planning, work undertaken, and progress made since then, the NNI—and nanotechnology as a whole—are still in early stages of maturation.

A sampling of the achievements resulting from NNI member agency investments includes the Network for Computational Nanotechnology (NCN) at Purdue, a cyber-resource for nanotechnology theory, modeling, and simulation that has over 92,000 users and has been cited in 430 scholarly papers. Over a dozen NSF Nanoscale Science and Engineering Centers, five DOE Nanoscale Science Research Centers, and many other research centers and user facilities spread across the country collectively serve as basis for a national program that encompasses the product life cycle from research through to commercialization. Eight NIH nanomedicine centers have produced research that has led to over 230 archival scholarly publications covering a broad range of disciplines. NIH's high-impact public–private partnership for cancer research, the NCI Alliance for Cancer Nanotechnology, has produced over 1,000 scholarly papers with an impact factor of ~7. The multiagency Nanotechnology Characterization Laboratory has enhanced collaborations among all 26 NIH institutes and offers its testing protocols freely through its website.

Over the course of the stakeholder workshop, participants should ask themselves whether and how these and other nanotechnology projects currently underway or in the planning stages should be continued, expanded, or in some cases defunded; how the infrastructure that has made them possible can be better supported, especially considering the flat budgets that are being projected for the immediate future; and how should future research dollars be distributed. Participants are encouraged to focus on recommendations that clarify what the NNI has done right, where the NNI has been going down the wrong path, and what the NNI can do in the future to address the four goals of the strategic plan. For the first time, the NNI member agencies have proposed objectives for each of the four NNI goals. We ask you to give us your evaluation of these proposed objectives in terms of the SMART (specific, measurable, attainable, realistic, and timely) criteria, and that you make suggestions for additional or revised objectives as appropriate.

Travis Earles, White House Office of Science and Technology Policy (OSTP)

The White House "Strategy for American Innovation: Driving Towards Sustainable Growth and Quality Jobs," released in September 2009,[1] explicitly notes the critical role of nanotechnology and other emerging technologies and provides vital context for revisiting the NNI Strategic Plan. There is increasing momentum in support of Executive Branch policies to link innovation and production so that, whenever possible, what is designed here is built here. This is because innovation encompasses not just the invention but the process of developing that invention and bringing it to market. Nanotechnology innovation is similar to other types of technology innovations in that it is dealing with unknowns, but it differs from other innovations in terms of control, manipulation, engineering, and properties at the nanoscale, as well as in the breadth of nanotechnology's impact and the speed of innovation. Today, it is difficult to identify a sector that isn't affected by nanotechnology in some way. Even the finance industry, for example, benefits from anti-counterfeiting technologies that incorporate nanoengineered materials. The vision of the NNI Strategic Plan has been, if anything, conservative in terms of its potential impact. This is why the NNI vision and overarching goals have been retained for the 2010 revision of the plan.

Stakeholder input is needed to help identify the aims of the NNI over the next decade. For example, the most recent PCAST report on the NNI[2] emphasized increased funding for commercialization and nanomanufacturing without decreasing support for basic R&D. However, the Administration is committed to maintaining and growing the skilled workforce, world-class infrastructure, interdisciplinary research collaborations, and tools that have been critical to the success of nanotechnology in the United States so far in areas such as the fight against cancer. Because it believes that the U.S. lead in commercialization may be transient, PCAST also recommended that interagency coordination along the line of the Nanotechnology Signature Initiatives be expanded, the NNCO be strengthened, EHS research be focused more on identifying application-specific risks, and immigration issues be disentangled. All of these areas require stakeholder input in order to develop a sound strategic plan.

OSTP would like to see support for fundamental R&D as well as the infrastructure of centers, networks, and user facilities maintained and strengthened because they are an innovation engine. Public-, private-, and academic-sector collaborations should be catalyzed to accelerate innovation and commercialization, and opportunities should be taken to strengthen international collaborations. Communications and public engagement in general need to be improved and expanded, the success of the NNI website and the public workshops notwithstanding. A new NNI strategy portal has provided a way for anyone who has expertise or an interest in nanotechnology and the NNI to provide input through an interactive Q&A

1 See http://www.whitehouse.gov/administration/eop/nec/StrategyforAmericanInnovation/.

2 March 2010, see http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nni-report.pdf.

format that staged the questions in the recent NNI Request for Information (RFI) published in the Federal Register. OSTP and NNI representatives are hopeful that the portal will serve as a significant additional source of input that can be used to refine the NNI strategy.

Courtney Smoot, Office of Management and Budget (OMB)

The OMB offers two guidance documents that are relevant to nanotechnology. The first is M-10-19, "Fiscal Year 2012 Budget Guidance" (June 8, 2010), issued to the heads of departments and agencies. The guidance memorandum includes a new section titled "Cross- Agency Goal and Budget Submission," which states, in part, that "OMB will formalize efforts that working groups have been exploring in several areas—including Science, Technology, Engineering and Mathematics education; large ecosystem restoration; climate science; climate technology; clean energy; nanotechnology; computing research; homelessness reduction; place-based policies; and obesity reduction—to coordinate FY 2012 Budget submissions among relevant agencies." This is the first time that nanotechnology has been called out specifically in an OMB budget memorandum, indicating the Administration's recognition of nanotechnology as an important multiagency initiative. OMB is currently preparing formal guidance on how agencies can coordinate their 2012 budget submissions.

The second guidance document relevant to nanotechnology is the forthcoming "Science and Technology Priorities for the FY 2012 Budget,"[1] prepared in collaboration with OSTP to establish R&D priorities for Federal science and technology programs. Although the specifics of the guidance could not be presented while the memorandum was still being prepared, nanotechnology is a priority for this Administration, and agencies should continue to work together in terms of funding support and interagency collaboration.

1 Since published as M-10-30. See http://www.whitehouse.gov/sites/default/files/microsites/ostp/fy12-budget-guidance-memo.pdf.

Mihail Roco, National Science Foundation (NSF)

A global scientific and societal endeavor was set in motion by the nanotechnology vision formulated in 1999 (*Nanotechnology Research Directions: Vision for the Next Decade*, Springer, 1999) that inspired the National Nanotechnology Initiative (NNI) and other national and international R&D programs. Establishing foundational knowledge at the nanoscale has been the main focus of the nanotechnology research community in the first ten years. As of 2009, this new knowledge underpinned a market of about a quarter of a trillion dollars worldwide, of which about $91 billion was in U.S. products that incorporate nanoscale components. Nanotechnology is already evolving towards becoming a general-purpose technology by 2020, encompassing four generations of products with increasing structural and dynamic complexity: (1) passive nanostructures, (2) active nanostructures, (3) nanosystems, and (4) molecular nanosystems. By 2020, the increasing integration of nanoscale science and engineering knowledge and of nanosystems promises mass applications of nanotechnology in industry, medicine, and computing, and in better comprehension and conservation of nature. Nanotechnology's rapid development worldwide is a testimony to the transformative power of identifying a concept or trend and laying out a vision at the synergistic confluence of diverse scientific research areas.

This presentation provides a brief perspective on the development of the NNI since 2000 in the international context, the main outcomes of the R&D programs after ten years, the governance aspects specific to this emerging field, lessons learned, and most importantly, how the nanotechnology community should prepare for the future. The results of the World Technology Evaluation Center (WTEC) international study sponsored by NSF will be published in December 2010 (*Nanotechnology Research Directions for Societal Needs in 2020*, M.C. Roco, C.A. Mirkin and M.C. Hersam, eds., Springer, 2010).[2]

2 In press. Electronic version available at http://wtec.org/nano2/.

George Thompson, Intel

During the first ten years of the NNI, long-range nanotechnology programs have changed the way scientists and the public look at nature and have enabled the training of skilled scientists. Likewise, public outreach and technology transfer and collaborations among the Federal Government and universities have all been tremendously successful. Currently over 1,000 products containing nano-engineered elements are on the market. In the past, innovation and the creation of new products (e.g., innovations such as transistors, automobiles, penicillin, and the Internet) took 20 years from the first lab ideas to mass market ready prototypes. Nanotechnology is still "new," and the major benefits from it are not expected to materialize yet; it is simply too soon. Looking at the semiconductor industry as an example, the ability to routinely control materials at the nanoscale already results in well-controlled 3D nanostructures available in high volumes and inexpensively. The history of the transistor is an excellent example of how market pull and technology push contributed to the development of the business ecosystem, increasing stability, decreasing cost, and leading to greater integration.

New technology adoption can be determined by a variety of product factors including function or usage, performance, cost, reliability, form factor, power consumption, and ethical issues. In the semiconductor industry, Moore's law, which is a synergy of performance and cost, represents more than a simple learning curve. In almost any industry, experience drives improved efficiency: for every doubling of the amount of product sold, efficiencies increase; 10 to 20 percent is not uncommon. For nanotechnology there may be not only the "typical" improvement as a result of experience, but additional efficiencies may emerge as a result of product synergies such as smaller-cheaper-stronger nanomaterials.

Rosalyn Berne, University of Virginia

The ability to make useful suggestions on the four goals of the NNI Strategic Plan requires exploration of the language used, reflection on its meanings, and understanding of the underlying beliefs implicit in it. Beginning with the plan's vision statement, the call to "understand and control matter" is derived from the ancient Judaeo-Christian decree that man ought to be "fruitful and multiply and fill the earth and subdue it." The symbolism inherent in the NNI Strategic Plan reflects shared values and beliefs that can be used to guide decisions and behaviors that affect the quality of human and other life on earth.

The use of the verbs "advance," "expand," and "invest" in the first three goals serve as a call to extend past current boundaries and limitations into new frontiers of territory to ensure that the United States continues to lead in nanotechnology R&D, rather than to refine what is already under control. This philosophy is reflected in Goal 2's emphasis on the application of knowledge for commercial profit and public benefit and in Goal 3's call to "develop," "sustain," "advance," and "produce." But what is so daunting about the present that it needs to be omitted from the language of the NNI Strategic Plan's goals? Perhaps the fact that there will always be another boundary and another frontier is taboo. The future as imperative negates possible alternative views, which is troubling when presented with evidence of the limits of our ability to act in the true public good, for example in the case of the Gulf oil spill.

The key word of Goal 4 is "responsible," which appears designed simply to placate public concerns while permitting unbridled commercialization. If the ethical model used to develop the NNI is one of outcome-based consequentialism, then results such as providing more efficient energy or curbing life-threatening diseases will serve as after-the-fact proof of the ethical nature of the NNI. This is an ethically precarious and compromised approach. However, if a Kantian, principle-based, deontological ethical model is used, then the important issue would not be about ensuring global R&D leadership but rather about how our current knowledge and financial resources might best be put to use addressing and supporting human well-being. Such an approach would allow the NNI to identify ways to embrace the profound capacity of the human mind and heart to better support life and to steward the earth with care and respect.

Kevin Ausman, Oklahoma State University

The biggest challenge facing the NNI over the next ten years is to understand the depth and breadth of nanotechnology's health and environmental impacts. In terms of the depth of its impact, nanotechnology is comparable to polymer science. However, this analogy does not apply in terms of the breadth of its impact because, where polymer science is largely the chemistry of carbon, nanotechnology spans the entire periodic table. That's why addressing its risks is both important and daunting; researchers are only just beginning to understand the structure–function relationships of all classes of nanomaterials in complex systems. The two categories in which risk is traditionally assessed—commercial relevance and scientific relevance—need to be more fully explored to provide researchers with insight into the structure–function relationships to enable better prediction of the environmental and health risks of nanomaterials. The NNI can play a significant role in addressing this issue by providing coordination or guidance on the health and environmental research being conducted on nanomaterials.

Vince Caprio, NanoBusiness Alliance

The nanotechnology community should continue striving to make the public, industry, the government, and other stakeholders understand that nanotechnology represents a game-changing technology, which the NNI has helped foster. Though investment has grown significantly, in order for the United States to continue as a world leader more needs to be invested in the future. Thousands of jobs have been created, between 80 and 100 nanotechnology companies are sustaining themselves as profitable businesses, and over the next ten years new breakthrough technologies and corporations will emerge that no one is even thinking about right now. As with mobile device manufacturers such as Research in Motion, in the next ten years, companies that no one knows today will become the household names of tomorrow.

Robert Hwang, Sandia National Laboratory

The NNI is poised on the edge of Dr. Thompson's "valley of death" between research and production. To help that transition, the DOE has invested over $100 million worth of new equipment in its five nanoscale research centers, which serve as user facilities for universities, small startups, and established companies active in nanotechnology and nanoscience to create and test prototype devices. For example, research into the construction and control of nanowires is ready to be exploited for a wide range of energy technologies including photovoltaics, battery storage, energy efficiency, and solid state lighting. Successful exploitation will require the ability to fabricate, characterize, and integrate materials of high purity and degree of control.

The NNI is now ready to tackle integration, which is key for the implementation of new nanotechnologies. The canonical example is the birth of the transistor; similar routes need to be taken with nanotechnology. Having spent over 10 years looking at nanoscale building blocks, the time has come to determine how to translate them into functional technologies and products. The successful ability to scale these new technologies from the nanoscale through the microscale and ultimately to the hand-held size will determine the NNI's success at improving quality of life in the United States and globally.

William Kojola, American Federation of Labor – Congress of Industrial Unions

Worker safety and protection should be clearly addressed in the NNI Strategic Plan because, as workers frequently have been the worst and first exposed to hazardous substances in the workplace, they have a vested interest in ensuring that nanomaterials do not represent a health and safety risk to them. Therefore the NNI should identify workplace measures that protect them from exposures, prescribe precautionary approaches and measures in the absence of complete evidence, and regulate where appropriate and necessary. In order to accomplish that, the NNI would need to craft explicit objectives related to protecting safety and health in the workplace environment and in communities as part of Goal 4 of the strategic plan. These objectives could be developed from the occupational safety and health research that is already underway, and they require sufficient research and funding (although resource recommendations fall somewhat outside the purview of the workshop).

James Murday, University of Southern California

There are four major educational challenges being faced today with regard to nanotechnology. First, educators face a significant challenge incorporating the large amounts of new transdisciplinary knowledge being created in nanoscale science and engineering into the traditional educational corpus. Second, the demand for skilled and knowledgeable workers will increase as nano-enabled technologies proliferate, and at the same time there will be a greater demand to address potential workplace safety risks. Third, an educated society is a prerequisite for any informed discussion about the risks and benefits of new technologies. Fourth, can the lure of nano-enabled technology solutions to societal problems help attract students to science and engineering (S&E) curricula and ultimately into S&E careers, especially in the United States? Among other problems, the lack of an effective, standardized science and engineering K–12 curriculum across the country represents a significant challenge to addressing these four challenges, as does the way younger generations derive knowledge differently than their elders as a result of social and collaborative media such as Wikipedia and Facebook. The conclusions and recommendations from last year's NSF-funded Partnership for Nanotechnology Education Workshop[1] with regard to the roles of K–12 education, community/technical colleges, universities, and public education provide vetted input for the next NNI Strategic Plan.

Robert "Skip" Rung, Oregon Nanotechnology and Microtechnologies Institute (ONAMI)

In addressing the question of what the NNI should do to accelerate the commercialization of nanotechnology—and more specifically, how it should encourage the development of state and local nanotechnology initiatives—the NNI must acknowledge the competing yet complementary forces of technology push and market pull. Whereas the former is the purview of research scientists and engineers, the latter is the domain of investors and business managers; because research is inexpensive when compared to product development, scale-up, and rollout, there is more at stake in this latter area. In order to attract sufficient capital, a business has to exhibit a strong market-pull orientation, and therefore future nanotechnology commercialization funding (including SBIR/STTR) should be directed according to the logic of investors rather than just that of peer review panels. Early-stage gap funding sources such as ONAMI help businesses bridge the divide between the two more quickly and effectively than SBIR and STTR funds can currently accomplish, not the least because companies are already formed or conceived before they apply for SBIR/STTR funding.

Specifically, the NNI should offer 1:1 matching for regional/local nanotechnology gap funds that are advised by venture capital partners, intend to form new growth companies, and can attract 10x leveraged private capital funding within 3–5 years. This can be done nationally with 5–7% of the current NNI budget. This estimate is based on ONAMI's commercial development fund, which has achieved 20x leverage so far.

Fran Schrotter, American National Standards Institute

ANSI leadership firmly believes that future editions of the NNI Strategic Plan should embrace the important role of globally developed and harmonized standards in advancing consumer confidence and the commercialization of nanotechnology. Through its participation in the International Organization for Standardization (ISO) Technical Committee TC229, which is one of the primary bodies working to advance nanotechnology standardization, the United States is strategically positioned to direct the development of standards for health and safety, through the development of stronger, safer, and more reliable technological applications, with both economic and competitive interest. While the European Commission recognizes that metrology and standards need further development to achieve these ends, the NNI should go even further and engage stakeholders to ensure that the standards are compatible with U.S. industrial interests and do not stifle innovation, as for example,

1 See http://www.nsf.gov/crssprgm/nano/.

a technical specification for labeling objects that contain nanomanufactured materials. Success in this effort requires a strong partnership between the public and private sectors and more active participation from government representatives and industry in ISO and with other stakeholders to ensure that the interests and the consensus positions of the United States are made clear.

Norman Scott, Cornell University

Nanoscience and nanotechnology promise a revolution in agriculture and food, perhaps ultimately representing a greater impact than the green revolution and farm mechanization. Food consumption in the United States represents $1.3 trillion annually (divided almost equally between food eaten at home and eaten out), representing on average 9.5% of disposable income per capita. The best estimate of the health-related economic cost of foodborne illness is over $150 billion per year, including as many as 5,000 deaths annually. Nanotechnology presents opportunities to address vulnerabilities related to food quality and safety, animal health monitoring, plant systems, and environmental monitoring, as well as related ethical/social issues, at every stage of the production and consumption cycle. Nanotechnology represents the possibility of many exciting innovations, including the construction of food at the atomic scale, the delivery of personalized nutrition, and a better understanding of how food interacts with healthy people. To accomplish these, the NNI should set decadal goals related to sensors, nutrient delivery, food packaging and contact materials that extend shelf life and reduce the need for refrigeration, animal and plant tracking from birth to consumption, nano-customized foods, and integrated systems for sensing, monitoring, and intervening in plant and animal production. Barriers that would have to be overcome include potential rejection by the public, the development of sound regulations and standards, and the establishment of partnerships between the physical science and agriculture communities to overcome what Agriculture Secretary Tom Vilsack described as "overcoming the fear of sharing."

Rep. Daniel Lipinski, U.S. House of Representatives

The United States and the world are at a critical juncture in the development of nanotechnology, and the decisions that are being made today will determine whether nanotechnology can deliver on its economic promise. Nanotechnology represents one of the most, if not the most, important technological keys to future U.S. economic growth and new jobs, and perhaps represents the next industrial revolution. The recession has been devastating, especially for manufacturing, and we need to be able to make the case to constituents that the money being spent on nanotechnology will benefit the economy through investments in new ideas, innovations, and materials to create new products and new jobs. The 2010 NNI Strategic Plan should therefore make clear how nanotechnology will maximize economic benefits for Americans.

Research is already being translated into startups and research centers, which have helped Illinois rank highly in technology commercialization and in research and education. Yet what has been accomplished so far has only scratched the surface of what some predict will eventually become a trillion-dollar industry. Sixty countries have already developed nanotechnology initiatives, many of them based on the NNI. For the United States to remain ahead of these other nations, it should focus on the following: technology transfer; education; the impact on environment, health, and safety; and funding.

With regard to technology transfer, the effort to transfer university-based nanotechnology research and innovation into jobs and venture capital-ready startups is crucial. Now is the time to rebalance the NNI portfolio to increase investments in activities that foster commercialization of new technologies. With regard to education, the National Science Foundation and other NNI participating agencies must develop STEM education programs, and nanotechnology can be an excellent way to raise student interest in STEM careers. With regard to EHS, the 2009 National Academies report[1] criticizing the NNI's EHS research

1 *Review of Federal Strategy for Nanotechnology-Related Environmental, Health, and Safety Research* (National Academies Press, Washington, DC, 2009).

strategy should be borne in mind and addressed in the next version of the strategy. As nanotechnology products proliferate in everything from solar cells to sunscreen, we need to make sure that EHS research keeps up. Public safety is paramount, and likewise, public support is essential for the continued success of the NNI. With regard to funding, there is concern that the FY 2011 budget contains a net decrease in funding for the NNI, particularly at NSF. Continued EHS research—which the budget calls for—should not be at the expense of successful basic R&D programs. We will continue to fight for full funding for all areas of nanotechnology R&D, and are working with Rep. Gordon to pass the Nanotechnology Initiative Amendments Act of 2010, which would reauthorize the NNI. NNI reauthorization enjoys widespread bicameral support, and the Act has twice passed in the House (most recently as part of the America COMPETES Reauthorization Act of 2010), though it is now awaiting consideration in the Senate. This strategic planning stakeholder workshop should consider the contents of the Act as it prepares the 2010 NNI Strategic Plan.

Paul Alivisatos, Lawrence Berkeley National Laboratory, University of California, Berkeley

Nanotechnology will play an ever more important role in sustainable and renewable energy, which is a key research area for Lawrence Berkeley National Laboratory. Nanoscience is an essential part of the laboratory's Carbon Cycle 2.0 framework for renewable energy and carbon cycle research, because sustainable/renewable energy will require new classes of low-cost, high-volume materials that exhibit highly controlled performance. Furthermore, many of the processes underlying energy production take place at the nanoscale. For example, carbon capture and sequestration (CCS) and artificial photosynthesis both have significant nanoscale processes.

Cost efficiency in CCS represents a deep problem for science because a typical current power plant has to cycle 25–30% of its generated power back into capturing the CO_2 that the plant emits. Metal-organic frameworks that incorporate nanomaterials can control gas binding sites at the microscopic level, promising to reduce the amount of parasitic energy required to capture emitted CO_2. Though the process of how CO_2 binds with mineral surfaces is still not completely understood, nanomaterials will likely have a role to play there too. Nanotechnology should help reduce the cost of CO_2 as well. Low-cost, high-volume nanomaterials offer the best approach to addressing the energy issue at a scale comparable to the problem (current total CO_2 emissions are about 30 gigatons per year), so other technologies such as sequestering CO_2 in cement will not make a significant enough impact alone.

With regard to biofuels, the key issue is the efficiency of the conversion process. For example, if 60 million acres of agricultural land were converted to energy use at just 1% conversion efficiency, the resulting energy would equal U.S. gasoline consumption for one year. However, the fastest growing natural plant, the grass Miscanthus giganteus, has a power efficiency of merely 0.3%. Nanoscience offers the promise of higher photon-to-biomass energy conversion. Natural chemically driven photon conversion happens at the nanoscale, and this process would have to be not only duplicated, but also made more efficient and less susceptible to fluctuation. Several research groups at Lawrence Berkeley National Laboratory are engaged in research to address these issues using a variety of nanotechnologies.

It is important to look at energy problems holistically in order to understand how the various elements connect and interact. There are nations with per capita incomes comparable to the United States that already emit less than a tenth the amount of CO_2, and low-cost technologies can help ensure that emerging nations continue to emit small amounts of CO_2 as their per-capita incomes increase.

James R. Heath, California Institute of Technology

Much of today's medical field is being driven by the concept of personalized medicine; its steady acceleration over the last decade is largely reflected in the advent of recent drugs, for example targeted cancer drugs that attack molecular lesions associated with cancers and that dramatically reduce the side effects associated with traditional treatments such as chemotherapy. In the coming decade, two new classes of drugs that are currently in early-stage clinical trials—genetically engineered t-lymphocytes and sRNAs—are likely to become standard treatments. The impact of such drugs on the biomedical industry has been huge.

Nanomedicines deliver highly targeted chemotherapeutics and small-molecular inhibitors, and they likely represent the only way to deliver sRNA drugs to so-called “undruggable” targets. The track record of nanomedicines in reducing toxicity—in many cases 50-fold—should be celebrated. The ability to control retention times to avoid immune system reaction has also been a significant development, as has the ability to control surface charge and chemistry and size to prevent absorption and to slow down travel. Nanomedicines will soon be developed that can avoid resistance mechanisms and target diseases, and will be engineered in the form of inhalants, swallowables, and injectables. The low toxicity of nanoparticles will also likely accelerate Phase I (toxicity) trials for new drugs. The transition from nonselective to highly selective drugs is increasingly coupled with the development of companion diagnostics that can guide the drug targeting. Genentech, for example, will not release a new drug without an accompanying diagnostic.

Because increasing specificity means a decreasing number of responsive patients, nanomedicines with marginal side effects promise to obviate the need for large, costly clinical trials and therefore bring down the cost of therapeutics and their associated diagnostics. Ultimately, measuring cell pathways will someday allow doctors to develop a decision tree that would allow them to assign the appropriate molecular therapeutics to the individual patient. Nanomedicines will also result in more cost-effective diagnostic protocols than the current “watch and wait” approach, which does not take into account the rapid kinetics of newer drugs.

The NNI should do the following: call for the application of government funding to clear technology bottlenecks; find solutions to the issue of assay reagents that will attract venture capital investment; and develop a matrix of the physical parameters of delivery agents so that scientists can pick the right particles for the right therapies for the right targets.

Appendix A. Workshop Agenda[1]

July 13 – Morning Session

7:30 Registration and continental breakfast

8:25 Call to order – Nora Savage, Environmental Protection Agency (EPA) and Hongda Chen, United States Department of Agriculture/National Institute of Food and Agriculture (USDA/NIFA)

8:30 Welcome and Charge to Participants – Clayton Teague, Director, National Nanotechnology Coordination Office (NNCO)

9:00 Overview of Strategic Plan Goals and Objectives – Travis Earles, Office of Science and Technology Policy (OSTP)

9:20 OMB Perspective – Courtney Smoot, Office of Management and Budget (OMB)

9:30 Overview of Nanotechnology Research Directions Study – Mihail Roco, National Science Foundation (NSF)

9:50 Nanotechnology and Maintaining the Engine of Innovation – George Thompson, Government Programs Manager, Intel

10:20 *Break*

10:35 Reflections on and Critique of the NNI's Strategic Plan: Ethical and Societal Aspects of Nanotechnology – Rosalyn Berne, Associate Professor, Department of Science, Technology and Society, University of Virginia

11:05 Brief invited expert presentations from various areas of expertise and sectors:

Kevin Ausman, Oklahoma State University
Vince Caprio, NanoBusiness Alliance
Robert Hwang, Sandia National Laboratory
William Kojola, American Federation of Labor - Congress of Industrial Unions
James Murday, University of Southern California
Robert Rung, Oregon Nanotechnology and Microtechnologies Institute
Fran Schrotter, American National Standards Institute
Norman Scott, Cornell University

12:00 Charge to participants on the mechanics and logistics of the breakout sessions, wrap-up session, evening activities – Janet Carter, Occupational Safety and Health Administration (OSHA), and Elizabeth Nesbitt, United States International Trade Commission (USITC)

12:15 -1:30 *Lunch*
(Participants will be on their own during this time)

July 13 – Afternoon

1:30 – 4:30 Concurrent Brainstorming Sessions (each session will begin with a brief presentation) for each of the following NNI goals:

1 Speakers' presentations are available at http://nano.gov/html/meetings/NNISPWorkshop/presentations.html.

Goal 1 – Advance a world-class nanotechnology research and development program

Discussion leader: Norm Scott, Cornell University

Presentations:

George Adams, Network for Computational Nanotechnology
Wade Adams, Rice University
Vinothan Manoharan, Harvard University

Questions to be discussed:

Where should NNI research be distributed on Pasteur's Quadrant?
(i.e., what is the appropriate mix of basic and applied research)?

Goal 2 – Foster the transfer of new technologies into products for commercial and public benefit

Discussion leader: John Cowie, American Forest and Paper Association

Presentations:

Shaun Clancy, Evonik
Sean Murdock, NanoBusiness Alliance
John Randall, Zyvex

Questions to be discussed:
Are there new forms of public/private partnerships that you could recommend to improve commercialization?

Goal 3 – Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology

Discussion leader: James Murday, University of Southern California

Presentations:

Vincent Caprio, NanoBusiness Alliance
Stephen Fonash, Pennsylvania State University
Charles Gause, Luna Innovations

Questions to be discussed:
How should NNI infrastructure be adapted to respond to future needs?

Goal 4 – Support responsible development of nanotechnology

Discussion leader: Richard Canady, International Life Science Institute/Research Foundation

Presentations:

Alison Elder, University of Rochester
Amy Jones, Applied NanoStructured Solutions
Pat Mooney, ETC
Dietram Schuefele, University of Minnesota (via video feed)

Questions to be discussed (tentative):
How do we develop appropriate risk analyses to ensure maximum benefit for society?

How do we engage stakeholders in both anticipatory and participatory governance (in the context of NNI) regarding the future of nanotechnology?

Overarching questions for all breakout groups:

- If you had a choice what would you have the NNI do differently with respect to this specific goal?
- What do you think of the draft objectives?
- Are there others you can suggest?

(Participants will be identified for expertise and placed in appropriate sessions)

Each of the breakout groups (Goal 1, 2, 3, or 4) will have a non-government person as discussion leader and a government person as recorder

Refreshments provided during breakout sessions at participant's convenience

4:30 *Break*

4:40 Public comment period

5:15 Wrap-up with brief verbal reports of the brainstorming breakout sessions

5:45 – 7:30 *Hors d'oeuvres and drinks*

July 14 – Morning Session

7:30 Continental breakfast

8:25 Call to order – Sally Tinkle, National Institutes of Health/National Institutes of Environmental Health Sciences (NIH/NIEHS)

8:30 Welcoming Remarks and Congressional Perspective – Rep. Daniel Lipinski (D-Ill)

8:40 Paul Alivisatos, Director, Lawrence Berkeley National Laboratory, University of California, Berkeley

9:10 James R. Heath, Professor of Chemistry, California Institute of Technology

9:40 Charge to breakout groups – Janet Carter, OSHA and Elizabeth Nesbitt, USITC

9:50 *Break*

10:00 – 1:15 – Concurrent Synthesis Breakout Sessions for:

Goal 1 – Advance a world-class nanotechnology research and development program

Goal 2 – Foster the transfer of new technologies into products for commercial and public benefit

Goal 3 – Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology

Goal 4 – Support responsible development of nanotechnology

(Reprise discussion of goals from breakout of day 1 as well as discussions on implementation of goals and objectives)

(Half of group will remain and half will be redistributed to other groups to refresh discussions)

Refreshments provided during breakout sessions at participant's convenience

1:15 – 1:45 *Lunch* (working lunch for discussion leaders, reporters, writing team and organizing team)

July 14 – Afternoon Session

1:45 Report out of breakout groups by discussion leaders to writing groups

Overview on some consensus items

2:30 Writing Session – At least the session co-chairs and writing teams, but all are invited to participate

5:30 Adjourn

Appendix B. List of Workshop Participants and Report Contributors[1]

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1 Affiliations as of the date of the workshop. See end of participants list for key to symbols.

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Key to symbols in list of workshop participants:

* Speaker

Breakout session discussion leader

+ Report contributor

Appendix C. Draft Objectives Proposed by the NNI Strategic Planning Task Force

Introduction

In advance of the July 13–14 NNI Strategic Planning Stakeholder Workshop, the NNI Strategic Planning Task Force drafted a list of possible objectives to be included in the 2010 update to the NNI Strategic Plan [originally scheduled for completion in December 2010; actually published in February 2011] under each of the overarching NNI goals. This list was sent to workshop participants in advance via email and was also included in the handouts at the workshop. This handout began with some introductory remarks concerning the background and need for specific objectives in the new NNI plan, and it suggested the criteria that should be applied in considering the merits of the draft objectives. The handout is reproduced in this appendix, as follows.

NATIONAL NANOTECHNOLOGY INITIATIVE

Strategic Plan

PROPOSED OBJECTIVES by Goal

(as of 7/5/2010)

The 21st Century Nanotechnology Research and Development Act (P.L. 108–153) requires the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of National Science and Technology Council (NSTC)—the interagency body responsible for coordination of the National Nanotechnology Initiative (NNI)—to update the NNI Strategic Plan every 3 years. Four strategic goals and eight program components areas are set out in the December 2007 NNI Strategic Plan. The updated NNI Strategic Plan due to be completed in December 2010 will include specific objectives under each of the goals. While cross-cutting in nature, within the overarching strategic goals articulated, the following objectives have been proposed. The NSET Subcommittee invites input on these and additional suggested objectives. In so doing, please consider

- the context of participating Federal agency missions and interagency functional limits;
- strengths and weaknesses or gaps in knowledge, innovation, and/or infrastructure;
- how to capitalize on U.S. leadership in nanotechnology research and development; and/or
- ways to build on the outcomes of previous developments supported by the NNI and/or further leverage existing activities.
- whether the proposed objectives are specific, measurable, achievable, realistic, time-limited, and relevant to nanotechnology as outlined below. The Strategic Plan drafting team has been striving to use these criteria in developing the objectives—but admittedly has not yet completed assessing the proposed objectives according to those criteria at this stage in our drafting.

Specific:

For example, it's difficult to know what the NNI member agencies should be doing if they are to pursue the goal to "work harder". It's easier to recognize "Draft a document".

Measurable:

It's difficult to know what the scope of "Draft a document" really is. It's easier to appreciate that effort if the objective is "Write a 30-page document".

Acceptable:

If the NNI member agencies are to take responsibility for pursuit of an objective, the objective should be acceptable to the agencies. For example, they are not likely to follow the directions of a directive telling them to draft a 30-page document when they are also committed to drafting five other documents. However, if they are involved in setting the goal so they can change their other commitments or modify the objective, they are much more likely to accept pursuit of the objective as well.

Realistic:

Is the objective realistic with the resources, funding and staffing, available?

Time frame:

Is the objective achievable in the time frame stated in the objective with the resources the agencies are willing to commit to the objective?

Extending:

Will the objective stretch the agencies capabilities? Is the objective stated in a way that will encourage the agencies to move into a new area of effort or to move more forcefully into an effort that is already underway? Will it expand the capabilities of the NNI to support the goal associated with the objective?

Rewarding:

Will there be a return on the effort proposed by the objective for the participating agencies and for the nation?

PROPOSED OBJECTIVES BY GOAL

Goal 1: Advance a world-class nanotechnology research and development program

A. Stimulate discovery and innovation in nanotechnology (2007 NNI SP) by developing at least five broad interagency nanotechnology initiatives over the next three to five years that substantially engage and draw funding support adequate to achieve stated initiative goals from three or more NNI member agencies– presumably $20 million or more annually (cf. PCAST, 2010 – Third Review of the NNI).

   Note: In moving forward on this objective, NNI member agencies will work together to align their contributions to the interagency nanotechnology signature [?]initiatives with their individual agency missions, responsibilities, and priorities and with national priorities.

B. Expand the boundaries of knowledge in the fields of science, engineering, and technology relevant to nanotechnology (2007 NNI SP) by focusing funding on at least five suggested R&D topics, selected by an interagency working group, not called out substantially under the 2007 NNI SP.

C. Sustain investment of R&D funding at the frontiers and intersections of many disciplines including biology, chemistry, ecology, engineering, geology, materials science, medicine, physics, and social sciences(2007 NNI SP) by maintaining funding specifically set-aside for multi- and interdisciplinary research centers, programs, and projects.

D. Develop an understanding of how the U.S. nanotechnology R&D program stands in the world by:

   i. Defining quantitative and qualitative measures for comparing the U.S. nanotechnology R&D program to that of other major economies of the world and obtaining data on the metrics to quantify the comparison (cf. PCAST, 2010).

   ii. Developing a database of these metrics for the quantitative comparison, including the following potential measures for comparison:

      a. Number of nanotechnology-related papers published per year by U.S. and other economies in either English or the official languages of these economies

      b. Number of nanotechnology-specific Ph.D. theses

      c. Number of classes offered in nanotechnology-specific topics, and number of students enrolled in these classes

      d. Total nanotechnology R&D funding by each economy' national, regional, and local governments

   iii. Coordinating assessment internationally via such fora as the Organization for Economic Cooperation and Development.

E. Strengthen support for the NNI throughout the Federal government from the Executive Office level to the NNI member agencies to the individual researchers at Federal agencies by:

   i. Establishing an NSET Subcommittee task force to initiate the development of a "mind map" of how the NNI Strategic Plan is related to nanotechnology-related components of member agency strategic plans and the priorities of the current administration. Use the "mind map" to monitor and improve alignment between NNI and member agencies' priorities and national priorities.

   ii. Planning for the NNI leadership (NSET Subcommittee Co-Chairs, OMB NSET Representative, NNCO Director, Working

Group Co-Chairs) to meet with top level management of each NNI member agency at least annually to facilitate and strengthen agency support for the NNI, to discuss how the NNI activities can integrate better with R&D programs of their agency, and to become better informed about what each member agency is doing with respect to nanotechnology, what their policies are with respect to agency staff participating in NNI activities, and how they see the NNI supporting their agency's missions, responsibilities, and priorities.

a. Form a task force of NNI leadership and lay out a schedule to visit two or more member agencies per month on average over the period from March 2011 to October 2012

F. Set research and education priorities with input from industry and partner with industry in achieving them [by…?? Holding workshops?]

G. Support small research grants that focus on reliable data collection, complete disclosure, sound theoretical models, and rigorous research.

H. Develop and support interagency pilot programs that explore novel approaches for transformative, cross-disciplinary research to foster discovery and innovation. New approaches in nanoscale science and engineering will have the potential to create or overturn fundamental paradigms. Programs will also pilot novel approaches to integrate peer-review and program management across agencies.

I. Foster cross-sector and international collaboration in nanotechnology research and development between government, academia, industry, and other stakeholders:

i. Establish multi-agency joint research calls and workshops with other countries, in part by working toward more compatibility between U.S. and other countries' funding mechanisms and also by better harmonizing NNI member agencies' mechanisms and methods of international interactions.

ii. Expand cooperation under existing bilateral and multilateral science and technology agreements through active NNI member agency participation, for example in annual/biannual Joint Committee Meetings, convened by the Department of State's Office of Science and Technology Cooperation.

iii. Maintain an easily accessible and updated listing of past and ongoing NNI member agency international research and development activities to promote information sharing between NNI agencies and other stakeholders.

Goal 2: Foster the transfer of new technologies into products for commercial and public benefit

A. Increase emphasis by NNI member agencies on manufacturing of nanotechnology-based products by doubling the funding devoted to nanomanufacturing (cf. PCAST, 2010 – Third Review of the NNI)

B. Increase emphasis by NNI member agencies on commercialization of nanotechnology-based products by launching at least five government-industry-university partnerships using successful models such as the Nanoelectronics Research Initiative (cf. PCAST, 2010 – Third Review of the NNI)

C. Establish at least three self-sustaining hubs that have the primary goal of transferring newly developed concepts into commercial products – possibly transitioning some existing NNI centers into such technology transfer centers or prototyping centers or foundries analogous to the foundries developed for micro-electro-mechanical systems.

i. Create Federal-state government-industrial sector partnerships to facilitate the transition of new research discoveries to regional, state, and local nanotechnology initiatives and then into commercialization

ii. Develop informational materials to assist small businesses in understanding the regulatory issues (e.g., environmental, health, and safety regulations as well as national security and international trafficking in arms export control regulations) that are relevant to and particular to nanotechnology-related products and businesses.

D. Improve the international environment for commercialization, technology transfer, and innovation related to nanotechnology:

   i. Increase engagement from the NNI member agencies and encourage participation from other U.S. and international stakeholder organizations in international forums such as the Organization for Economic Cooperation and Development Working Party on Nanotechnology (WPN) and Working Party on Manufactured Nanomaterials (WPMN)

   ii. Secure consistent interagency support of documentary standards development necessary to facilitate nanotechnology innovation.

Goal 3: Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology

A. Accelerate innovative nanotechnology discoveries by developing, maintaining, and publicizing information on nanotechnology facilities, including those supported by States, that are accessible for use by individuals from academic institutions and industry. This information may include the facility location, contact information, terms and conditions for use, and a description of the equipment available for use.

B. Develop effective mechanisms to communicate to K-12, undergraduate students, and the public an understanding of nanotechnology and the broad opportunities for nanotechnology-related careers:

   i. Leverage Science, Technology, Engineering, and Mathematics (STEM) educational initiatives being sponsored by NNI member agencies to equip future nanotechnology researchers and developers.

   ii. Create programs to support the development and implementation of outreach programs such as workshops, public forums, or mobile nanotechnology demonstrations. Benchmark these programs by identifying and comparing them with international best practices.

   iii. Survey existing mechanisms for international collaboration on issues of education and workforce development.

   iv. Establish a national network for developing and implementing education and training courses for stimulating nanotechnology innovation.

   v. Sustain outreach and education programs currently supported at the NNI agencies, and increase efforts to disseminate and use the best ideas developed.

C. Sponsor the creation of educational and training programs to advance nanotechnology innovation, such as science and engineering doctorate degrees in nanotechnology, professional science masters program, two-year programs for training in proficient use of all the tools and instrumentation of nanotechnology.

D. Institute effective mechanisms for educating, training, and sustaining a skilled workforce in nanotechnology:

   i. Design and distribute communication tools such as videos/presentations/slide shows that workers and employers can use to promote good product stewardship in the manufacture and production of nanomaterials.

   ii. Develop educational and training materials for best safety practices in manufacture and production of nanomaterials for integration into overall training programs.

   iii. Develop statistical data on nanotechnology-related workforce opportunities and potential career pathways

E. Develop and implement informatics tools that will advance the understanding and utility of nanomaterials

F. Support infrastructure and tools development to advance nanotechnology innovation.
    i. Develop new tools for imaging, displaying, measuring, and manipulating matter at the nanoscale.
    ii. Develop advanced methods and hardware capabilities for modeling and simulating nanoscale materials, phenomena, and processes.
    iii. Develop advanced methods for high throughput analysis of the physico-chemical properties of nano-objects and nanostructured materials.

G. Create and maintain programs that will facilitate sustained and expanded investments in NNI interdisciplinary research centers, user facilities, and networks; continuously update/upgrade equipment at those facilities, and sustain staffing levels, to maintain cutting edge research capabilities.

Goal 4: Support responsible development of nanotechnology

<u>Environmental, Health, and Safety Objectives</u>:

A. Develop tools to monitor and control handling, manufacture, and production of nanomaterials by:
    i. Developing measurement tools (defined as protocols, standards, models, data, and instruments) to assess the physico-chemical properties of engineered nanoscale materials (ENMs) and toxicity in the environment and human health.
    ii. Identify, characterize, and quantify exposures of workers, the general public, and the environment to specific nanomaterials in order of priority based on risk assessments across the nanotechnology-enabled product life cycle.
    iii. Develop exposure-specific engineering controls and nanomaterials-specific exposure measurement tools.

B. Develop risk assessment models and surveillance models for engineered nanomaterials, both for the general population and for susceptible populations.
    i. Risk Assessment Models
        a. Provide data to understand the relationship of physico-chemical properties of ENMs to *in vivo* physico-chemical properties and biological response.
        b. Understand the ecological effects and environmental fate of commercial ENMs that offer the highest potential for exposure and/or hazard.
        c. Develop specific standardized predictive methodologies and protocols that are broadly applicable to predict human health and ecological effects and fate for newer classes of manufactured nanoparticles.
        d. Transition from absolute to comparative risk assessment using tools of decision analysis, value of information analysis and life cycle analysis for risk management.
        e. Integrate life cycle considerations and tools into risk assessment and management including ELSI considerations, such as stakeholder values, environmental justice
        f. Develop information feedback loops between physical scientists, risk managers and assessors, and social scientists to inform each others' studies and decisions
    ii. Health Surveillance Models
        a. Characterize and identify the health outcomes among exposed populations, especially occupational settings
        b. Monitor exposures to determine safe levels of exposures
        c. Develop a stored blood repository as part of the health surveillance programs for future evaluation of exposure and health consequence.

C. Increase research that would inform definitions, standards, and protocols relevant to interagency regulations development and implementation.

D. Create an information system for all stakeholders to find in real time the nanotechnology-related EHS research results

Public and International Outreach/Engagement Objectives:

E. Continue monitoring of public awareness of, and concerns and hopes about, future developments in nanotechnology.

    i. Provide ongoing assessment of stakeholder awareness of, and concerns and hopes about, future developments in nanotechnology. Multiple efforts under way include surveys, focus groups and citizen's panels.

    ii. Start-ups and larger companies should be included to determine what they regard as the market, how they are protecting against potential risks, and whether current workforce training is adequate to meet their needs.

F. Increase joint solicitations with target countries on environmental, health, and safety research related to nanomaterials, and where appropriate convene workshops.

G. Increase U.S. involvement in international organizations (e.g., OECD, UNEP/SAICM, UNITAR) that focus on issues of specific relevance to developing countries and economies in transition to ensure a proper balance of the benefits of nanotechnologies and nanomaterials with their potential risks.

H. Develop robust interactive public engagement program to solicit the views of the general public and various stakeholder groups.

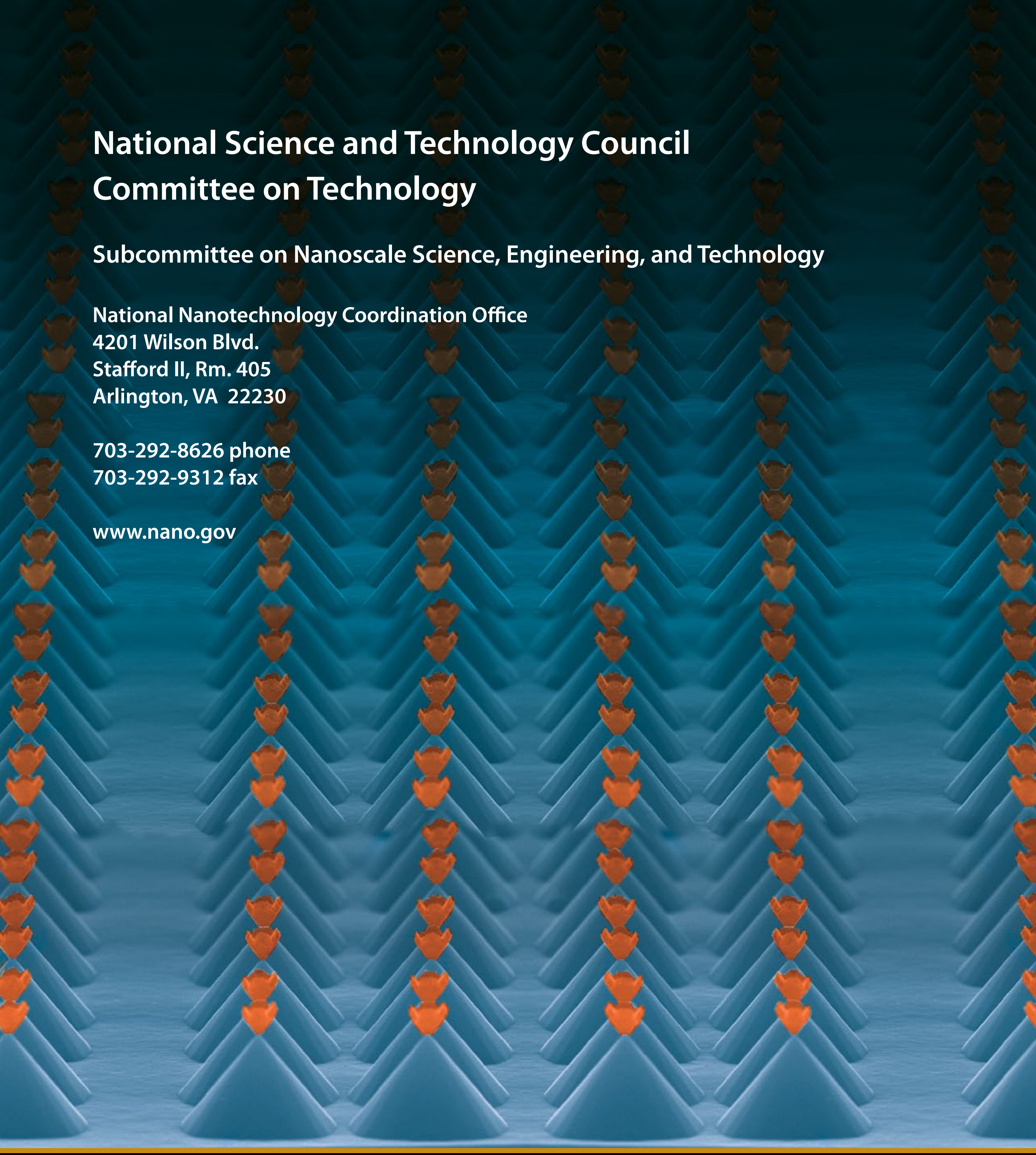
Ethical, Legal, and other Societal Implications (ELSI) Objectives:

I. Create and monitor collaborations among social scientists, regulators, ethicists and scientists and engineers specializing in nanotechnology exploring possible futures together. The engagement should include workshops and conversations, but should go beyond to actual collaborations.

Appendix D. List of Abbreviations and Acronyms

ANSI	American National Standards Institute
ATP	Advanced Technology Program (former NIST program)
CDC	Centers for Disease Control and Prevention
CPSC	Consumer Product Safety Commission
CSREES	Cooperative State Research, Education, and Extension Service (USDA)
DARPA	Defense Advanced Research Projects Agency
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
EHS	Environmental, health, and safety
ELSI	Ethical, legal, and other societal implications
EPA	U.S. Environmental Protection Agency
EU	European Union
FDA	Food and Drug Administration
GOALI	Grant Opportunities for Academic Liaison with Industry (NSF program)
HHS	U.S. Department of Health and Human Services
HVAC	Heating, ventilation, and air conditioning
IP	Intellectual property
ISO	International Organization for Standardization (and associated standards)
MEMS	Microelectromechanical systems
NACK	Nanotechnology Applications and Career Knowledge Center (Pennsylvania State University)
NASA	National Aeronautics and Space Administration
NEHI	Nanotechnology Environmental and Health Implications Working Group of the NSET Subcommittee
NGO	Nongovernmental organization
NIEHS	National Institute of Environmental Health Sciences (NIH)
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health (CDC)
NIST	National Institute of Standards and Technology
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network
NSE	Nanoscale science and engineering
NSEC	Nanoscale Science and Engineering Center (NSF)
NSET	Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council's Committee on Technology
NSF	National Science Foundation
NSTA	National Science Teachers Association
NSTC	National Science and Technology Council
NTP	National Toxicology Program

OECD	Organisation for Economic Co-operation and Development
ORNL	Oak Ridge National Laboratory (DOE)
OSHA	Occupational Safety and Health Administration (DOL)
OSTP	Office of Science and Technology Policy (Executive Office of the President)
PPP	Public-private partnership
PCAST	President's Council of Advisors on Science and Technology
R&D	Research and development
REACH	Registration, Evaluation, Authorization, and Restriction of Chemical substances (EU regulation)
SEMATECH	SEmiconductor MAnufacturing TECHnology (nonprofit research consortium)
SBIR	Small Business Innovation Research Program (across several U.S. Government agencies)
SMARTER	Specific, measurable, acceptable, realistic, timeframe, extending, rewarding
STEM	Science, technology, engineering, and mathematics
STTR	Small Business Technology Transfer Program (across several U.S. Government agencies)
TEM	Transmission electron microscope/y
TIP	Technology Innovation Program (NIST)
UN	United Nations
UNEP/SAICM	United Nations Environment Program/Strategic Approach to International Chemicals Management
UNITAR	United Nations Institute for Training and Research
USDA	U.S. Department of Agriculture
VC	Venture capital
WTEC	World Technology Evaluation Center



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