Regional, State, and Local Initiatives in Nanotechnology

Report of the National Nanotechnology Initiative Workshop
April 1–3, 2009

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). It 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 in the preparation of multiagency planning, budget, and assessment documents, including this report.

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. The NNI's member agencies are committed to involving the full spectrum of stakeholders in development of responsible and forward-looking U.S. R&D and regulatory programs with respect to nanotechnology advancement. More information about the NNI can be found at http://nano.gov.

About this Report

This document is the report of a workshop held in April 2009. It was the third in an ongoing series of workshops designed to bring together people who are involved in Federal, regional, state, and local governmental and nongovernmental efforts to support nanotechnology-related economic development in order to jointly address associated key issues. It is one of the topical workshops sponsored by the NSET Subcommittee to inform long-range planning efforts for the NNI. Any ideas, findings, conclusions, and recommendations presented in this report are those of the workshop participants.

About the Report Design

The background image on the front and back covers is a false-color scanning tunneling microscopy image revealing the atomic-scale electronic perturbations caused by a lattice defect in bilayer graphene (courtesy of Joseph Stroscio, National Institute of Standards and Technology, http://cnst.nist.gov). The book design is by the staff of the National Nanotechnology Coordination Office. The cover design is by Kathy Tresnak of Koncept, Inc.

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Report of the National Nanotechnology Initiative Workshop

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Workshop Plenary Speakers: Mostafa Analoui (The Livingston Group); Ralph Cavin (SRC/SIA); Rich Chapas (Batelle, PNNL/IRI); Ed Cupoli (CUNY-Albany); Mauro Ferrari (University of Texas); Jim Mason (Oklahoma Nanotechnology Initiative); Sean Murdock (NanoBusiness Alliance); Matthew Nordan (Lux Research); Mihail Roco (NSF); Skip Rung (ONAMI); and Marc Stanley (NIST Technology Innovation Program).

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Workshop Logistics and Report Editors and Readers: The staff of the National Nanotechnology Coordination Office (NNCO) assisted the organizing committee with all workshop logistics and with assembling and reviewing the report document at all stages. In particular, Marlowe Epstein coordinated the organizing committee, and she, Phil Lippel, Heather Evans, and Halyna Paikoush handled workshop planning and operations. Marlowe Epstein was also executive editor of the report. Clayton Teague, Geoff Holdridge, Heather Evans, Liesl Heeter, and Pat Johnson assisted in reviewing and proofreading the report. Kristin Roy, Kathy Tresnak, and Pat Johnson handled the report layout and final design.

Finally, many thanks are due to all the workshop participants whose stimulating presentations and lively discussions provided the foundation for this report.

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[1] Affiliations are as of April 2009.

Preface

This report on Regional, State, and Local (RSL) Initiatives in Nanotechnology is the result of a topical workshop convened 1–3 April 2009 in Oklahoma City, Oklahoma, by the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council's Committee on Technology. The report was made possible with the help of the NSET Subcommittee's Nanomanufacturing, Industry Liaison, and Innovation (NILI) Working Group and with staff support from the National Nanotechnology Coordination Office (NNCO). The workshop is part of the NSET Subcommittee's long-range planning effort for the National Nanotechnology Initiative (NNI), the multi-agency Federal nanotechnology program. The NNI is driven by long-term goals based on broad community input, in part received through workshops such as this one. The NNI seeks to accelerate the research, development, and deployment of nanotechnology to address national needs, enhance our nation's economy, and improve the quality of life in the United States and around the world through the coordination of activities and programs across the Federal Government.

The NNI's various reports are the result of an ongoing series of workshops organized by the NSET Subcommittee to inform the professional communities as well as various agencies and organizations that have responsibilities for coordinating, implementing, and guiding the NNI.

The goal of the Workshop on RSL Initiatives in Nanotechnology was to improve the outcomes of nanotechnology research, education, and business activities undertaken by U.S. organizations working to advance nanotechnology, such as small and large businesses, universities, research and education foundations, industry groups, and nongovernmental organizations. The strategy for reaching this goal is to exploit synergies between the various initiatives, promote sharing of information and resources, and develop ongoing mechanisms for relevant interactions.

The specific objectives of the workshop were to:

- Exchange information and stimulate collaboration between the workshop participants
- Explore mechanisms to better link the NNI and regional, state, and local initiatives
- Explore the roles of Federal, regional, state, and local entities in nanotechnology transfer, education and training, and economic development
- Identify common goals and objectives among the initiatives
- Identify paths forward to enhance the effectiveness of the initiatives through collaboration, information exchange, and resource sharing

On behalf of the NSET Subcommittee, we wish to thank Jim Mason of the Oklahoma Nanotechnology Initiative for hosting the workshop and both Jim Mason and Mihail Roco for chairing and taking the lead in organizing the event. Thanks are also due to the NILI Working Group for leading the planning effort on behalf of the NSET Subcommittee. We also thank all the speakers and participants for their time and efforts to join the workshop and to make their individual contributions to the discussions at the workshop and to this report. Their generous sharing of their insights ensures that this document will serve as a valuable reference for the NNI.

Sally S. Tinkle Co-Chair NSET Subcommittee	Travis M. Earles Co-Chair NSET Subcommittee	E. Clayton Teague Director NNCO

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Executive Summary

The April 2009 National Nanotechnology Initiative (NNI) Workshop on Regional, State, and Local (RSL) Initiatives in Nanotechnology examined the new landscape of nanotechnology partnership programs and organizations in the United States compared to those at the time of two previous NNI RSL initiatives workshops held in 2003 and 2005. The workshop was attended by representatives of nanotechnology R&D providers and users from 25 states, international organizations, industry, academia, and the Federal Government. In 2009, there were 34 RSL initiatives (Figure 1, Hawaii and Alaska not shown) across the United States, using various organizational models. The workshop report summarizes the current status of those RSL nanotechnology-focused efforts and presents the main recommendations from presentations and discussions regarding what steps might help promote the success of future RSL initiatives in nanotechnology.

The general goals of RSL initiatives, and of this workshop, are to advance development of nanotechnology research, education, infrastructure, commercialization, and positive societal outcomes by exploiting synergies between the various regional,

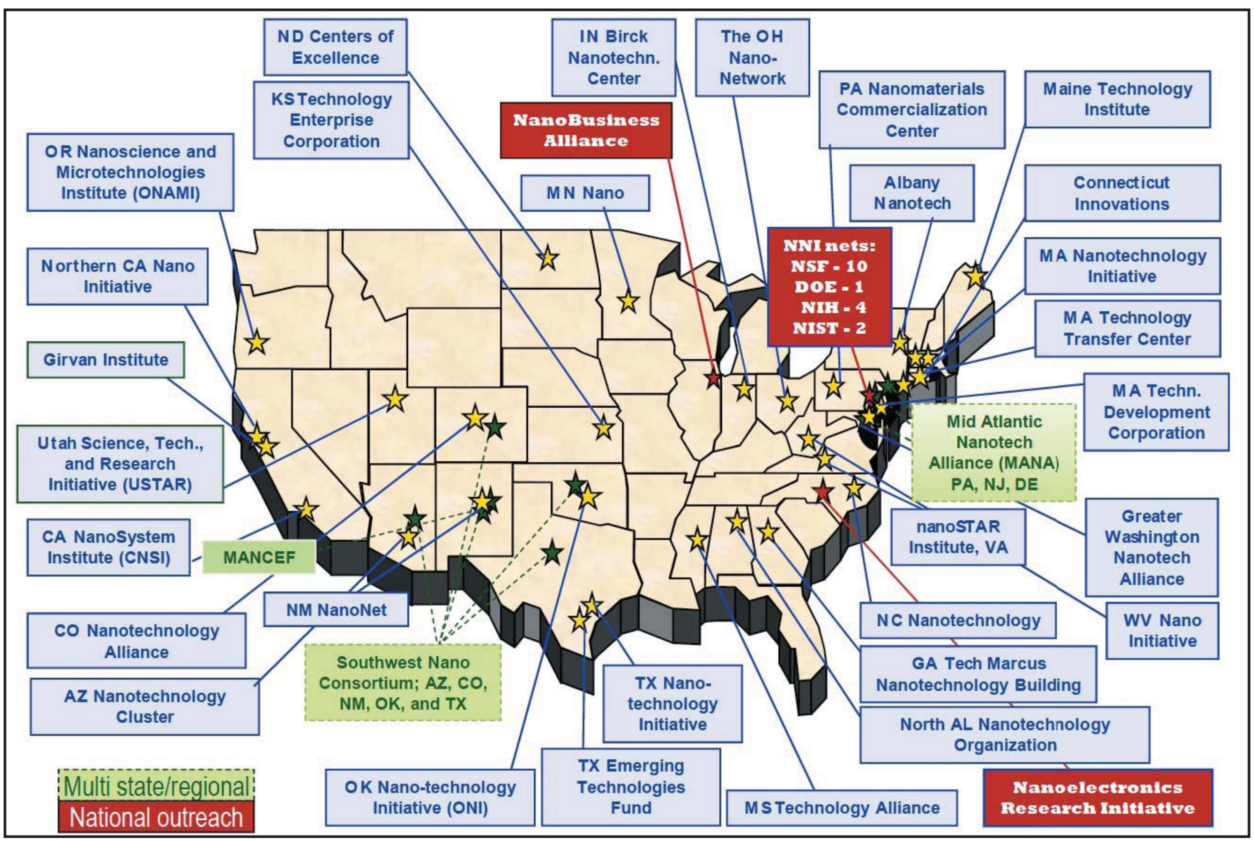

Figure 1. Nanotechnology RSL partnerships in the United States in 2009 (see Appendix D for details; updates are available online at http://nano.gov/html/funding/businessops.html#RSLI).

state, and local initiatives; by promoting the sharing of information and resources; and by developing mechanisms for cross-sector interactions. The specific objectives of the workshop were to exchange information and improve collaborations and to examine longer-term goals reflected in the five main structural themes of the workshop: (1) models for regional, state, local, and international partnerships in nanotechnology; (2) workforce education and development; (3) research and development infrastructure; (4) economic development and commercialization; and (5) resources for RSL partnerships, exchanges, and continuing information systems.

Common Themes and Recommendations

Common themes of the various presentations and working sessions included the immediate needs for broader science, technology, engineering, and mathematics (STEM) education at all levels; more partnerships; better resource sharing (especially at precompetitive stages of R&D); new kinds of information exchanges (e.g., on best practices for environmental, health, and safety efforts and other best practices for nanotechnology, via Internet-accessible nanotechnology databases); and better support of commercialization by academia and government. Workshop participants stressed that the Federal Government can most effectively encourage the initiation and durability of RSL nanotechnology initiatives by providing some form of matching funds.

Several other broad recommendations follow for those groups interested in pursuing RSL nanotechnology initiatives as a means to share resources and make the most of transdisciplinary expertise to raise the bases of regional, state, and local economies:

- **Consider a variety of new R&D initiatives** in response to nanotechnology characteristics and the evolving innovation environment in recent years.
- **Explore the roles of Federal, regional, state, local—and international—entities in nanotechnology transfer, education and training, and economic development** to find ways to capitalize on R&D momentum and better nurture emerging industries.
- **Identify common goals and objectives among RSL initiatives and disseminate information on successful practices**, including new strategies such as limited contracting; basic agreements; frame agreements; and the development of memberships, subscriptions, and other low-threshold and low-overhead relationship-framing arrangements.
- **Explore mechanisms to better link the NNI and the regional, state, and local initiatives**, including broadening access to Federally supported facilities and implementation of a national system/network for testing and characterization to produce useful nanomaterials property data.

Chapter-by-chapter themes and recommendations follow.

1. Exchange Information and Advance Collaborations

Workshop participants presented and discussed their ideas about ways to improve information exchange and advance collaborations for nanotechnology development and commercialization in a broad variety of keynote and short presentations and posters, and in breakout sessions and panels. The broad participation in the workshop by individuals from many disciplinary research areas and sectors of the economy and government at various local, state, and Federal levels helped to provide balanced perspectives and meaningful conclusions (participants' affiliations are included in the list of participants in Appendix B). To facilitate ongoing information exchange, Appendices C and D, respectively, provide the lists of RSL initiatives in 2003 and 2009, and Appendix E and the NNI website http://nano.gov/html/funding/businessops.html provide lists of Federal Government programs suitable for interactions with industry and the states. The NSET Subcommittee's Working Group on Nanomanufacturing, Industry Liaison, and Innovation (NILI; see http://nano.gov/html/about/nsetworkinggroups.html) will play a continuing role after the workshop in carrying out recommendations from the workshop.

2. Models for Regional, Local, State, and International Partnerships in Nanotechnology

A variety of state and regional models for assembling, organizing, and funding nanotechnology initiatives have been successfully developed in the United States since the inception of the NNI. Among the more successful state initiatives are ones in California, New York, Ohio, Oklahoma, Oregon, Pennsylvania, North and South Dakota, and Texas, several of which are detailed in case studies in Chapter 2. There are four typical RSL models: (1) a model comprising multiple economic sectors; (2) an intrastate model (for very large states); (3) a statewide model; and (4) a multistate/regional model (for smaller states). Creation of mutually beneficial partnerships and secure stable funding are the main keys to success in the activities of nanotechnology initiatives. Demonstration of funding leverage is also critical for success. Federal encouragement of interstate, regional, and international efforts may be highly desirable, especially for small states that would most benefit from enhanced access to resources such as educational offerings, core facilities, and business partners located in neighboring jurisdictions; however, multistate or international initiatives are difficult to fund. An example of a successful international initiative is Singapore, where the country's Economic Development Board recruits talented researchers from abroad, whereas the United States currently has a low cap on visas for skilled immigrants. The appropriate model for and scope of an initiative depends on local conditions such as geography, industry, and state resources.

Participants discussed how best to maintain the vision, commitment, and funding necessary to sustain RSL initiatives over time. Reasons to organize and maintain RSL initiatives have centered on various aspects of attracting and creating high-skill, high-paying jobs and supporting advanced local economies. Deterrents include scarce or difficult funding mechanisms, lack of infrastructure to support science activities (e.g., within state bureaucracies) or dedication of infrastructures to competing interests (e.g., at universities), insufficient industry involvement, communication difficulties between groups with different backgrounds and perspectives, and an intrinsic lack of popular connection to the issues.

Potential remedies to some of the deterrents to successful RSL initiatives include Federal co-funding of local initiatives, new kinds of "promotion" of nanotechnology (e.g., as a tool to allow companies to make better products), building nanotechnology-community databases to help connect members, investigating "joint jurisdiction" funding mechanisms that don't now exist, and promoting better publicity and information-sharing about the roles and benefits of existing initiatives. An employment/employer database (with both Federal and state employment agency contributions), organized by nanotechnology-relevant North American Industry Classification System (NAICS) codes, would be a valuable tool for identifying needs/opportunities and for tracking the kinds of results state governments require. Some evidence suggests that nanotechnology initiatives may do best when focused on supporting multiple small groups that are linked well institutionally, rather than on building large centers. However, there is insufficient information to generalize about successful or unsuccessful approaches.

3. Workforce Education and Development

Two main educational milestones must be achieved to realize economic outcomes from the application of nanotechnology: a skilled workforce must be available, and the public must understand and accept the balance of benefits and risks that deploying new technology entails. This involves tasks at every level of the educational system. Informal education and K–12 education both play a role in developing awareness of nanotechnology and of its broad impact on society. It is also important that educational activities create interest in nanotechnology-based careers. Preparing people for these careers and creating a skilled nanotechnology workforce are the tasks of post-secondary education. Efforts are already underway in each of these areas.

A systematic examination of all national and state science standards should be undertaken prior to their next periodic revisions to ensure that they are compatible with new knowledge and best practices in nanotechnology education. The recent adoption of standards in Math and English by 43 states is a model that should be emulated to set standards in science and technology, to include knowledge accumulated in nanotechnology. Nanoscience concepts can help provide the integrative force that is needed in the teaching of science, technology, engineering, and mathematics subjects. Replication of successful programs at all levels should be accelerated. Networking that is now underway among various education efforts must be promoted, and more collaborations must be encouraged. To keep information websites up-to-date and to avoid the expense of duplication, the community should promote cross-linking between general-purpose nanotechnology sites like http://nano.gov and major nanotechnology education sites such as those maintained by:

- The Nanotechnology Applications and Career Knowledge (NACK, http://nano4me.org) center at Pennsylvania State University
- The Network for Computational Nanotechnology (NCN, http://nanohub.org)
- The National Center for Learning and Teaching (NCLT, http://www.nclt.org) at Northwestern University
- The Nanoscale Informal Science Education Network (NISE Net, http://www.nise.org)

Two-year institutions must assess the value of creating four semesters of new nanotechnology courses in terms of local needs. Industry-based learning experiences such as internships should be utilized more extensively. The nanotechnology higher education program exit skill set and related course models developed jointly by industry and NACK (see http://www.nano4me.org/industry.html#contenttop) are exemplary starting points but must be further validated and customized. Sharing of courses and laboratory facilities should be expanded and supported. There should be a national discussion about how best to stimulate increased enrollment of U.S. nationals in advanced science and engineering degree programs, and/or to encourage foreign-born scientists and engineers trained at U.S. institutions to remain in the United States throughout their careers. More attention must be paid to training incumbent workers.

4. Research and Development Infrastructure

A key issue for building U.S. R&D infrastructure is identifying what improvements or additions—including supporting facilities, tools, and services—would best catalyze ongoing nanotechnology innovation. Nanotechnology, particularly the nanomanufacturing infrastructure, comprises both physical and intellectual aspects. Developing the U.S. R&D infrastructure requires the interaction of four key components:

- **Information**, including fundamental knowledge about nanomaterials, creation of standards of documentation, curation of this data, and federation of data and information
- **Tools and facilities** to integrate the standards, data, and information
- **Know-how**, including professional development of technicians and engineers and best practices for innovation and technology management
- **Communication** of industry needs to academic and government scientists, e.g., by constructing strategic roadmaps and holding forums to create and bolster a culture of sustainable nanomanufacturing

To achieve any of these components, partnerships between and among public, industry, and education sectors are an indispensable means to sharing and leveraging investment, facilities, personnel, ideas, and experience. Numerous successful examples at the Federal, state, and international levels can be used as models; a number of these are described in Chapter 4.

The 25 Federal Government agencies participating in the NNI are working together to build basic knowledge, facilitate innovation, and advance nanomanufacturing. In fiscal year (FY) 2009, the NNI had an annual budget of $1.7 billion, with an additional $500 million in funding from the American Reinvestment and Recovery Act (ARRA), of which $250.1 million is for infrastructure. There are over 80 Federal centers and networks across the United States that support nanotechnology R&D. In some cases, better processes need to be established for sharing results of Federal investments with manufacturers and for supporting broader and fuller access of industry and academia to Federal laboratory facilities and expertise.

Research to develop tools, measurements, standards, data, and models—at laboratories at the National Institute of Standards and Technology, the Department of Energy, the National Science Foundation, and other public, academic, and industry laboratories—will be a vital part of structural support for nanotechnology commercialization, due to the central role of standards in manufacturing and trade. Consortia for individual industries (such as SEMATECH in the semiconductor industry), as well as other kinds of collaborations between industry, universities, and national labs, should be helpful to guide the development of standards and tools for specific nanotechnology applications.

To further support the national nanotechnology infrastructure, national leadership and investment should be focused on building an accessible national materials database with a standard and widely accepted schema and rigorous gate-keeping functions to ensure the reliability and consistency of submitted data. A database activity that has been initiated by the National Nanomanufacturing Network might serve as a starting point for a national nanomaterials database.

There is some successful experience in industry for building roadmaps as a means to establish, communicate, and then accomplish R&D targets in a timely way. It was proposed that the NNI agencies should survey various industry roadmaps and meet with key industry executives to learn from their experience how to set goals and form public-private partnerships to better focus nanotechnology R&D.

5. Economic Development and Commercialization

Emerging and advanced technologies generally require a time-, labor-, and cost-intensive R&D phase to deliver a product to market. New nanotechnology-related businesses share the critical challenges of all startups, both intrinsic (funding, staffing, management, product development, and sales) and extrinsic (competition, general economic climate, government regulation, and taxation); they have additional complexities and costs in terms of tools, metrology, materials preparation, characterization, utilization, and regulatory treatment. The generally longer time to application and the more widely distributed user base create additional burdens. Conventional venture capital funding for nanotechnology-based innovations has largely shifted from startups to later-stage deals, with larger investments made in fewer, later-stage companies. The aptly named "valley of death"—where, due to lack of capital, many promising new technological developments fail to transition to market viability—is particularly difficult to traverse for nanotechnology startups.

Federal and RSL projects that provide limited support for new nanotechnology businesses (e.g., the SBIR/STTR programs) and broader support for public-private partnerships to foster innovation do encourage development of emerging technologies and new businesses. Some larger technology-based businesses are finding new and cost-effective ways to cultivate product innovation, one being the "open-innovation" model of looking outside the company for product and process solutions via partnerships—some international. Most emerging nanotechnologies and products, however, start within very small businesses. Ways that were identified to help nanotechnology businesses achieve sustainable profitability include the following:

- Federal and/or state governments and/or nongovernmental organizations (NGOs), such as the Pennsylvania NanoMaterials Commercialization Center, should provide more early-stage funding assistance for commercialization, using more standardized procedures.
- More states should consider instituting incentives (e.g., tax incentives) and cooperative initiatives to support nanotechnology commercialization. A vibrant state or regional initiative can survive on about $100,000/year, which might be leveraged to include matching Federal and/or industry investment. Regional, state, and local clusters have proved to be effective and efficient at resource-sharing to support nanotechnology-based industry development.
- A thoughtful, balanced approach should be applied to regulation and testing of new technologies and products.
- New standard intellectual property (IP) language should be worked out to support fair

distribution of benefits to partners in advance of commercialization, to avoid the impediments of protracted later-stage negotiations.

- Federal and state R&D funding programs should increase their focus on commercialization, and they should balance technical and commercial considerations in project review processes.
- The Federal and RSL entities should build more and better business training programs for personnel in new technology startup businesses.

6. Resources for RSL Partnerships, Exchanges, and Continuing Information Systems

Because nanotechnology is still an emerging area, the pathway from a lab demonstration to a specific commercial product has a considerable amount of uncertainty and many unmet needs. Gaps exist in nanomaterial properties data; scalable nanomanufacturing process tools; suitably trained workers; knowledge cyberinfrastructure; environmental, health, and safety (EHS) best practices; nanomanufacturing design science; and the network of research, development, and commercialization partners. Four key ideas emerged from the breakout discussions as means to more efficiently and more rapidly build resources to advance nanomanufacturing and commercialization in the United States:

- Use co-funded pilot projects to build on existing initiatives, gain practical experience, and advance strategic development. These should be facilitated where possible by communities of interest (COIs)—such as the National Nanomanufacturing Network, the NanoCollaboratory, and the GoodNanoGuide wiki—and organized to engage small- and medium-sized companies.
- Build a more comprehensive and deeper information infrastructure on the foundation of existing software tools and resource models like nanoHub, InterNano, and the Nanomaterial-Biological Interactions database. Two helpful database additions would be (1) a comprehensive database on who is doing what and where in the field of nanotechnology, to facilitate identifying and communicating with potential partners, tools, services, and instrumentation resources across fields and disciplines; and (2) a database for nanomaterials properties that includes metadata and measurement protocols. Access should be national, but means to preserve a local focus should be built in. The COIs that need these systems should be engaged in planning, creating, and maintaining them.
- Establish a more robust and comprehensive system for workforce training and education. Components might include constructing a national training network, surveying needs for workforce skills, and complementing university education with on-the-job training under expert guidance within industry. It is imperative to develop a strong technology and innovation management education culture. Likewise it is imperative to develop a strong manufacturing education culture to support advanced statistical design, informatics, process control, manufacturing automation design, and advanced instrumentation development. These kinds of educational goals can only be achieved through coordination between sectors.
- Better utilize and grow existing infrastructural resources through continuous, bottom-up evaluation and accountability. Support for organizations at all levels should be strongly attuned to the needs of users. Researchers and practitioners should be open-minded with respect to developing best practices in this new arena. New thinking is needed to reframe research and entrepreneurial engagement modes.

1. Introduction

The NNI and RSL Initiatives

One of the aims of the National Nanotechnology Initiative (NNI) is to support discovery, development, and deployment of nanotechnology, and to build on that foundation to advance nanotechnology-related nanomanufacturing applications in the United States (*1*). Such an objective can be achieved only by strong research and education programs and by promoting partnerships among players involved in various disciplines and economic sectors. Regional, state, and local organizations have a key role in establishing the infrastructure, preparing a skilled workforce, and supporting industry, with a special focus on small business. Supporting partnerships with such organizations has been a goal since the inception of the NNI, when the first regional meetings were organized in Southern California and Texas in 2001. In 2009, the NNI organized the third national Workshop on Regional, State, and Local Initiatives, after hosting two similar national events in 2003 and 2005 (*2*). This report presents the main conclusions of the 2009 workshop and proposes follow-up activities. Individual plenary and panel presentations given at the workshop are available on the NNI website at http://nano.gov.[1]

The Workshop

The NNI Workshop on Regional, State, and Local (RSL) Initiatives in Nanotechnology was convened April 3–5, 2009, in Oklahoma City, Oklahoma. The workshop was sponsored by the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council's Committee on Technology, along with the Oklahoma Nanotechnology Initiative and the National Science Foundation (NSF). The agenda is included as Appendix A to this report. Attending this workshop were nearly 100 nanotechnology experts hailing from industry, academia, and Federal and state agencies, as well as representatives from regional, state, local, and international nanotechnology initiatives. Attendees and their affiliations are listed in Appendix B.

Figure 1.1. Co-chair Dr. Mihail Roco at the NNI Workshop on RSL Initiatives in Nanotechnology.

The workshop brought together various stakeholders to promote interactions of these groups with one another and with representatives of the NNI. As stated in the 2007 NNI Strategic Plan, "The NNI will support and foster [leveraging of nanotechnology-related R&D investments] by working with national, state, and regional groups… to facilitate communication between local nanotechnology initiatives and to identify barriers to commercialization" (*3*).

The goal of the RSL Initiatives Workshop was to improve the outcomes of nanotechnology research, education, and business activities undertaken by U.S. organizations working to advance nanotechnology,

1 Visit http://nano.gov/html/meetings/nanoregional-update/workshop.html for direct access

such as small, medium, and large businesses, universities, research and education foundations, industry groups, and nongovernmental organizations. The strategy for reaching this goal is to foster synergies between the various initiatives, promote sharing of information and resources, and to develop ongoing mechanisms for relevant interactions.

The specific objectives of the workshop were to:

- Exchange information and stimulate collaboration between the workshop participants regarding the activities and resources of various regional, state, and local nanotechnology initiatives
- Inform workshop participants about the NNI and other Federal resources or activities and receive feedback about the Government's NNI programs
- Explore mechanisms to better link the NNI and the regional, state, and local initiatives, including using a continuous approach for networking, the development of shared or common databases, and publication and distribution of specific opportunities for NNI interaction
- Identify common goals, objectives, and organizational approaches among the initiatives
- Engage the participants in dialogue regarding opportunities for collaboration among the initiatives and for sharing of best practices
- Explore the different roles that Federal, regional, state, and local entities play in nanotechnology transfer, education and training, and economic development
- Identify paths forward to enhance the effectiveness of the initiatives through collaboration, information exchange, and resource sharing

The workshop included the following activities:

- Nine keynote speeches from leaders in the nanotechnology field
- Two case study presentations of exemplary nanotechnology initiatives
- Nine panel discussions featuring various experts on the respective panel topics
- Five breakout sessions
- Tours of local nanomanufacturing and research and development facilities

The purpose of the breakout sessions was to debate various challenges and develop a vision for future work. Chapters 2–6 of this report provide overviews of the five breakout sessions held at the workshop.

About the NILI Working Group

The Nanomanufacturing, Industry Liaison, and Innovation (NILI) Working Group is a subgroup of the NSET Subcommittee. The NILI Working Group was central to organizing and planning the Workshop on Regional, State, and Local Initiatives in Nanotechnology as part of the overall mission and goals put forth by the NILI Working Group. NILI coordinates many of the NNI activities related to promoting U.S. leadership in the creation of products and manufacturing processes at the nanoscale. NILI creates mechanisms to facilitate nanotechnology innovation and to improve technology transfer to industry. The working group promotes the exchange of information among Federal agencies, academia, and state, regional, and local organizations. Within the Federal Government, this effort includes interagency cooperation in the areas of standards, nomenclature, nanomanufacturing research, and programs that encourage innovation in small business. Industry liaison groups, that is, partnerships between the NNI and industry sectors, are a key tool in this undertaking (*4*).

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2. Models for Regional, State, Local, and International Partnerships

Moderators: Jim Mason, Oklahoma Nanotechnology Initiative
Robert D. "Skip" Rung, Oregon Nanoscience and Microtechnologies Institute

Introduction

Several state and regional models for assembling, organizing, and funding nanotechnology initiatives have been developed since the inception of the NNI (see the lists in Appendices C and D). There is at least implicit evidence about what has worked well and what has not, based on which initiatives have lasted from the relatively early days (2000–2005) to the present, and whether or not they have been able to establish beneficial partnerships and secure stable funding for their activities. Several initiatives, notably in California, New York, Oklahoma, Oregon, Pennsylvania, and Ohio, have been successful in these respects. However, several others have either ceased or diminished their activities, due to lack of funding or other less obvious reasons, possibly related to lack of perceived stakeholder benefits.

The role and functions of a partnership organization were addressed at the workshop, and possibilities for increasing the effectiveness of regional, state, and local partnerships in nanotechnology were explored. This chapter presents several different case studies and models of initiatives and partnerships, including a description of different models employed in the United States, followed by a brief look at international nanotechnology partnerships. Finally, the chapter describes challenges to and possible solution paths for regional, state, and local initiatives.

A preliminary question is how and why have nanotechnology initiatives started and operated? Broadly speaking, most initiatives have branched out from traditional academic centers, business associations, or state/regional economic development agencies and partnerships. Most of the experience and data gained so far come from state and regional efforts, though often with strong academic and business participation.

State-Dominated Models

The State Government Investment Model

Case Study: Oregon

The Oregon Nanoscience and Microtechnologies Institute (ONAMI, http://www.onami.us) is both Oregon's first "Signature Research Center" (an economic development initiative run by a 501(c)(3) nonprofit corporation) and a collaborative community of world-class industry and research institutions in the Pacific Northwest that form a vibrant network of nanoscience and microtechnology expertise.[1] ONAMI is moving nanoscience and microtechnology innovations from basic research to commercialization by growing research revenue (e.g., with matching grants) and gap funding for spinoff companies. ONAMI's seed and ongoing funding comes from the state of Oregon, at $37 million cumulatively as

1 Oregon's "Silicon Forest" arguably includes the world's top industrial "small-tech" R&D assets, e.g., Intel semiconductors, HP inkjet, FEI headquarters, and Life Technologies' nanotechnology division.

of the date of the workshop, but the research and investment revenue provided to ONAMI-affiliated university groups and companies comes from multiple sources, including the Department of Energy (DOE) and the National Science Foundation Small Business Innovation Research (SBIR) programs. A network of three complementary university-based user facilities is open to all researchers and industry collaborators on an equal-priority basis. Over 100 companies have used one or more of the ONAMI facilities.

ONAMI results since its inception in 2004 include fourfold growth (to about $40 million/year) in net nano/micro research awards to ONAMI member researchers from Oregon State University, the Pacific Northwest National Laboratory (PNNL), Portland State University, and the University of Oregon, and $16 million since 2007 in funds leveraged by startups/spinoffs participating in the ONAMI gap fund proof-of-concept project in collaboration with ONAMI researchers or facilities. As the capital markets recover, the participating ONAMI gap fund companies are expected to attract significantly more funding from investors and strategic partners.

State Government Investment Model

In this model, significant state funds are invested in facilities, staff, and equipment for economic development reasons, i.e., to grow research, develop the workforce, attract more "high-tech" industry, and attract investment in new companies. Typically, there is already a significant "nano" industry presence in such cases, e.g., in New York and Oregon.

Case Study: New York

The integrated success strategy of Albany, New York, has four key drivers: (1) target a comprehensive nanoelectronics discipline-enabling technology; (2) invest in state-of-the-art infrastructure; (3) support world-class, hands-on education and training; and (4) create leveraged public-private partnerships. New York grew its investment in the College of Nanoscale Science and Engineering (CNSE, http://cnse.albany.edu/) at the University at Albany from a $50 million "seed" to more than $1 billion only after corporations committed an estimated $3 billion in private investment in their own co-located facilities. For illustration, companies both large and small considered co-funding shared access to a common "core" of unique assets (e.g., extreme ultraviolet lithography) to be four times less expensive than acquiring their own dedicated assets.

Case Study: Ohio

Several years ago, Ohio established its Ohio Third Frontier initiative (http://www.development.ohio.gov/ohiothirdfrontier) with a $1.6 billion funding commitment over ten years. While this program has numerous subprograms, one of special interest to nanotechnology-related companies is the advanced materials program. Offering funds to match outside investment, this program is nondilutive to a participating company, meaning that the program offers a way to raise money without incurring losses. Ohio does an initial screening of proposals by calling on the National Academies to make recommendations, then a board from the Ohio Department of Development (ODOD) does further reviews. Reliance on the National Academies for initial proposal review, and other policies enacted by ODOD, remove political considerations from the grant process.

Since Ohio is already a center of materials processing in the United States and home to several large companies such as the advanced structural materials company Hexcel, the focus on advanced materials plugs in well to existing strengths of the state. Favoring consortia of Ohio-based companies or Ohio companies with large out-of-state partners, this program can offer significant help to companies that pass through the competitive process.

Ohio also has state incentives to recruit companies in industries favored by the state, including move-in grants and loans. Unlike many other state incentive programs, which only offer tax reduction or tax holiday incentives, Ohio actually provides up to $1 million in move-in funding—an offer that is extremely attractive to small companies. The common state offer of a tax holiday, usually for moving to a high-tax state, is useless to a small company with losses and the prospect of continuing losses. Actual cash to match outside investment, which can be used to set up a lab, is quite valuable in comparison.

Ohio's programs, with no equity dilution to the company and matching funds for outside investment, are attractive to company founders as well as investors looking to effectively multiply their investments.

Case Study: North Dakota

North Dakota's Centers of Excellence program (http://www.commerce.nd.gov/centers/) (2005–present) is the product of Gov. Hoeven's initiative to combine education and economic development to create higher-paying jobs and new business opportunities for North Dakota citizens. The centers are hubs of research and development on the campuses of North Dakota's 11 colleges and universities. Their objective is to research, develop, and commercialize products and services to create well-paying jobs for the citizens of the state, especially young people. The Economic Development Center of Excellence (EDCOE) Program matches 2:1 the resources contributed from industry for research and commercialization, and the North Dakota State University (NDSU) match is in cash. The NDSU Center of Surface Protection and Hard Coatings is developing technologies that enable cost-effective manufacturing of wear-resistant nanostructured coatings. It is currently funded at $2.6 million in matching funds from the state of North Dakota.

Case Study: Pennsylvania

The Pennsylvania Nanomaterials Commercialization Center (http://www.pananocenter.org/) was founded through the vision of the major materials companies in southwestern Pennsylvania. Its goal is to create an industry-driven, nonprofit organization to accelerate development of promising nanomaterials technologies from universities and early-stage companies. Targeted products and processes are market-driven and have application in either the commercial or defense markets.

The center's model is to create partnerships between universities and small and large companies to leverage their respective strengths and to focus on specific new product applications for nanotechnology. Further, through a highly competitive bid process, the center then provides early-stage seed funding and other support services to quickly transition the product concept to a working prototype that meets a customer need. To the date of the RSL workshop, the center had funded 12 projects with 11 companies and invested $2.75 million. This produced six new technologies, two new products, five new patents, and over $35 million in leveraged additional investment by portfolio companies.

In southeastern Pennsylvania, the Nanotechnology Institute (NTI; http://nanotechinstitute.org/) is changing the way the greater Philadelphia region advances new, transformative technologies from discovery to commercialization. The NTI is the region's first partnership created to be a catalyst for nanotechnology development, commercialization, and company formation. Ben Franklin Technology Partners of Southeastern Pennsylvania (BFTP/SEP), the University of Pennsylvania, and Drexel University created the NTI in 2000. It has been aggressive in the areas of technology and economic development. To date, the NTI has helped produce more than 80 intellectual property assets, facilitated seven technology licenses, created or assisted 13 young companies, and attracted more than $172 million in public and private investment to the region.

Case Study: Texas

Texas has a three-part program under its Texas Emerging Technology Fund (TETF; http://members.texasone.us/site/PageServer?pagename=tetf_homepage), which includes nanotechnology. Initially funded in 2005 at $200 million over two years by the state, then renewed in 2007 for $185 million over two years, the program was most recently reauthorized in 2009 amid a tight recession budget. The three components of the TETF are Research Superiority Acquisition, Research Matching, and Commercialization awards. Research Superiority Acquisition is set up to help recruit top professors to Texas universities by matching private and university startup funding.

This type of 3:1 leverage assures substantial funds (typically $3 million per top recruit) with the substantial commitment from the university and private sector to avoid the concern of "free money" that could trouble programs without matching requirements. Several of these awards have been made in nanotechnology. Texas universities are disqualified from future awards if they attempt to recruit from other Texas universities; this program is strictly to recruit out-of-state talent. Since brainpower is vitally important to the development of technology, and top professors in top programs attract top students, this program has high potential to become a winning investment.

The State Government Organization Model

Case Study: Oklahoma

The Oklahoma model, initiated in 2003, is built on a state legislative initiative to utilize nanotechnology commercialization to bring new and improved products to market. This model is implemented via the Oklahoma Nanotechnology Initiative (ONI; http://www.oknano.com/). The Oklahoma Center for the Advancement of Science and Technology (OCAST) operates the ONI under a public/private partnership with The State Chamber of Oklahoma. ONI has four primary objectives: (1) create statewide awareness of the emerging nanotechnology industry and its potential impact on the state; (2) promote Oklahoma and its resources as a valuable site for nanotechnology industry location; (3) serve as a clearinghouse of information on nanotechnology for the academic, business, financial, and industrial communities; and (4) provide outreach and referral support to the Oklahoma Nanotechnology Applications Program (ONAP; http://www.ok.gov/ocast/Programs/).

State Government Organization Model

This model includes having a paid staff, government buy-in, and support with dollars tied to state agencies (public) and private partnerships (e.g., state chambers of commerce). It also includes involvement of and with education and workforce training at all levels. A successful example of this model is the Oklahoma Nanotechnology Initiative.

ONAP was formed as a result of the Oklahoma Nanotechnology Sharing Incentive Act of 2006, a cash incentive program to assist Oklahoma business and industry in acquiring—through licenses, patents, or partnerships—nanotechnology discoveries and processes from anywhere in the world. Such acquisitions enable Oklahoma companies to bring new or improved nanotechnology-enhanced products to market. The legislature annually funds between $1.5 million and $2 million to OCAST for ONI and ONAP and as of 2009 had invested more than $6 million since 2005. The ONI utilizes The State Chamber's statewide business networks and the Oklahoma Network for Nanostructured Materials (Oklahoma NanoNet) to bring business and industry together with public and private nanotechnology researchers to commercialize nanotechnology products. In 36 months, Oklahoma increased its number of companies utilizing nanotechnology from six to more than 50; approximately half are startup companies, and half are established companies. Each spring the ONI hosts NanoFocus, a conference that showcases Oklahoma nanotechnology-focused businesses, scientists, and researchers. The ONI works closely with the NSF-funded Oklahoma Nanotechnology Education Initiative. The ONI program complements the suite of OCAST services, which include a pipeline of programs from concept to commercialization.

In 2002, NanoSource Technologies of Oklahoma City was acquired by DuPont, which was widely considered to be the first major liquidity event in the nanomaterials industry. The state is home to other prominent nanotechnology-enabled companies, including SouthWest NanoTechnologies (SWeNT), a commercial manufacturer of single-walled carbon nanotubes; OrthoCare Innovations, a developer of technologies for prosthetics; and Charlesson, an ocular biopharmaceutical company with several nanoparticle-based therapeutics under development.

Oklahoma NanoNet is a related program designed to build nanotechnology infrastructure in Oklahoma. The Oklahoma NanoNet is a statewide group of 60 science and engineering faculty members in three Oklahoma universities, their students, and industrial researchers. It is funded by the National Science Foundation through the Office of Experimental Research to Stimulate Competitive Research (EPSCoR). Because many researchers are working on collaborative projects that cross disciplines, universities, and academic and private sectors, the goal is to share facilities and access to characterization instrumentation for researchers statewide. As noted earlier in this chapter in the New York case study, access to core facilities is considered significantly less expensive to a business than acquiring a dedicated asset. Oklahoma NanoNet's collaborative and cost-sharing model has led to significant improvements in instrumentation.

Figure 2.1. David Arthur of SWeNT speaking at the RSL workshop.

Case Study: South Dakota

South Dakota is notable as the state with the smallest population that has a meaningful focus on nanotechnology and nanomaterials. With a well-equipped polymer processing lab just off the campus of the South Dakota School of Mines, the state has embarked on recruitment of nanotechnology-based businesses to broaden the user base of this lab and to provide in-state jobs to graduates of South Dakota universities.

Run from the Governor's Department of Tourism and State Development, this program can tailor industry attraction grants to match the needs of small businesses. In a streamlined process, the state can close deals quickly, with a minimum of paperwork, no equity dilution, and friendly, personalized help in getting established in the state.

The Single-Goal Foundation Model

An example of a single-goal foundation is the Nanotechnology Foundation of Texas, which had a narrow scope: to attract junior researchers to the state and grow them. It accomplished its goal for a period of time and then dissolved.

The Volunteer and Business Association Model

Case Study: Colorado

The Colorado Nanotechnology Alliance (CNA; http://www.coloradonanotechnology.org/home/) is a 501(c)(6), not-for-profit, nanotechnology-focused economic development agency and industry association. The primary mission of the CNA is to guide 21st century economic development through nanotechnology commercialization. The CNA is governed by an industry-led board, which includes representatives from government, economic development organizations, academia, research laboratories, workforce development, and service sectors. Located in Boulder, Colorado, it was formed as the lead organization to drive Colorado's nanotechnology economic development efforts. The CNA has implemented an aggressive plan to meet the objectives of the 2006 Colorado Nanotechnology Roadmap, which was funded by the U.S. Department of Commerce Economic Development Administration.

> **Volunteer and Business Association Model**
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> Member businesses, including service providers such as law firms, take the lead in directing and funding the initiative for the state, e.g., the Colorado Nanotechnology Alliance.

Regional Models

MidAtlantic Nanotech Alliance (MANA)

MANA (http://www.midatlanticnano.org/) was formed in the fall of 2004 and is funded by the U.S. Department of Commerce Economic Development Administration (EDA). The goal of MANA, which links Pennsylvania, New Jersey, and Delaware, is to build the infrastructure needed to translate emerging nanotechnology developments into practical applications, in order to spur economic development in the Mid-Atlantic region. MANA works toward this goal by attracting and securing funding for the region, and by developing and sharing information on best practices, policy and planning, informed investment, and emerging opportunities.

Southwest Nano Consortium

The Southwest Nano Consortium was formed in 2009 and consists of nanotechnology networks and alliances in Arizona, Colorado, Oklahoma, New Mexico, and Texas. The consortium pools resources to highlight nanotechnology activity in the region, encourage collaborative ventures, and host internationally recognized events.

Alliance for Nanohealth: Partnering in Medicine

The Alliance for Nanohealth (ANH; http://www.nanohealthalliance.org/) was established in 2008 as a network of over 500 investigators and laboratories across eight Houston-area medical institutions and with multi-institutional collaborations with the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD). These partnerships have funded seed grants and multi-advisor training programs, as well as symposia and outreach to the community. Support for ANH is multi-source, coming from local seed money, state and local community investments to develop commercialization, and Federal support of basic science and technology.

NanoBusiness Alliance

The NanoBusiness Alliance (http://nanobusiness.org/) is a trade association that represents the nanotechnology industry. Headquartered in Chicago, the NanoBusiness Alliance has been an active voice on Capitol Hill and around the country to support nanotechnology and to develop a range of initiatives to support the nanotechnology business community. The primary goals of the organization include the development of research and education programs, public policy and lobbying initiatives, public awareness campaigns, and industry support networks.

National User Facilities and Networks

National user facilities and networks are a way to share resources both nationally and within geographic regions. Such programs and collaborations minimize the need for funds to build independent, dedicated facilities for each group of nanotechnology researchers, and they mitigate the costs of dedicated, independent lobbying and promotional groups.

National Nanotechnology Infrastructure Network

The National Nanotechnology Infrastructure Network (NNIN; http://www.nnin.org/) is an integrated partnership of fourteen user facilities distributed across the United States and supported by NSF that provides opportunities for nanoscience and nanotechnology research through a comprehensive collection of user facilities. There were about 4,600 research and fabrication users as of 2008, from academic institutions and small and large businesses in all 50 states. Access to all facilities is provided continuously during the year after a two-week response time. Besides research and fabrication support, the network provides assistance in nanotechnology educational programs; environmental, health, and safety research; and public participation. The network provides extensive support in nanoscale fabrication, synthesis, characterization, modeling, design, computation, and hands-on training, available to all qualified users.

Nanoscale Science Research Centers (DOE)

The DOE Office of Science developed, constructed, and operates five Nanoscale Science Research Centers (NSRCs; http://www.science.doe.gov/nano/) across the country to support synthesis, processing, fabrication, and analysis at the nanoscale. As part of DOE's contribution to the NNI, these NSRC facilities are an integrated network, designed to be user centers for interdisciplinary research at the nanoscale, and serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. Each center focuses on a different area of nanoscale research, such as materials derived from or inspired by nature; hard and crystalline materials, including the structure of macromolecules; magnetic and soft materials, including polymers and ordered structures in fluids; and nanotechnology integration. Access to the labs is determined by submitted proposals that are reviewed by independent proposal evaluation boards.

National Characterization Laboratory

The Nanotechnology Characterization Laboratory (NCL; http://ncl.cancer.gov/), located in Maryland, performs and standardizes the preclinical characterization of nanomaterials intended for cancer therapeutics and diagnostics developed by researchers in academia, government, and industry. The NCL, which is part of the National Cancer Institute, serves as a national resource and knowledge base for cancer researchers, and facilitates the development and translation of nanoscale particles and devices for clinical applications. The goals of the NCL are to speed the development of nanotechnology-based products for cancer patients, reduce the risk of doing so, and encourage private-sector investment in this promising area of technology development. By achieving its goals, the NCL will provide a comprehensive set of baseline characterization parameters that will enable cancer biologists, drug and diagnostic developers, and clinical oncologists to apply their tools to solving problems that most affect cancer patients.

NanoFab (National Institute of Standards and Technology, NIST)

The NanoFab facility (http://cnst.nist.gov/nanofab/nanofab.html) is part of the Center for Nanoscale Science and Technology (CNST) at NIST in Maryland. NanoFab houses a suite of state-of-the-art nanofabrication and nanomeasurement equipment, selected to provide flexibility for upgrades as technologies advance and change. The tools within the NanoFab are designed to accommodate a wide variety of materials and sizes. The tools and operating procedures were selected to provide hands-on, easy-run operation by users ranging from novice to expert, or to be operated by one of the center's engineers. The research program focuses on developing measurement methods within three fields: future electronics; nanofabrication and nanomanufacturing; and energy conversion, storage, and transport.

Models Outside the United States

It is informative to look outside the United States to see what some other countries are doing in geographical partnerships to recruit top talent and build world-class companies. Because over 60 countries have national nanotechnology strategies and policies, understanding the rapidly evolving global context of nanotechnology is essential. Regional and local partnerships between academia, industry, and government have been established in various countries in Europe (by the European Union, in France, Germany, Finland, and other countries), Asia (Japan, Korea, China, and Singapore), Australia, the Middle East, and South Africa. An illustrative example is Singapore.

Singapore

Singapore is one of the most aggressive countries in terms of its focus on talent recruitment, including in nanotechnology. Singapore has long been favored by foreign investors due to its free-market economy and well-regarded rule of law. Singapore is ranked highly for its attractive environment for highly skilled foreigners. Having dramatically raised its standard of living in part by welcoming technology companies and embracing free trade, Singapore is now moving to become a technology hub of Asia, with a significant focus on nanotechnology as an enabler for many other areas. The Singapore government increased its R&D budget in 2006 to S$13.6 billion (≈US$9.7 billion) and established the National Research Foundation (Singapore's version of the U.S. National Science Foundation) with a budget of S$5 billion (≈US$3.6 billion) in its Science and Technology Plan 2010. In addition to research talent recruitment for such efforts as its research centers (Biopolis and Fusionopolis) and its top universities, Singapore has programs "INTECH" and "STRAT" to assist companies in hiring and training Singapore residents, and has recently begun limited commercialization grants to local companies under its SPRING program (http://spring.gov.sg/). Another program under the National Research Foundation provides 85% matching funds for startups in its incubator (up to S$500,000, or ≈US$357,000), with an option for the founders to buy that back, and an expectation for an eventual four-fold return on the total of S$50 million (≈US$3.6 million) set aside for this program.

> **Singapore's Economic Development Board** has worldwide offices that seek to bring talented researchers to Singapore. Unlike the United States, which has a low cap on skilled immigrant visas, Singapore recruits talent worldwide.

Incentives for Starting Regional, State, and Local Initiatives

Just as fundamental as the "who" in establishing regional, state, and local initiatives in nanotechnology are the "why" and the "what." Typical motives and objectives for RSL initiatives include:

- Creating new jobs (which is typically what a legislature primarily wants to invest in)
- Promoting growth in research and commercialization
- Growing Federal and private grant revenue

- Assisting both startup companies and more established companies
- Encouraging existing industry expansion and new corporate investment
- Promoting local nanotechnology education
- Assisting small businesses
- Creating local infrastructure for R&D

Logically, the nature and structure of RSL activities will be directed toward the accomplishment of their respective purposes (and ideally, with clear, measurable objectives). It is generally observed in the most successful cases that accomplishment of objectives and communication of that success has been crucial for continued or increased state support.

RSL activities may be classified by goal and structure, as shown in Table 2.1.

It has proven much easier for RSL initiatives to generate initial vision and enthusiasm, determine purpose and objectives, and even obtain initial startup funding than to keep stakeholders engaged and to sustain themselves (especially financially) for an extended period of time. Much of the discussion at the breakout session on models for RSL initiatives in nanotechnology revolved around how to address this generic problem.

Challenges to the Success of RSL Initiatives

A number of factors were identified as being critical to sustained progress in RSL activities in nanotechnology. In no particular order, these issues are briefly described as follows:

- There is no systematic and appropriate public or private funding source for RSL partnerships. There is often a mistaken belief that "industry" is willing to fund state or regional economic development without a specific advantage. Initiative organizing attempts based on a "pass the hat" business model have not been successful. In some states where the "nano community" is ready for an effective economic development investment, public funding may still be effectively impossible (e.g., in Colorado, due to its Taxpayer Bill of Rights legislation).
- Industry does often invest in advancing its interests through professional associations, e.g., the Technical Association of the Pulp and Paper Industry, American Chemistry Council, Semiconductor Industry Association, etc., but these are rarely regional in nature. There is a fundamental mismatch of interests between global markets/businesses in sophisticated, high-investment sectors and regional, state, and local economic development, though it can in special cases be bridged (as in New York) with a large investment in a single-sector initiative.
- Various geographical issues can make statewide or regional initiatives difficult to organize. Large size and low population density (e.g., much of the western United States) make the necessary networking difficult, and in many cases, the major research universities are not co-located with the political/population centers. Some states are too big to create a single statewide nanotechnology focus (e.g., California, Texas),

Table 2.1. Classification of RSL Activities in Nanotechnology

Goal	Structure	Examples
Industry development	Recruiting, job in-sourcing	NY, OK
Shared facilities	Facilities infrastructure at universities	CA, NY, OR
Economic development	Trade association	CO, TX
Full Service	Grow research, translate into commercialization stage	OK, OR
Development of entrepreneurial startups	Fund startups	OK, OR
Science networking and promotion	Activities around national laboratories, for example	TN, IN, WA, NM
Single-sector focus, e.g., on education		TX

though they typically have diverse local activities in their major population and industrial centers that include some "nano" component. In these cases, political reality may favor multiple intrastate regional investments. It is also the case, conversely, that some smaller states (such as Oklahoma and Oregon) have a networking advantage ("everyone" knows one another), whereas advocates in big states can find it difficult to "know what they know."

- Many (if not most) states do not have a state government–based science and technology agency or organization. Some of the notable nanotechnology initiatives had such state-led efforts as antecedents, often involving citizen/industry volunteer leadership, e.g., New York's NYSTAR, Oklahoma's OCAST, and Oregon's OCKED. In addition, there generally is no organization to formally connect the state executive branch to the state government science and technology agencies.
- Closely related to the previous issue, by no means do all states recognize or acknowledge the importance of a state role in innovation-based economic development in general, or in nanotechnology in particular. Securing public funding typically entails broad advocacy (from logically interested constituencies such as the high-tech industry) and political support that takes several years to develop. Compounding this problem is that the necessary collaborators in these efforts, such as business people, academics, government staff, and elected officials, typically do not understand each other, and must expend significant "mental effort" to be able to effectively work together.
- Administrators of existing and mature structures and institutions, such as university academic units, state business assistance offices, and Federal agency programs (e.g., Manufacturing Extension Partnership, or MEP), and other structure types may not understand or be particularly interested in nanotechnology or other endeavors that may require change or lead to disruption. Yet these institutions may already occupy the organizational and budget "space" that is required for nanotechnology support.
- Two other issues raised in the Models for RSL Initiatives breakout group are somewhat more fundamental:
    - Nanotechnology may be related to the process or inclusion of a process in the final product. It frequently entails more of a "how" than a "what" group of issues, and businesses and business groups are better off identifying or aligning with sets of market needs and customer needs than with technology distinctions.
    - A study of organizational factors influencing highly creative scientific breakthroughs suggests that the most productive collaborative groups begin small, e.g., six to eight people, and build out from there, as opposed to value being created by bringing diverse groups together and hoping to capture synergy (*1*). Though there are cases where this has worked, such as Oregon, there is no substitute for identifying true win-win situations as well as people who are interested in collaborating. A broader implication of this research is that nanotechnology initiatives should focus more on stimulating research in multiple small groups that are linked well institutionally, rather than immediately seeking to build singular large research centers. However, there is no generally successful or unsuccessful approach.

Other Issues; Potential Solution Paths

Funding

There is clearly a disconnect between the Federal Government's funding of nanotechnology research and encouragement of RSL initiatives, and most state governments' willingness to fund such initiatives. It might make sense for the Federal Government to consider something like co-funding incentives for states and regions to establish RSL initiatives.

Public Understanding

A significant issue is that most people in the general population do not know about or understand nanotechnology, and therefore the political impetus to form RSL initiatives does not exist. Given the extent to which nanotechnology progress is important to the national interest, the Federal Government may need to do more to educate the broader public about nanotechnology—possibly in cooperation with and via assistance to state initiatives. Promoting nanotechnology as a tool to allow companies to make better products may be a good tactic. This is working well in Oklahoma, a state many might not have considered to be an obvious place for nanotechnology to become a major focus.

Databases

Related to building both funding support and public understanding, states could perhaps help things along by developing (or contributing to developing) a database of both industry and research institutions that are actively engaged in nanotechnology.

Regional Opportunities

Encouragement of inter-state, regional, and international efforts may be highly desirable—especially for small states that lack significant relevant industrial and academic resources and would benefit from better access to resources like educational offerings and core facilities located in neighboring jurisdictions. Obviously, artificial boundaries such as state lines do not accurately delineate economic regions (e.g., Portland, OR/Vancouver, WA; the Potomac region near Washington, DC). Nevertheless, these "arbitrary" boundaries determine the availability and terms for most non-Federal public funding, and cooperative arrangements between states will be politically cumbersome to achieve even in the presence of good will. Legislators naturally want to be certain that state money is spent in their home states to the greatest extent possible. Lacking some clear and efficient "joint jurisdiction" funding mechanism, it will be difficult or impossible for interstate or international initiatives to do much more than host joint/regional events and engage in informal networking. As noted earlier, industry associations and interests are not regional in nature.

Concluding Remarks and Ideas for the Future

The right level of nanotechnology initiative depends on local conditions—geography, industry, state resources, etc.—but it is difficult to get funding for multistate or international initiatives. Typical models include multiple/intrastate (very large states); statewide; and multistate/regional (smaller states). Perhaps some new RSL initiative models are needed, but a clear problem must first be defined, then the right solution determined, including who benefits, who is willing to pay, etc. It may be useful to have some kind of NNI "road show" to state houses to encourage nanotechnology-related, technology-based economic development investment. Conversations could be given to making this workshop an annual event, rotating through model sites of RSL initiatives.

It would be useful to have a study of 2003 and 2005 participating initiatives, with Federal and state contributions to data collection, in order to answer the following questions: (1) What happened to each initiative? (2) What worked and what failed? and (3) What lessons were learned?

Nanotechnology in a global context creates challenges and opportunities for regional, state, and local initiatives in the United States: proponents must act locally but think globally. Key drivers for this approach are the large markets forecast for nanotechnology, increasing globalization and capacity due to interdisciplinary and cross-sector research, and business models incorporating open innovation and global value chains. There are numerous opportunities for U.S. nanotechnology initiatives in terms of collaborative initiatives, shared best practices, investments, networking, and match-making.

RSL Initiative Business Models

Like any other business, an RSL initiative needs a realistic business model that is compelling to stakeholders. In cases where state funding is sought or secured, the question of "self-sustainability" inevitably comes up. Opinions and situations vary as to whether RSL initiatives can successfully fund themselves post-state support, though few/no examples of actually doing this are known to the authors of this chapter.

One possible response to this is that an RSL initiative, like a company division or even a whole company, should not plan to be a permanent institution, but should only exist and be funded as long as it generates the required and measurable return on investment. Universities and state agencies, by contrast, are much more likely to be perpetual entities.

The current reality is that most state budgets are being cut, and there will be less funding for existing initiatives, and little or no likelihood of new starts. In addition:

- Surviving initiatives are likely to have good results, political support, and private advocacy.
- Demonstration of leverage is key; e.g., for New York and Oregon, most of the money that flows through the "organization" is Federal or private.
- An employment/employer database (again, with both Federal and state employment agency contributions) that includes nanotechnology-relevant North American Industry Classification System (NAICS) codes would be a valuable tool for identifying needs, opportunities, and tracking the kinds of results that state governments care about.

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3. Workforce Development and Education

Moderators: Steve Fonash, Pennsylvania State University
Philip Lippel, National Nanotechnology Coordination Office
Krish Mathur, U.S. Department of Education

Background and Needs

An educated workforce and an informed public are essential for achieving the goals of national, regional, state, and local nanotechnology initiatives, and ultimately, for fulfilling the promise of nanotechnology to benefit society. Two main issues were raised with respect to this topic:

- What are the main education and training needs of the nanotechnology community?
- What has to be done in the immediate future to meet these needs, and at what level (Federal, regional, state, local)?

The "nano" world has evolved over the last decade from its R&D phase into beginning the manufacturing phase—from discovery to the first phases of commercialization. The nanotechnology industry is not yet mature, but there is sufficient demand for nanotechnology-enabled products across many industrial sectors to fuel expectations of significant job growth. Two main educational milestones must be achieved for the economic application of nanotechnology:

1. A skilled workforce must be available.
2. The public must understand and accept the balance of benefits and risks that deploying the new technology entails.

Achieving these milestones involves tasks at every level of the educational system. Developing awareness of nanotechnology and of its broad impact on society lies jointly in the realms of both informal education and K–12 education. Such activities also must share the task of creating interest in nanotechnology-based careers. Empowering people for these careers and creating a skilled nanotechnology workforce is the task of post-secondary education. Efforts are already underway in each of these areas. The purpose of this chapter is to assess current efforts in light of the presentations and discussions at the 2009 Workshop on RSL Initiatives in Nanotechnology, and to present ideas emerging from the workshop regarding future emphases and the most appropriate roles for the many interested parties.

State, local, and Federal K–12 and post-secondary education efforts to date have been predicated on the need for students to understand materials, medicine, and important early projections of growing industrial opportunities in nanotechnology. If future educational activities are to support the expected sustained growth in the skilled nanotechnology workforce, Federal, regional, and state authorities must make major new investments. To get commitments for such investments, the community will need to develop more detailed industry plans, including specific job-creation statistics and projections.

Nanotechnology workforce preparation raises specific issues. Nanotechnology is an enabling technology that affects many industries, and nanotechnology-related skills are used in many different types of jobs. The word nanotechnology itself does not often appear in job descriptions; *monster.com* has no category for nanotechnologists. Economists have begun to describe "nano" as a general-purpose technology, as it was projected to be at the inception of the NNI (*1*). Techniques used to track the labor market in other general-purpose technologies (e.g., information and computer technology) may be helpful in furthering the analysis needed to justify growing investments in nanotechnology education.

Broad "STEM" Education Issues and K–12 Nanotechnology Education

Nanotechnology is emerging amid a widely recognized crisis in science, technology, engineering, and mathematics (STEM) education in the United States. There has been for some years a waning interest in STEM careers among U.S. students, in sharp contrast to the situation in Asia especially. If the U.S. education community can leverage the interest and excitement currently surrounding nanotechnology to generate more student curiosity regarding STEM topics and STEM careers, nanotechnology could also turn out to be a significant part of the solution to the larger problem of how to regrow U.S. strength in STEM-related occupations generally. To effectively turn students' initial excitement about the nanoscale world into real career interest, nanotechnology education programs should be aligned with known best practices in STEM education. Inquiry-based learning and design-based activities will be important aspects of such efforts. In selecting and sequencing activities, educators and curriculum developers should utilize theories of learning and cognition from modern STEM education research. Following these principles, successful integration of nanotechnology concepts into STEM education at all levels will help maintain U.S. leadership in research and innovation.

Roles and Players

The United States is unusual in giving the lead role in primary and secondary education to states and localities. This deeply entrenched concept of local school control has, of course, both advantages and disadvantages. Among the latter is a lack of uniformity in state standards for formal education programs. This educational fragmentation makes a "retail" approach to nanotechnology education complicated and expensive. Significant effort is needed to adapt nanotechnology education programs to individual state standards and approved curricula. Frequent "siloization" of schools—meaning math educators do not talk to science educators, nor do science educators talk to business educators—adds to the problem's complexity. This is particularly acute for an interdisciplinary topic like nanoscience, but setting up interdisciplinary approaches also presents opportunities to stimulate new interactions among teaching disciplines. Another aspect of local, state, and regional issues is the variation across the country in specific areas of interest, which also can be addressed within the model of nanotechnology as an enabling or general-purpose technology.

Despite the varied practices of U.S. local school districts, there are strong national support systems that act as cohesive forces for educational organizations. The roles of Federal agencies include making funding available to states or localities through entitlement programs and through support for education research and innovation. Federal agencies support state and local efforts to create new infrastructure, establish partnerships among local efforts, and stimulate information sharing. Federally

Stakeholders

In addition to the Federal agencies, national stakeholders in educational programs to advance nanotechnology include publishers of national science education standards, such as the National Academies and the American Association for the Advancement of Science; professional associations representing STEM teachers, including the National Science Teachers Association, the American Association of Physics Teachers, the American Chemical Society's Division of Chemistry Education, the National Education Association, and the IEEE Education Society; other scientific and engineering societies; and industry, trade, and labor groups.

funded projects can also play a role in helping to define performance metrics that can be used to evaluate nanotechnology education programs.

There is already a proliferation of nanotechnology programs at various educational levels. While many share common themes, no agreed-upon set of core concepts has emerged to date. Nor has independent quality control been put in place. Further coordination and communication among these activities will strengthen and accelerate all the efforts. At the K–12 level, there is a need for rigor and passion across the country to stimulate increased interest and improve student abilities and performance in science and math, building a basis for future careers in all STEM fields, not just nanotechnology.

Post-Secondary Nanotechnology Education and Workforce Training

To date, statistical forecasts for the nanotechnology workforce have large uncertainties and must be considered preliminary. The oft-quoted estimate made in 2000 that about one to two million workers will be needed worldwide by 2015 (*2*), and that a two-year degree will be sufficient for a significant fraction of these workers, needs an updated, detailed supporting analysis. A survey undertaken by the Pennsylvania State University in collaboration with the National Association of Manufacturers showed a consensus that few jobs are currently available for which nanoscale fabrication and characterization skills are essential, but there is wide industry awareness of the growing need for nanotechnology skills development, coupled with expectations of higher future workforce needs and even worker shortages.

Detailed projections and forecasts of worker needs at each degree level, for various time periods in the next few decades, would assist in planning future educational activities. In some areas, a shortage of skilled technicians and instrument developers has already been noted. Several high-end instrument manufacturers have moved overseas, in part due to better availability of these workers abroad than in the United States. Many companies report that they are hiring PhDs for routine characterization jobs, which could be more suitably filled by skilled technicians were they available. Major research labs note an immediate need for U.S. citizen-students who will become the innovators behind tomorrow's new industries. A broad, multidisciplinary skill set that includes both science and business skills is required to meet this need.

Of the approximately 8,000 PhD engineers produced in the United States each year, roughly two-thirds are foreign nationals, many of whom are likely to eventually return to their home countries. To increase the share of highly trained scientists and engineers who remain in the United States, two paths could be pursued: (1) stimulate increased enrollment of U.S. nationals in advanced science and engineering degree programs, and (2) make it easier and more desirable for foreign-born scientists and engineers to remain in the United States throughout their careers. A national discussion of whether to follow one or both of these paths should include special consideration of nanotechnology and other emerging STEM fields, since an annual increase in jobs is expected as projects progress from research to production.

Table 3.1. Survey of graduate students and postdoctoral jobs after graduation from NSEC, NCN, and NNIN institutions* (survey in December 2008) (*3*)

Institution	Graduate Students			Post-Doctoral Researchers		
	Total Number of Graduates	Graduates in Industry	Percent in Industry	Total Number Completed Appointment	Number in Industry	Percent in Industry
NSEC	528	193	36.6%	270	99	36.7%
NCN	44	22	50.0%	20	0	0.0%
NNIN	2600	2080	80.0%	950	475	50.0%
Total	3172	2295	67.2%	1240	574	44.6%

* There are 3 NSF-funded university-based collaborative educational and research efforts to advance nanotechnology:
NSEC = Nanoscale Science and Engineering Center; NCN = Network for Computational Nanotechnology;
NNIN = National Nanotechnology Infrastructure Network

Key Role of the National Center for Learning and Teaching in Nanoscale Science & Engineering

The National Center for Learning and Teaching (NCLT; http://www.nclt.us/) in Nanoscale Science and Engineering has been tasked by the National Science Foundation with a leadership role in middle school and high school nanotechnology education. Its agenda includes teacher training, materials development, and research for developing tools and mechanisms best suited to teach the concepts of nanoscience.

NCLT has been working on the development of inquiry- and design-based "nano concept" instructional materials for middle school and high school. The first task was to understand how students learn nanoscience and then to identify key nanoscience concepts that can eventually be integrated with the national curricula. Specifically, NCLT has built a consensus for the core ideas of nanoscale science and engineering education for grades 7–12. Through collaboration between scientists, educators, and learning researchers, nine key concepts, the "big ideas of nanoscience," were established. The "Big Ideas in Nanoscience" monograph is now available through the National Science Teachers Association Press. These "big ideas" and the related document guide the work throughout the NCLT, including research, assessment, professional development, and curriculum development. In addition, these core ideas are already impacting science curricula and standards on the state and national levels.

In order to determine the points in the curricula that would be appropriate for the introduction of nanoscience concepts, NCLT explored how students in grades 7–16 build their ideas relating to "size and scale," "surface-to-volume ratio," and the "nature and properties of matter." Understanding the developmental trajectory of students' conceptions of size and scale and the nature of matter, and how they develop connections between and within these topics, is critical for supporting student learning about nanoscience. Both students and teachers were interviewed to develop best practices for incorporating key nano concepts into existing curricula and to develop appropriate learning progressions for the emerging field of nanoscience.

Nanoscience researchers and science teachers, supported by the NCLT, have collaborated to develop curricula and modules that are linked to the key nanoscience concepts identified by the center's learning researchers, and to national standards. "Introduction to the Nanoscale," "Nanotechnology," and "Manipulation of Light in the Nanoworld" are now available for national dissemination. Additional lessons on microscopy, self-assembly and nano-patterning, dye-sensitized solar cells, and nanoscale drug delivery are in development.

The next key step is the training of teachers to teach nanoscale science and engineering (NSE) in middle school, and NCLT has developed a robust professional development program for teacher training. It has reached out to numerous school districts nationwide, including those in Nashville, Huntsville, El Paso, Virginia Beach, Chicago, Detroit, Los Angeles, Baton Rouge, and Indianapolis. The impact and growth of these participants has reached 100-plus schools, and teachers are being trained annually. The NCLT Professional Development Program (NCLT-PD Program) involves a two-week summer institute, academic year follow-up activities, classroom visits, and other collaborations with teachers. The program is designed with the goals of providing science teachers with: (a) an enhanced understanding of nanoscience; (b) inquiry-based methods for teaching nanoscience; (c) a collection of suitable classroom lessons; (d) assistance in developing their own nanoscience lessons for classroom use; and (e) assistance to enhance their awareness of the connections between nanoscience and the traditional sciences of chemistry, physics, biology, and mathematics.

In order to support continuous dissemination of educational materials on nanotechnology, NCLT launched the NanoEd Resource Portal (http://nanoed.org/) as a hub for the NSE Education community to gather and disseminate information, archive learning and teaching materials, view lectures, etc. Contributions from the global research community, such as courses with multiple notes, videos, and lesson documents, can be supported by this hub. Curriculum materials developed by NCLT are available through the NanoEd Portal, along with contributions from external collaborators. As online access grows, the ability to connect students to useful and engaging curricula also grows. A number of new web-based tools to support learning and teaching of nano concepts, such as animations, simulations, visualizations, and a nanoscience card game, have been developed. These new learning tools are also available via the NanoEd Resource Portal. Several of these tools have also been incorporated into the instructional materials developed by NCLT.

The time scale on which the availability of a skilled and sufficiently large nanotechnology workforce affects commerce will vary by industry sector. For example, the semiconductor industry needs skilled nanotechnology workers now. Near-term needs for additional workers are predicted for photovoltaic cell manufacturing, other coating-based manufacturing, advanced batteries producers, and building materials suppliers. The pharmaceutical and medical device industries will likely have somewhat longer deployment time scales, due in part to regulatory issues.

The effect of the current global recession on the opportunity timeline for nanotechnology workers is difficult to predict, but some stretching can be expected. Anticipated shifts in the demographics of the U.S. population will have an overall effect on the situation for STEM workers in general and nanotechnology workers in particular, upon which must be overlaid a large variation by state. For example, Oklahoma reports a 30–50% dropout rate among many segments of its population, along with an aging workforce. It is actively seeking new ways to keep young people in school and train them for good jobs. The demographics of STEM education internationally are also changing, and the age distribution of the global population will change in coming years. In 20 years, other countries may not rely on U.S. institutions to educate their scientists and engineers to the degree they do now. U.S. response to national and international shifts in population and in opportunities for STEM students will have an important role in maintaining U.S. leadership in the global research and development enterprise and in all industrial sectors for which R&D is a long-term economic driver.

Overview of Current Educational Activities

Current Federal, state, local, and regional education efforts in nanoscale science and engineering cross all formal educational levels and extend into many informal settings. The National Science Foundation is the largest single sponsor of educational activities within the National Nanotechnology Initiative, supporting $35.9 million in spending for 2008 on education and societal dimensions (*4*) and $39.8 million for 2009 in the same Program Component Area, including $8.5 million in ARRA funding (*5*).

All the research agencies with significant extramural programs, notably the Department of Energy, the Department of Defense, and the National Institutes of Health, support significant numbers of undergraduate and graduate students engaged in research experiences. The Department of Education and the Department of Labor are following the developments in nanotechnology closely but to date have not made major investments. Several states including New York, California, Pennsylvania, Oklahoma, and Minnesota have made significant investments in their state university and community college systems. Several important coalitions and consortia have formed. Many of the important NNI research centers[1] include either formal educational activities or informal outreach activities as part of their overall project plans. Taken as a whole, the NNI and regional, state, and local initiatives support quite a broad spectrum of educational activities, as detailed below. One area that seems to be lacking attention is incumbent worker training.

K–12 Activities

Primary education (elementary and middle school) does not generally differentiate among fields of science. The general approach here has been and should continue to be building awareness of the nanoscale and of the centrality of nanoscale structures like atoms, molecules, DNA, and other biological structures in modern science. Nanoscience ideas can be introduced as part of the general science curriculum, connecting and reinforcing central concepts. On moving from elementary to middle school, students can build on these fundamentals as they begin to develop awareness of their own personal interests and career preferences. Inclusion of design- and inquiry-based activities featuring nanomaterials, nanoscale devices, or biological nanostructures appears to be appropriate at this level. Design- and inquiry-based activities continue to be highly suitable in high school as students begin to differentiate between various STEM fields, learn the connections between them, and develop a more nuanced understanding of potential career paths.

1 These include NSF's NSECs, NNIN, NCN, and part of the Materials Research Science and Education Centers; DOE's Nanoscale Science Research Centers; the National Institutes of Health Nanomedicine Centers; and NIST's Center for Neutron Science.

Post-Secondary Activities

Current activities are extensive and quite varied across the field of post-secondary education, ranging from community colleges with their direct emphasis on workforce development through associate's degree programs and continuing education, to undergraduate certificates, minors, concentrations, and in a few cases, majors programs, to specialized graduate-level programs training the research scientists of tomorrow. Primarily three types of institution participate in formal post-secondary nanotechnology education and workforce development: (1) the associate's degree-granting community and two-year technical colleges, (2) the bachelor's degree-granting four-year-degree institutions, and (3) research-intensive universities offering both undergraduate and graduate programs.

Two-year and four-year degree-granting colleges and non-research-intensive universities teaching nanotechnology have varying levels of faculty expertise, staff support, and equipment available. They often lack the tools necessary to "see" at the nanoscale, a position analogous to teaching astronomy without a telescope. Most cannot afford the equipment base required to deliver a broad, hands-on education in nanotechnology or the staff to maintain such equipment. Yet these institutions are critical to developing the technician base of tomorrow's nanotechnology workforce. The two-year institutions in particular offer relatively inexpensive tuition rates and have the largest numbers of students from underrepresented groups, precisely the people who would benefit most by entering into the country's nanotechnology workforce in greater numbers. They also often have dedicated faculty for whom education is the single mission. In contrast, universities have far more extensive resources, including expert faculty, support staff, and a substantial equipment base, but their mission is not singular; the demands of undergraduate education, graduate education, and research must be balanced. Resource sharing among the different types of institutions is a straightforward approach to mitigating these disparities; it is being used in several programs, some of which are briefly described below, to enhance nanotechnology workforce education.

In Pennsylvania, the Nanofabrication Manufacturing Technology Partnership (http://nano4me.org/

Resource-Sharing for Post-Secondary Nanotechnology Education: NMT & NACK Models

Through Pennsylvania's Nanofabrication Manufacturing Technology (NMT) Partnership, 550 students had received degrees or concentrations in nanotechnology from over 29 institutions in the state at the time of the RSL workshop. By linking Pennsylvania State University, its community colleges, and 4-year, non-research-intensive colleges and universities across the state, pathways have been established for students to transition from community colleges to 4-year degrees. Over 65% of the students who took the nanotechnology training continued to 4-year degree programs. Furthermore, students who have taken this training are employed at almost 80 micro- or nanotechnology companies in the state, ranging from pharmaceutical to photovoltaics to materials companies.

To address curriculum issues, the NSF Nanotechnology Applications and Career Knowledge Center (NACK) at Penn State University has created a suite of six nanotechnology-specific courses designed to give students a broad, hands-on nanotechnology education. The six courses can be taught in one semester or spread across several semesters; they have the flexibility to be inserted into pre-existing technology programs (from chemical technology to biotechnology) to create concentrations, or they can be used to establish new degrees such as bio-nanotechnology or nanofabrication technology. In Pennsylvania, these six courses have been plugged into 56 degree programs at 29 institutions.

NACK courses and laboratories are available free of charge online at http://nano4me.org, and train-the-trainer workshops were being held bimonthly at the time of the RSL workshop. Courses are modular and may be used as-is or reassembled with or without new material added to create alternative delivery approaches. NACK also offers a web-based lecture series and online access to nanotechnology characterization tools, such as a field emission scanning electron microscope (FESEM) with 1 nm resolution and atomic force microscopes, so that students can run and utilize the "telescopes and microscopes" of nanotechnology from their home institutions.

PaNMT/) has used a resource-sharing approach for nanotechnology workforce development for almost ten years with notable success. A recent NSF grant created the national Nanotechnology Applications and Career Knowledge Center (NACK) at Pennsylvania State University to develop a national network of nanotechnology workforce education programs. (See also the previous sidebar about these programs.)

In Oklahoma, NSF's Advanced Technology Education (ATE) program has supported the development of new associate's degree programs such as Nano-Scientific Instrumentation. The State Department of Career and Technology Education took a leadership role in establishing the Oklahoma nanotechnology-focused science and engineering programs. The primary pathway for students there includes two years in the Oklahoma State University Institute of Technology in Okmulgee in preparation for direct entry into the job market. Secondary pathways feed into other state universities for an additional two years of study leading to a bachelor's degree and then into the job market. Rounding out this program are collaborations with other Oklahoma universities and with out-of-state universities.

In California, the Donald F. Averill Applied Technology Training Center (ATTC; http://www.attctraining.org/) of the San Bernardino Community College District won a $2 million competitive grant from the U.S. Department of Labor's Community-Based Job Training Program to establish an education program providing nanotechnology-trained workers for local and state-wide manufacturers. NASA's Ames Research Center in Moffett Field, CA, is a partner, and the state was contributing additional funding through the University of California Chancellor's office.

In Minnesota, a Dakota County Community College program exemplifies the early spinouts from the Penn State effort, adapted to meet local industry needs of Minnesota's LifeScience Alley® association members. In this program, the University of Minnesota shares its expertise and facilities to enable community college nanotechnology education and workforce development. Through a grant from NSF's ATE program, this spin-out has now evolved into Nano-Link, a three-state ATE Regional Center, with the University of Minnesota continuing its resource-sharing role.

Common Themes

The community-college-based workforce education programs share several common themes. These programs are designed to support commercialization of emerging technologies and the introduction of advanced manufacturing into strong existing local industries, so working with local industry leaders to understand and respond to their needs is essential. Institutions must look at costs, enrollment, sustainability, and equipment and staffing issues. The need for faculty development programs to support these new initiatives is universal, as is the need for access to capital equipment—the "telescopes" and "microscopes" of nanotechnology—along with fabrication facilities. Another issue is the lack of commonality in the plethora of new courses and programs being developed.

Degree program and course development at community and technical colleges is currently *ad hoc*, with no agreed-upon core of skills or standard sequence of courses within which to develop those skills. A skill set such as that developed by industry and NACK needs to be vetted in an open national forum. The short history of these programs provides some of the best evidence available to date of industry belief in the prospects for nanotechnology jobs. In addition to the nearly 80 micro- and nanotechnology companies that have hired students who have completed the NACK program, Intel's February 2009 announcement of a $7 billion investment in U.S. manufacturing facilities for the 32 nm semiconductor node explicitly mentioned a trained workforce and high-quality job creation as reasons for seating these programs domestically.

Many of the issues outlined above for community and technical colleges also apply to four-year colleges and non-research-intensive colleges and universities. Several four-year institutions have started using the six NACK nanotechnology-specific courses, offering them in the sophomore year of four-year degree programs. Students completing these four-year degree programs typically graduate from their colleges or universities with degrees in physics, chemistry, or biology that include a concentration in nanotechnology, having acquired an exit skill set approved by their departments in consultation with local industry.

The research-intensive universities have generally been integrating nanotechnology, nanoscience, and nanoengineering into existing disciplinary curricula at the undergraduate level. Motivated by the idea that nanotechnology and nanoscience support an innovation ecology, they have begun to offer new degree programs, minors, concentrations, and certificate programs and to offer new paths to complete or enhance existing degree programs. These complement the graduate-level programs through which universities have been training students for both academic and industry-based career paths for as long as they have been performing nanotechnology research. These are the programs that develop our future research leaders, industrial innovators, product designers, and nanotechnology-savvy technical marketers.

One particularly interesting case is the nanotechnology-based university grants provided under NSF's Integrative Graduate Education and Research Traineeship program (IGERT; http://www.nsf.gov/crssprgm/igert/intro.jsp). NSF is currently funding 14 such projects directly and managing an additional four grants funded by the National Institutes of Health (NIH) National Cancer Institute.

The NIH-funded Northeastern University IGERT was described in a presentation at the RSL workshop. It is serving a cohort of 25 doctoral students plus 25 master's- or undergraduate-level research trainees, has developed several nanomedicine courses, and is interacting strongly with both the medical research community and industry in the Boston area. Vigorous outreach programs and a strong internship program are now in place. Northeastern University is working with other universities to replicate this model and is in the process of creating new degree programs and expanding partnerships, some international. As this program grows, it is identifying needs for additional activities in the area of adult continuing education and retraining programs and teacher training to prime the pathways. It is also increasing efforts to build public awareness and media awareness.

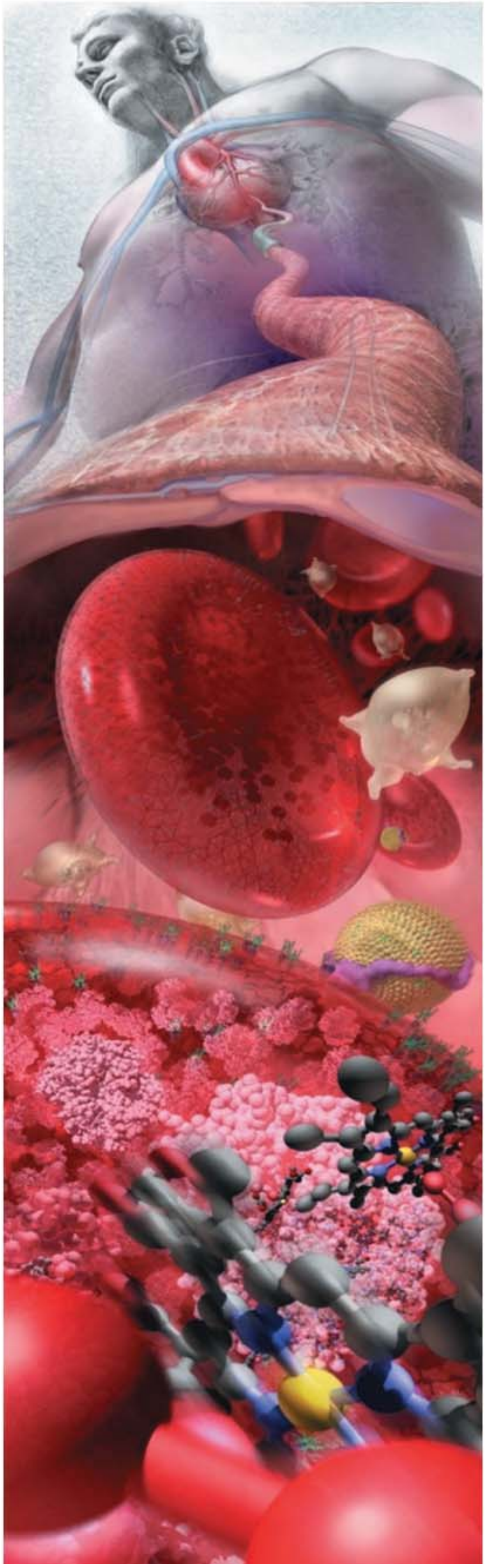

Figure 3.1. "Zoom into the human bloodstream": an illustration that won the NSF Visualization Challenge in 2008 (courtesy of NISE Net/Viz Lab).

Informal Education Activities

Significant efforts are already underway in the arena of informal and supplemental education. Opportunities in this arena occur in after-school, weekend, and summer programs for children at schools, museums, and universities; in community forums, exhibits, and science cafés for families or adults at museums, universities, libraries, or community centers; and in summer research experiences for undergraduate students, high school teachers, and exceptional high school students. The U.S. Department of Labor and Department of Education also offer funding to support internships in high-need areas.

Several large research centers and nodes of excellence have emerged in the field of nanotechnology education. The National Center for Learning and Teaching in Nanoscale Science and Engineering is a leader in teacher training, concept mapping (matching nanoscience concepts to existing curricula and standards), and research into how we learn and understand nanoscience concepts.

The Nanoscale Informal Science Education Network (NISE Net; http://nisenet.org/) has established a network of over 100 institutions around eight regional hubs. NISE Net members are developing exhibits and educational materials using teams drawn from both the nanoscale science research and the science museum communities. The NACK program is spreading to millions rather than hundreds of students. Cornell University nanoscience educators have partnered with Disney and with the producers of National Public Radio's "Earth & Sky" radio program to bring a retail approach to teaching while emphasizing basic nanoscience concepts: "All things are made of atoms; at the nanometer scale atoms are in constant motion; molecules have size and shape; molecules in the nanometer-scale environment have unexpected properties" (e.g., see http://nanooze.org/english/articles/tsts_commandments.html).

Information resources play an important role in disseminating information and helping to establish a community of practice for nanoscience educators. Several online information resources dedicated to nanoscience education already exist; Federal funding of efforts like these helps makes resources that are developed at state or local levels more broadly available:

- The NCLT maintains the http://nanoed.org portal, primarily aimed at educators and education researchers.
- NACK has established the website http://nano4me.org, which currently has 10 introductory modules available online.
- Cornell's nanotechnology education group maintains a website, Nanooze, http://nanooze.org and publishes corresponding print materials.
- The NNI website, http://nano.gov, maintained by the National Nanotechnology Coordination Office, features an Education Center.
- NSF has a nanoscience classroom resources website at http://nsf.gov/news/classroom/nano.jsp.
- NNIN has an education portal at http://nnin.org/nnin_edu.html.
- The National Institute for Nano-Engineering (NINE) program at Sandia National Laboratory maintains the website http://sandia.gov/NINE, which incorporates education modules.
- The NanoLink website http://nano-link.org/ was developed by Dakota Community College and five other Midwest community college partners.

Some important databases are also already extant:

- http://nano4me.org, maintained by Penn State University Center for Nanotechnology Education and Utilization with state and national partners provides prospective students with a map-based catalog of two-year nanotechnology degree programs and offerings in 12 states.
- The NCLT is working on cataloging four-year programs. The two groups have agreed to work together on collecting and organizing this information.
- The NISE Network has an online catalog of exhibits, forums, and other public engagement activities at http://www.nisenet.org/.
- Webinars are regularly hosted and archived by the NCLT and the Network for Computational Nanotechnology's website http://nanohub.org.

NACK, Sandia, and others are experimenting with remote access to advanced instrumentation, which when used for classroom demonstrations led by experienced users is especially promising and could be thought of as specially enhanced guest lectures. NACK is currently experimenting with new methods of leveraging physical resources, for example building a cleanroom dedicated to teaching. By separating the students from working cleanrooms, NACK educators will have more freedom to test laboratory setups in order to understand what is needed as the minimum facility in which to introduce the tools and techniques of nanofabrication.

Nanotechnology-related education activities been reported on annually since 2005 at NSF's Nanoscale Science and Engineering Education (NSEE) conference. There was no NSEE conference in 2009, but the Advanced Technology Education program conference in October 2009 featured many projects in the field of nanoscale science and technology education. NSF also sponsored a workshop at the University of Southern California April 23–24, 2009, on the topic of partnerships in nanotechnology-related education.

Concluding Remarks and Ideas for the Future

The NSF has invested $3.25 billion in nanoscale science and engineering R&D since the inception of the NNI (fiscal years 2001–2010, inclusive) (*5*). Currently the activities detailed above annually engage over 13,000 students and researchers in nanotechnology-related academic work, teaching, and learning. These programs are providing a terrific kick-start to the nanotechnology enterprise but should be supplemented and enhanced.

According to current predictions, nanoscale materials and devices will be incorporated into $3.1 trillion worth of products by 2015 (*6*). Nanotechnology adds real value to a great variety of products and systems, and skilled workers are needed to produce them. To meet growing worker needs domestically, U.S. nanotechnology education programs must provide students with a rigorously identified core set of nanotechnology skills. Specialized skills will also be needed for each industry or product class. Energy workers must know how to produce, qualify, install, and maintain power distribution systems made of advanced materials such as superconductors or carbon nanotubes, and how to build and deploy large-scale nanofiltration systems to reduce pollutants and capture greenhouse gases. Water workers will need skills to handle new water purification and desalination technologies and nanotechnology-enabled monitoring sensors. Medical workers, from researchers to clinicians, will need skills in bionanotechnology if they are to utilize novel nanotechnology-enabled drug delivery, disease detection, and combined "theranostic" tools.

The first challenge in planning future nanotechnology workforce programs is for all stakeholders to make a realistic assessment of workforce needs over time, by industry sector. An accurate forecast would build confidence and motivate a workforce. This would spur greater investment, monetary and otherwise, from various stakeholders, including private industry. In a rapidly changing, increasingly urbanized and globalized world, accurately forecasting workforce needs and related educational demands will not be easy. But this step needs to be taken. Education and training in nanoscale science and engineering are resource-intensive. The health of an industry depends on worker supply, and demand cannot be sustained without balancing the two.

Workshop participants identified several specific opportunities and actions that are worthy of consideration by Federal, regional, and state agencies and by the private sector:

- **In elementary and secondary education, it is critical to identify and exploit linkages to existing standards wherever possible.** The community must explore how well it can integrate nanotechnology-based education units or modules into current state standards. A systematic examination of all national and state science standards should be undertaken prior to their next periodic revision to ensure that they are compatible with new knowledge and best practices in nanotechnology education. Given the long time delay before changes in voluntary national standards trickle down through individual state standards to textbook publishers and curriculum developers, this effort should start now. The recent adoption of standards in math and English by 43 states is a model that should be emulated in science and technology.

- **Educators and administrators must address the fear, and real danger, that these educational efforts may be introducing yet another subject and dropping it on the already overburdened shoulders of K–12 students**. This need not be the case. The historic separation of the teaching of mathematics and science forces much duplication and creates undue hardship for those not gifted in math. Creative thinking and problem-solving have been left out. Nanoscience, transcending many boundaries, can bring together disciplines and scales. Science can be taught top-down, starting from the scale of a real system students know and understand, then repeatedly dissecting it into parts down to the nanoscale. Nanoscience concepts can provide the integrative force much needed in the teaching of STEM subjects. As amply demonstrated by the work done at NCLT under the leadership of Dr. Robert Chang, nanotechnology provides an opportunity to rethink STEM teaching. Nanoscale science could be used to organize and reinforce a smaller, more rigorous set of STEM standards, as suggested in the report from the Carnegie Corporation of New York and the Institute for Advanced Studies, "The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy" (http://www.opportunityequation.org/) (7).
- **Replication of successful programs should be accelerated.** When the state of Oklahoma recognized a gap in its current offerings, personnel at relevant state agencies were already familiar with NSF-funded work in community-college-based nanotechnology education. It was easy to garner support for replicating features of the Penn State model such as leveraging of expensive infrastructure by creating additional sites to host students who want to learn to operate high-end equipment. In the Oklahoma adaptation of the Penn State model, students will not go to a remote site for a full semester, but instead will participate in weekend programs run by university partners.
- **Networking among various education efforts now underway must be promoted and more collaborations encouraged.** Existing partnerships should be enhanced while new partnerships are created. Existing similarities and synergies may be exploited in the development of additional regional consortia; for example, states that receive EPSCoR funding may be natural partners with each other. Partnerships and collaborations can help provide retail distribution for the best nanotechnology education ideas. Partnerships between research universities and smaller post-secondary institutions should become a generic part of the machinery for developing the nanotechnology workforce, rather than limiting the research university role to being a pipeline to fuel the research enterprise.
- **Educators should think broadly about ways to distribute nanotechnology educational materials,** because many students have limited access to informal science education programs. Exploiting retail channels may offer a solution, especially in the summer months. Outreach packages should include the use of games and television shows—not just funding of public broadcasting specials, but also placement of nanotechnology threads in commercial network television shows with technology components, such as "Numb3rs" or "CSI."
- **It is important to maximize the impact of information curated by individual websites.** While websites and portals are important, site creation and maintenance is labor-intensive. The community should promote cross-links from general-purpose nanotechnology sites like http://nano.gov/ to major nanotechnology education sites such as those maintained by NACK, NCN, NCLT, and NISE Net. Web tagging and other semantic web approaches will ultimately not only make it easier for nanotechnology-specific websites to collect and present educational information in the most palatable form for their specialized audiences, but also for generalized web portals and search engines (Google, Yahoo, Bing) to discover and serve up this information. Such leveraging of information collected and organized by experts minimizes redundancy in attempts at comprehensive data collection.
- **Educators must continue to engage industry in the development of curricula and the selection of topics for learning modules**. Industry-based

learning experiences, such as internships, should be utilized more extensively. Federal and state programs should be sought out to fund these experiences, along with funding by industry itself or by foundations.

- **The nanotechnology education community (and interested industrial or research partners) should begin to engage standardization, certification, and accreditation authorities to discuss validation of nanotechnology education programs and the development of metrics for comparability**. In the area of workforce education particularly, efforts should get underway to agree on common core skills relevant to nanotechnology as a general-purpose technology and to identify additional industry-specific skills relevant for subareas such as nanomaterials, nanobiotechnology, and nanoelectronics. Academic institutions and industries must work together to create and hone skill sets that define what industry expects of a nanotechnology workforce. The exit skill set developed by industry and NACK in June 2009 (see http://www.nano4me.org/industry.html#contenttop) is a good starting point, but it must be further validated. Industry and academic accreditation organizations have a key role in making sure Americans have access to a high-caliber nanotechnology workforce education. Program quality monitoring responsibilities need to be assumed by accreditation organizations. For example, the Accreditation Board for Engineering and Technology (ABET), which is involved with many of the two-year degree technology programs, must become active in establishing the faculty credentials and equipment resources required for nanotechnology workforce education.
- **Two-year institutions must assess the value of creating four semesters of entirely new courses for nanotechnology programs.** In particular, consideration must be given to (1) the cost in time and money of such an endeavor across the country, (2) the pressure to recover costs by maintaining high enrollments, (3) the roadblocks that will be created by the time and money investment required for setting up a full four semesters of new courses, (4) the loss of flexibility incurred by the imposition of four semesters of nanotechnology courses. Most importantly, (5) they must balance nanotechnology course development with existing courses, since nanoscience builds on and integrates material currently taught in other established programs. Community and technical college curricula should be structured to reflect these realities. Curricula and courses should also be structured to reflect the broad application range of nanotechnology.
- Some NNI agencies, academic institutions, and interested industries have provided a tremendous push to nanotechnology commercialization, creating sufficient thrust and a critical mass of educated workers to seed sustainable industries. **Now it is time for the states and the Federal agencies to capitalize on this momentum and take affirmative actions as recommended above to nurture these emerging industries**. By ignoring this, the United States may once again see itself fall behind on the global stage in the application of R&D in science and technology.
- **If science and technology is to add new value and create additional resources to meet global needs, all U.S. states and regions must identify appropriate investments in this new nanotechnology economy.** Just as history has shown with information technology, the risk of staying on the sidelines is much higher than any known or predicted risks of participating.

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4. Research and Development Infrastructure

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Introduction

What improvements or additions to the United States R&D infrastructure would catalyze nanotechnology innovation? Along these lines, the infrastructure breakout group asked what presently unavailable (or under-available) facilities, tools, or services are most urgently needed. Another issue was how to get there: what should be done in the immediate future to meet these needs, and by whom? These actions were discussed in the context of what Federal, regional, state, or local entities should do in terms of infrastructure development. Finally, an important component to these actionable items consists of the roles of government, academia, and industry, as developers and as users of infrastructure components.

Nanotechnology and particularly nanomanufacturing infrastructure is both physical and intellectual. It requires the interaction of four key components: (1) information, (2) tools and facilities, (3) know-how, and (4) roadmaps.

Information

Knowledge is critical to enabling product and manufacturing design. This will require better understanding of nanomanufacturing process-property relationships and the collection of nanomaterials properties with sufficient statistics and metadata. Experts and facilities are needed in combination with quality suppliers of materials and tools. The creation of standards of documentation, curation of data, and the ultimate federation of data and information are all needed.

Tools and Facilities

The tools and the facilities to enable commercial production should be scalable and have a high degree of automation. The need for standard reference materials cannot be underestimated; the development of new nanoinformatics tools will streamline the discovery, modeling, design, and evaluation of new materials and processes.

Know-How

To achieve high-quality manufacturing craftsmanship and ultimately spur innovation, students will need to be trained in nanomanufacturing science and engineering. The professional development of technicians and engineers will aid the success of the United States in this regard. Best practices for innovation and technology management should be a component of this training.

Roadmaps

Finally, roadmaps can help forge the path forward by pooling resources and expertise. This can happen through topical clusters, similar to those in the International Technology Roadmap for

Semiconductors (ITRS) model. These roadmaps communicate industry needs to academic and government scientists and are a good forum to create and reinforce a culture of sustainable nanomanufacturing. A corresponding forum for fundamental research infrastructure would be helpful for long-term planning.

This chapter begins with a background section on the Federal investment and resources, including partnerships with industry. The following section presents some case studies of international activities and some partnership models for success. Challenges facing the United States R&D infrastructure are then discussed, followed by conclusions and some near-term recommendations.

Federal Resources for R&D Infrastructure

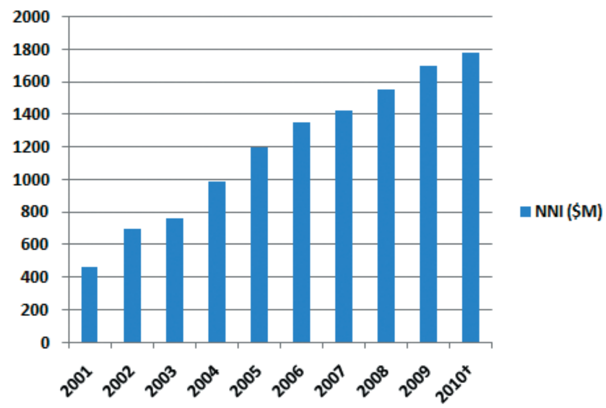
Federal Investment and Resources

The Federal investment in nanotechnology-related research and development has grown steadily (see Figure 4.1) since the inception of the NNI in fiscal year (FY) 2001. Budgeted contributions from thirteen (fifteen as of 2010) Federal agencies comprise the U.S. Government funding of nanotechnology R&D across eight NNI program component areas. The Federal agencies create a foundation to facilitate innovation and advance nanomanufacturing. They support R&D to create the technology base, with approximately 6,000 active projects across the Federal Government.

Table 4.1 shows estimated FY 2010 NNI investment by agency and program component area (PCA).

Table 4.1. Estimated 2010 Agency Investments by Program Component Area (*1*)
(dollars in millions)

	1. Fundamental Phenomena & Processes	2. Nanomaterials	3. Nanoscale Devices & Systems	4. Instrument Research, Metrology, & Standards	5. Nanomanufacturing	6. Major Research Facilities & Instrument Acquisition	7. Environment, Health, and Safety	8. Education & Societal Dimensions	NNI Total
DOE	103.0	114.5	17.2	21.8	7.0	106.3	2.6	0.5	372.9
NSF	152.6	78.7	43.7	18.3	22.4	37.8	29.8	34.3	417.7
HHS/NIH	48.0	75.9	180.7	18.0	2.2	14.0	17.3	4.6	360.6
DOD	138.8	75.3	148.0	5.9	37.2	28.0	3.1	0.0	436.4
DOC/NIST	22.3	8.4	22.5	19.1	27.2	11.2	3.6	0.0	114.4
EPA	0.2	0.2	0.2	0.0	0.0	0.0	17.1	0.0	17.7
HHS/ NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	9.5
NASA	0.0	8.6	5.1	0.0	0.0	0.0	0.0	0.0	13.7
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	7.3
DHS	0.0	6.5	4.9	0.0	0.3	0.0	0.0	0.0	11.7
USDA/ NIFA	1.0	2.0	5.7	0.0	0.2	0.0	1.0	0.5	10.4
USDA/FS	2.0	1.4	0.7	1.1	0.2	0.0	0.0	0.0	5.4
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2
DOT/ FHWA	0.0	2.0	1.2	0.0	0.0	0.0	0.0	0.0	3.2
DOJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	467.9	373.5	429.9	84.3	96.7	197.3	91.6	39.9	1781.1



† Estimated
Figure 4.1. NNI investments, 2001–2010 (*1*).

Illustrations of these NNI projects include nanomanufacturing projects at the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST), and the Department of Defense (DOD). As an example, the Microelectronics Advanced Research Corporation (MARCO) is a not-for-profit research management organization that funds and operates a number of microelectronics technology–oriented, university-based research centers. MARCO is subsidiary of the Semiconductor Research Corporation (SRC) and is funded 50/50 by industry and government. In its FY 2009 plan, MARCO allocated $1.17 million for fundamental research related to nanomanufacturing.

The Federal investment is substantial in terms of infrastructure for nanotechnology instrumentation, tools, and labs, with over 80 centers and networks across the United States. In addition to the user facilities listed below in Table 4.2, the NNI has funded many large research centers and networks that are not user facilities in a strict sense but are available for use in collaborative projects. A comprehensive list of facilities can be found on the NNI website http://nano.gov; additional resources on nanomanufacturing may be found at the National Nanomanufacturing Network InterNano website, http://www.internano.org/. In addition, there has been considerable Federal focus on nanomanufacturing issues, as indicated in the discussions at the 2006 interagency Workshop on Instrumentation, Metrology, and Standards for Nanomanufacturing (*2*). Table 4.2 lists user facilities with explicit agreements for both academic and industry-based users.

Measurements for accurate characterization of nanomaterials are infrastructural elements needed by manufacturing. To that end, it is the mission of NIST to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life. This mission is accomplished through direct collaboration with industry, government agencies, and universities. NIST has active programs in infrastructural nanotechnology and nanometrology in all of its technical laboratories. This is a consequence of NIST's continuing interest in pushing measurement technology to its limits. Researchers at NIST laboratories are developing the measurements, standards, data, and models that will provide the enabling infrastructure to facilitate the commercialization of nanotechnology. In addition, NIST's nanotechnology work is making possible new, quantum-based realizations of the fundamental

Table 4.2. User Facilities by Agency

Agency	Resource	Details
DOE	Nanoscale Science Research Centers (NSRCs)	Five centers are located across the country
NIH	Nanotechnology Characterization Lab (NCL)	Located in Frederick, MD, the NCL is a formal collaboration between the NIH's National Cancer Institute, FDA, and NIST.
NIST	Center for Nanoscale Science and Technology (CNST)	Located in Gaithersburg, MD, the NIST NanoFab at CNST is an advanced nano-fabrication facility available to outside users.
NSF	National Nanotechnology Infrastructure Network (NNIN)	A total of 14 sites as of March 2009 had an estimated 4,600 users in 2008, about 15% from industry.
NSF	Network for Computational Nanotechnology (NCN)	NCN's Internet resource, nanoHUB.org, had an estimated 90,000 users in 2008
NSF	National Nanomanufacturing Network (NNN)	A network of nanomanufacturing research and education facilities provides services in R&D, databases, and nano-informatics.

units of measurement (meter, kilogram, second, mole, degrees Kelvin, candela, ampere) in support of traceability for international metrology, and ultimately, international trade.

NIST has enhanced this mission with the development of the Center for Nanoscale Science and Technology (CNST; http://www.cnst.nist.gov). CNST consists of a research program and the NanoFab, which is a shared-use facility. The NanoFab is an advanced nanofabrication facility available to both NIST and external users that includes fabrication and characterization tools as well as access to specialized measurement tools. Other programs of relevance to nanomanufacturing can be found in NIST's Manufacturing Engineering Laboratory, Precision Engineering Division, and Manufacturing Metrology Division.

It is important to note that NIST welcomes external collaborations and works closely with other Federal agencies. Some of its collaborations are explained later in this chapter in the section entitled Government-University-Industry Partnership Models. Other NIST mechanisms for collaboration include guest researcher arrangements, cooperative research and development agreements (CRADAs),[1] and the Manufacturing Extension Partnership Program (http://www.mep.nist.gov).

NSF currently sponsors the National Nanofabrication Infrastructure Network (NNIN) and the National Computational Network (NCN) as infrastructure programs to support nanotechnology research. NNIN provides access to a wide range of distributed fabrication services at several university laboratories. As indicated in Table 4.2, usage of NNIN is apparently fairly extensive, especially by university researchers. NCN provides online access to computational and educational resources, including sophisticated modeling and simulation software. Both of these infrastructure programs are viewed as essential to supporting nanotechnology research. However, there remains a missing infrastructure element, a national nanotechnology design infrastructure to support the translation of nanotechnology research to functioning systems (*2*). While there are many potential new nanotechnology devices being developed, the electric design automation industry, as one example, is largely not cognizant of these devices and will be unable to support their rapid introduction into products. Without a mechanism for supporting the transfer of research into real products, there is a risk that even if the Nanoelectronics Research Initiative (NRI) is able to develop the next switch, U.S. industry may be unable to quickly integrate it into the design of superior products.

NSF also sponsors the National Nanomanufacturing Network, composed of four main research and education centers, and it partners with industry, states, other Federal agencies (i.e., DOD, NIST, and DOE), and international organizations.

DOE investment is significant in the planning, construction, and operation of five Nanoscale Science Research Centers (NSRCs) located at DOE laboratories. These operate as user facilities, with access based on submission of proposals that are reviewed by independent evaluation boards, and at no cost for nonproprietary work. The NSRCs support synthesis, processing, fabrication, and analysis at the nanoscale and are designed to be state-of-the-art user centers for interdisciplinary nanoscale research, serving as an integral part of DOE's comprehensive nanoscience program.

The National Cancer Institute of the National Institutes of Health has built a Nanotechnology Characterization Laboratory (NCL), which performs assessments of material physical and chemical properties and also evaluates material toxicology. NCL executes or plans to execute physical, *in vitro*, and *in vivo* characterization for detection, diagnostics, and therapeutic applications. The methods for handling these materials, many of which must be maintained at cryogenic temperatures during transport, and the specific modalities used for measurements, are important factors in obtaining valid and repeatable data. Characterization of materials for biological applications is an exacting and time-consuming process.

Federal funding for nanotechnology R&D also supports investments in environmental, health, and safety (EHS) research, which in part inform regulatory decisions. In September 2008, NSF and the U.S. Environmental Protection Agency (EPA) jointly announced the creation of two Centers for

1 Further information is available through the NIST Office of Technology Partnerships at http://patapsco.nist.gov/ts/220/external/index.htm

Environmental Implications of Nanotechnology, at the University of California Santa Barbara and Duke University. EHS work was planned to approach $117 million in the proposed FY 2011 NNI budget.

Federal Government-Industry Partnerships

To advance nanomanufacturing and facilitate innovation, Federal interactions with industry and states are also critical. Federal funding collaborations with industrial partners is one mechanism for interaction with industry; the following are examples:

- Small-Business Innovation Research (SBIR) and Small-Business Technology Transfer (STTR) programs across all agencies (e.g., see http://www.nsf.gov/eng/iip/sbir/)
- Cooperative Research and Development Agreements (CRADAs) at DOE and other agencies (e.g., see http://www1.eere.energy.gov/industry/financial/crada.html)
- Technology Innovation Program (TIP) at NIST (see http://www.nist.gov/tip/)
- Grant Opportunities for Academic Liaison with Industry (GOALI) and Industry/University Cooperative Research Centers (IUCRC) at NSF (see http://www.nsf.gov/pubs/2009/nsf09516/nsf09516.htm and http://www.nsf.gov/eng/iip/iucrc)
- Industry-led Nanoelectronics Research Initiatives at NSF and NIST (see http://nri.src.org/)

Furthermore, partnerships with industry groups are an important mechanism of interaction. As an example,various industries have initiated Consultative Boards for the Advancement of Nanotechnology (CBANs) to work with the NNI in several key technology sectors. These liaison groups establish a connection between the NNI agencies and industry groups (see Figure 4.2).

Currently, CBANs exist within the electronics, forestry and paper products, and chemical industries, as well as within the industry research management community. The regulatory measures and services provided by Federal agencies serve to guide and advance nanotechnology research as it relates to products and services.

Case Studies

International Models

There are several types of models that are employed to promote nanotechnology research and commercialization. Some nations are investing heavily to facilitate applied research and its transfer/translation to commercial products. For example, in Singapore in 2007, approximately S$6.3 billion

Figure 4.2. CBANs have helped the NNI establish partnerships with industry in key technology sectors.

(≈US$4.5 billion) was invested by the government in the creation of the Biopolis and Fusionopolis facilities to house research institutes whose programs support research leading to commercialization, making Singapore one of the highest-ranked countries in per-capita R&D expenditures. Likewise, the DuBiotech program in Dubai, United Arab Emirates, is designed to support late-stage development and commercialization.

Many European Union programs support joint university-industry research to expedite transfer of research results to practice. Also in Europe, government organizations such as the French Atomic Energy Commission (CEA) and its Electronics and Information Technology Laboratory (LETI) perform research that is closely related to industrial practice. In terms of "survival capacity," the EU model appears to be successfully building a framework to eliminate the "valley of death" between commercial startup and profit-generation while building the capacities to apply assets to clearly communicated EU priorities. The UK, French, and Dutch models, along with the EU model, are successfully supporting regional and intra-regional collaborations.

Government-University-Industry Partnership Models

An example of a government-university-industry research model that differs from the traditional university research model is the partnership fostered by the state of New York at the State University of New York at Albany. This model involves both industry and the state government, which decided it would be in the state's best interest to seed funding at the university.

Another example of this model is the Nanoelectronics Research Initiative (NRI; http://nri.src.org/), a consortium of companies in the Semiconductor Industry Association. The goal of the NRI is to use nanotechnology to improve upon current semiconductor capabilities and maintain economic competitiveness in the semiconductor field. As of 2008, semiconductors were the second largest U.S. export, with the United States holding a 48% share of the nearly $2.5 billion world market. Both NSF (in 2004) and NIST (in 2007) have joined the NRI, creating a public-private partnership that drives university nanoelectronics research and infrastructure by leveraging funds from industry, universities, and both state and Federal governments. Figure 4.3 outlines the Semiconductor Research Corporation's collaborative programs.

Research Park Models

The research park model is widely employed by many universities and usually offers physical sites to host industry R&D programs that are located in close proximity to university campuses. For example, both SouthWest NanoTechnologies (SWeNT) and Charlesson LLC have benefited from a research park model in Oklahoma. The research park model may place occupancy constraints on startup companies, usually related to time required for profitability.

Challenges for RSL Initiatives

The success of the National Nanotechnology Initiative hinges on its ability to positively affect the well-being of U.S. citizens through improved and affordable health care, the creation of well-paying jobs in industry, and so on. Arguably, the NNI has laid the cornerstone by creating an array of research activities whose general excellence and broad scope is second to none. Moreover, there are creditable indicators that the NNI investments are beginning to pay dividends in the marketplace. However, session participants asked, "Are there actions that might be taken to expedite and fuel the growth of social and business applications on the foundations being laid by the NNI?"

Some participants expressed the view that the existing array of high-quality fundamental research should be conducted concurrently with engineering pathfinding research that has specific goals. The Nanoelectronics Research Initiative (described above) is an excellent example of such a program. This public-private partnership seeks to define the next switch that will enable continued Moore's Law[2] benefits for information technologies when the current Complimentary Metal-Oxide Semiconductor (CMOS) switch reaches its physical scaling limits. The NRI utilizes NNI infrastructure as an integral

2 "Moore's Law" refers to the historical trend in which the processing power of microprocessors, or in this case semiconductors, doubles approximately every 18–24 months (Merriam-Webster Online Dictionary, http://www.merriam-webster.com/dictionary/moore's%20law).

Semiconductor Research Corporation: Collaboratively Sponsored University Research

The Semiconductor Industry Association members have recognized that collaboration among industry, government, and academia is the most efficient means of advancing university research capabilities (3). Strong university research is critical to maintaining technology innovation. Research at universities can probe new concepts and come up with breakthrough ideas and solutions to problems for which no known solutions currently exist. The Semiconductor Research Corporation (SRC) has been established to facilitate collaboratively sponsored university research, managing a full spectrum of research related to CMOS-and-beyond technologies. In 2005, the SRC was awarded the National Medal of Technology.

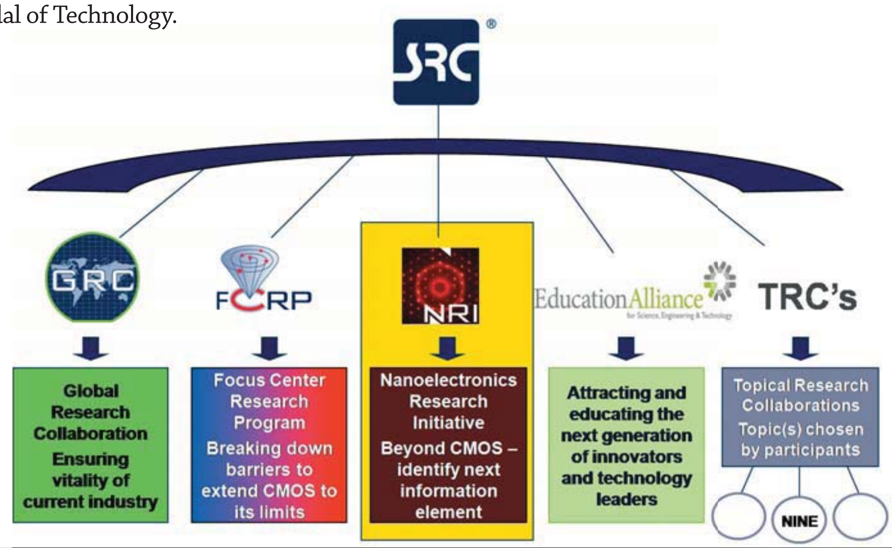


Figure 4.3. Semiconductor Research Corporation's collaborations and structure (3)

and essential part of its programs. If a breakthrough is achieved, the industry partners in the NRI will be better-positioned to take advantage of the result to obtain a competitive advantage worldwide. This suggests it might be possible to create similar programs for other industry sectors that would be focused on transitioning NNI research to practice.

The NRI originated with the semiconductor industry as a result of its work on the International Technology Roadmap for Semiconductors (ITRS), which provides a fifteen-year view of needed technologies. Workshop participants suggested that perhaps NSF and other interested government agencies could identify industry sectors where roadmaps exist and use these as a basis for encouraging other industry initiatives similar to the NRI.

One of the challenges in moving ideas from the research laboratory to commercialization is that research tools that work quite well in the laboratory often do not scale-up well to volume production. As markets become better defined, it may be desirable to form consortia like SEMATECH (a semiconductor manufacturing technology nonprofit consortium) to guide the development of manufacturing-worthy tools in several industry sectors. The National Cancer Institute is cognizant of this challenge and has instituted a developmental therapeutic program to help companies scale up to produce larger volumes of materials. Could this idea be applied across a broader range of disciplines?

Historically, strong support for metrology research at the nanoscale has come from specific industries or consortia (such as the SRC or SEMATECH); such support also led to the ITRS. Nanotechnology spans across and is represented in a variety of industries. If nanotechnological commonalities and focus could be derived, a consortium-type organization (or organizations), initially co-funded by government and industry, could make huge strides in needed instrumentation and metrology and act as the focal point for roadmaps. Participating Federal agencies[3]

3 For example, the Department of Commerce, Department of Defense, Department of Energy, National Science Foundation, National Institutes of Health, and/or the Department of Agriculture.

Figure 4.4. Dr. Mike Postek of NIST speaking at the workshop.

could then map their program areas to align with the diverse potential nanotechnology application areas to accomplish targets set by the roadmaps. Consideration should be given to developing a national (or international) roadmap for precompetitive nanotechnology topics, similar to the current ITRS for semiconductors. Such a roadmap for nanotechnology-enabling instrumentation and metrology would not only guide technology development but also guide instrument manufacturers to provide the needed tools with reasonable lead time. Instrument development associated with the semiconductor manufacturing industry has been an evolutionary process fueled by the defined needs of the ITRS and funded by the established semiconductor industry. The emerging nanomanufacturing industry does not have sufficiently deep pockets (especially in this economy) to fund similar high-risk development, and this creates a significant funding gap leading to an impending technology gap. A significant challenge is identifying and establishing funding sources for the high-risk development of diverse and needed instrumentation, some of which may need to be revolutionary.

As noted earlier, the research infrastructure already created by the NNI is quite extensive, including over 80 research centers and networks supported by NSF, five research facilities at DOE Laboratories (Sandia/Los Alamos, Brookhaven, Argonne, Lawrence Berkeley, and Oak Ridge), the Nanotechnology Characterization Laboratory of NIH, the NIST CNST NanoFab, and many DOD laboratories. In the FY 2010 NNI research plan, over $280 million was allocated for research on instrumentation, metrology, and standards ($84.3 million), combined with funds for new major research facilities and acquisition of instrumentation ($197.3 million). It seems clear that NNI agencies are intent on providing the needed infrastructure for nanotechnology research (*1*).

NIST, as an agency of the Department of Commerce, is quite open to collaboration with both university and industry researchers. The DOE Office of Science user facilities (e.g., nanoscale science research centers, X-ray and neutron scattering sources, microscopy centers) actively encourage collaboration with both university and industry researchers, providing access on a competitive, peer-reviewed basis at no charge for nonproprietary use. In addition, interaction has benefited from the advent of university-DOE laboratory programs such as the National Institute for Nano Engineering at Sandia National Laboratories, where university research and access to Sandia facilities is co-sponsored by an alliance of industry and DOE. Workshop participants recognized the DOE laboratories and facilities for the quality of their laboratory resources and scientific personnel, although some of them commented that historically it has been more difficult to engage the DOE labs in programs with industry. Continued efforts to expand access to facilities and expertise at all national laboratories is desirable from the standpoint of increasing NNI impact on universities and industry.

Concluding Remarks and Ideas for the Future

Workshop participants observed that development of standards, which are very important in commercialization, usually do not involve university researchers on whose work these standards depend. This is certainly a consequence of academic incentives practices for faculty but is likely an impediment to commercialization. It is unlikely that the long-accepted faculty merit system based on research productivity and teaching will soon change.

In the current economic environment, successive rounds of venture capital funding for nanotechnology startups are increasingly difficult to obtain. Thus, new companies often find it difficult to sustain themselves across the sometimes lengthy period of time needed to bring basic research to a viable product. This suggests a need for some sort of incubation system where fledging companies obtain access to instrumentation and processing facilities, administrative support, etc., to enable them to be much closer to a product before seeking external funding. The NIST TIP program or the NSF SBIR program might be able to prototype such an incubation program by partnering with state governments.

It was noted that there are many U.S. materials characterization facilities, and many of them appear to be underutilized. There is also a desperate need for an accessible national materials database that has a standard and widely accepted schema supported by a rigorous gate-keeping function. There is a database activity underway that has been initiated by the National Nanomanufacturing Network that might serve as a starting point for such a national materials database. One should not underestimate the magnitude of this undertaking; national leadership and investment is required to make it a reality.

The development of a national materials database requires the creation of an accurate measurement infrastructure. Size matters where nanotechnology is concerned: knowing dimension with a known uncertainty is primary to understanding the function of nanomaterials. Whether or not a new material property is being exhibited at 5 nm or 6 nm is a question that needs an accurate answer. In addition, many of the databases currently under development are incorporating data from multiple sources.

Are these sources accurate in generating these data? Nanomaterial database development relies on the quality and consistency of the data submitted. To describe the properties of a nanomaterial, accurate measurement infrastructure must be developed and adopted so that these data are valid and useful. Data being generated for programs such as the Nano Risk Framework (DuPont & Environmental Defense Fund) or the EPA Nanoscale Materials Stewardship Program needs to be accurate so decisions regarding the suitability of these materials for use in a commercial product or as a component of a commercial product are made on a strong scientific basis. The instruments used to make these measurements must function at their best performance level and must be properly calibrated. In a NIST study of scanning electron microscope calibration, the error in the calibration ranged from 10% to 60%. When that work was done, the useful instrument performance range was about 100,000x maximum magnification. Today, instruments can perform at more than 10 times that magnification range with higher resolution; even a 10% error in the magnification of these instruments yields an error larger than the entire performance range of the earlier microscopes.

Opportunities

1. Joint industry-university alliances to co-engineer fundamental research results with specific, singular goals, similar to the NRI, would expedite the transfer of NNI research into industry practice. Perhaps an NNI survey of industry roadmaps followed by meetings with key industry executives in sectors with roadmaps could result in the formation of public-private partnerships for pathfinding research.
2. A clearinghouse that identifies laboratory capabilities, provides contacts, and defines how one obtains access to these resources would be of significant value. There is a considerable NNI investment in critical research infrastructure, but the rules of engagement with this infrastructure are not uniformly well developed or disseminated in a consistent format.
3. A national nanomaterials database would be of tremendous value to researchers and to companies planning use of the materials in their processes and products. Such an undertaking is akin to the Genome Project and would require patient funding and the engagement of all stakeholders.

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5. Economic Development and Commercialization

Moderators: Mike Moradi, Charlesson LLC
Jim Von Ehr, Zyvex Labs
Alan Brown, Pennsylvania NanoMaterials Commercialization Center

Introduction

Two main questions were raised in the breakout session on economic development and commercialization:

1. What is needed to catalyze the successful economic development and commercialization of new nanotechnologies (e.g., physical infrastructure/facilities & tools, intellectual infrastructure and/or service offerings, and innovation models)?
2. What has to be done in the immediate future to foster and meet these needs, and at what level (Federal, regional, state, and local)?

Successful commercialization of nanotechnology requires crossing the aptly-named "valley of death," which is a colloquial term used to describe the precarious period of time after a startup company receives initial funding but before it begins to generate profits (see Figure 5.1). The valley of death is particularly difficult to traverse for high-technology and emerging technology development, as it requires

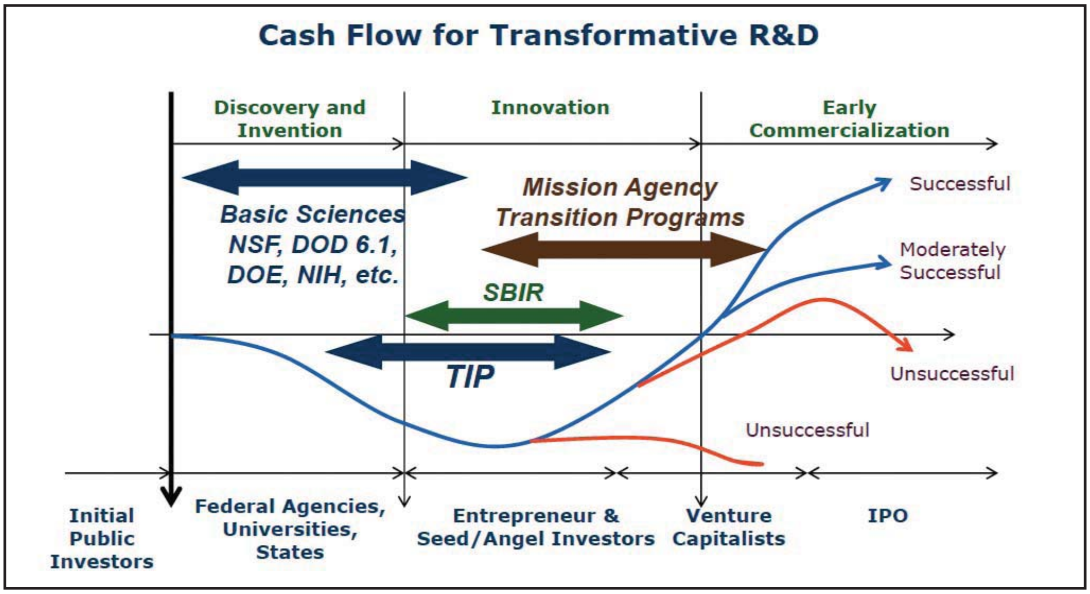

Figure 5.1. Science and technology funding transition, from Marc Stanley's workshop presentation. Note the "valley" in the development timeline and its closely associated failure lines.

a labor- and cost-intensive R&D phase in order to deliver a product to market, causing many startups to fail due to lack of funding during this period.

The scope of this chapter is to discuss state and regional initiatives in the context of development of nanotechnology-related businesses.

Catalyzing Innovation for Nanotechnology

The group identified the following major requirements to stimulate innovation for nanotechnology:

- Resources that are commensurate with the challenge:
    - **Talent** – an educated and motivated workforce with diverse skills and interests
    - **Investment** – resources for invention and innovation
    - **Infrastructure** – physical environments to support innovation and business conditions that encourage risk-taking and collaborative endeavors
    - **Public-private partnerships** that engage all tiers of the innovation ecosystem
- Local, state, and Federal cooperation and collaboration
- Collaboration with foundations, consortia, and philanthropists
- Corporations, venture capitalists, angels, investors
- Strategies that adjust to the realities and opportunities of the day:
    - Master the practice of clusters, networks, and open innovation
    - Capture talent and resources in social entrepreneurship and innovation
- Institutional policies and cultures that consistently reward invention, innovation, and competitiveness

Fostering Innovation

The private sector and government both benefit from the creation of new businesses. The private sector has a chance to create private or institutional wealth by choosing winners (or reallocating that wealth to others if they pick losers), and the government sector has a chance to foster creation of good jobs, overall well-being in society, and of course, more well-off taxpayers. Table 5.1 shows the industrial partnerships and overall impact of three National Science Foundation (NSF) projects that promote public-private partnerships to foster innovation: the Nanoscale Science and Engineering Centers (NSECs), the Network for Computational Nanotechnology (NCN), and the National Nanotechnology Infrastructure Network (NNIN).

Innovation is the key to true wealth creation, to making more valuable products with less input of material and labor. True wealth creation advances humanity. One hundred years ago, society saw beach sand as just sand. Fifty years ago, sand was seen as a valuable component of the concrete used to build the interstate highway system, which multiplied the value of the automobile industry and knit our

Table 5.1. Industrial Impact of NSF's NSECs, NCN, and NNIN
(based on a December 2008 survey)

Institution	Number of Startups	Industrial Partnerships		Support from Other Organizations
		Number of Partners	Industrial Support ($ million)	Total Support ($ million)
NSECs	37	392	41.9	279.4
NCN	0	403	2.0	11.3
NNIN	38	358	86.0	300.0
Total	75	1,153	129.9	590.8

*The 10 Richest US Cities	The 10 Poorest US Cities
Arlington, VA	Brownsville, TX
Thousand Oaks, CA	Flint, MI
Naperville, IL	Syracuse, NY
Alexandria, VA	Rochester, NY
Stamford, CT	Dayton, OH
Irvine, CA	Cleveland, OH
San Francisco, CA	Detroit, MI
Scottsdale, AZ	Buffalo, NY
Huntington Beach, CA	Erie, PA
Sunnyvale, CA	Waco, TX
Semiconductor, software, and biotech	"Industrial" manufacturing

*by average income

Compiled by Skip Rung of ONAMI

Figure 5.1. A comparison of the richest and poorest cities in the United States in 2008, with their corresponding primary industries.

country together. Today, we see it as a raw material for computer chips and fiberoptic cables that have led us into the computer age and then the Internet age, and created immense wealth in both physical infrastructure and intangible intellectual property.

As Figure 5.1 demonstrates, the most successful cities in the United States have been able to effectively harness innovative technologies and incorporate them as an integral part of their growing economies. Conversely, formerly successful cities that have continued to rely on older, traditional manufacturing economies are now among the poorest metropolitan areas in the country.

Small businesses are well known for creating more jobs and innovation per unit of input than big business does. Fostering the growth of small business therefore can be beneficial to both the private sector and government. Yet the process of starting a successful business has become harder over the last decade. Some governments, including a few countries and numerous states, have recognized this and are trying to help startups make it through the difficult period between initial invention and successful commercialization. Others are saying the right words while, in the view of some workshop participants, doing the wrong things.

Historically, the growth of business was fostered by wisely managed capital, coupled with reasonable regulation, rationally applied by government under a "rule of law" approach to governance. That predictability in capital and regulation created a benign environment for business that left it to the entrepreneur to do the right things to be successful. Today however, we have impatient or uninterested capital and unpredictable or even capricious governmental regulation. Business must also attempt to cope with the rise of influential but unaccountable nongovernmental organizations (NGOs), some of which at times have been hostile to profit-making corporations. Some workshop participants expressed the view that a business that spends half its resources complying with outside directives will see growth constrained by half, converting an otherwise high-growth business into an ordinary business and handing opportunity to other regions without those growth-killing regulations.

A new challenge to nanotechnology companies is the escalating role played by nongovernmental organizations. These organizations ask that societal implications be addressed and create uncertainty for nanotechnology-related companies and investors. Citing the "precautionary principle" as a guide, some NGOs recommend banning anything that has not been proven safe. If applied to existing materials, this approach would immediately ban most materials in use today, pending years of testing to prove lack of harm under any imaginable usage scenario. While sensitizing companies to the potential harm of new materials is certainly valuable, outright bans on emerging technologies would be destructive to the innovation behind the productivity gains that create societal wealth.

Research showing problems with nanomaterials, even if methodologically unsound, gets immense publicity, while studies showing no problems are usually ignored, if they even get published. This bias towards negative news does not seem to have significantly affected the public yet, although it has potential to influence policymakers to require a higher standard of testing that could transform the business of materials into one more like the drug business, where approval of a new compound can cost over $500 million and require ten years of testing. This would destroy most small nanomaterials companies. Europe appears to be going down this path,[1] while some workshop participants expressed the view that a more growth-oriented country might choose a more thoughtful approach to regulation of new things.

New nanotechnology-related businesses share the critical challenges of all startups:

- *Intrinsic*: funding, staffing, management, product development, and sales
- *Extrinsic*: competition, general economic climate, government regulation, and taxation

Nanotechnology businesses have additional complexities in materials preparation, characterization, utilization, and regulatory treatment. Coupled with few visible exits for investors, the headwinds against successful nanotechnology-related startups are extremely challenging.

How should a new nanotechnology-related business help itself to be successful in today's business environment? How can state and regional initiatives help foster the innovative businesses that will form the core of their next-generation industries?

Capital is critical for business formation. Customary funding options include self-funding, friends and family, angels (individual investors), venture capital (VC), private equity (PE), and government. A startup today is much less likely to receive initial VC funding than in the recent past, making the other sources of capital vital. Active investors encourage companies launched from universities to stay in the university setting longer, using government grants to move the product development further along before spinning off. "Bootstrapping" (using less initial capital) is back in favor; this term describes developing a product with very little upfront money and getting it to market as soon as possible, then growing on the reinvested profits at whatever rate those profits can justify. Figure 5.2 illustrates the rate at which nanotechnology-related products and applications are expected to be developed and to enter the marketplace, according to Lux Research.

Angel investors have historically been a source of early funding, but most sophisticated angels have learned to avoid companies that later take VC money, since the VCs often restructure the company in ways that harm the angels. Furthermore, unsophisticated angels often demand terms such as antidilution clauses that can make the company toxic to later

1 For example, Europe has banned lead in solder, based on the theory that this lead in consumer electronics pollutes landfills. This ban led to a replacement by unproven materials that have been demonstrated to be less reliable due to shorts caused by tin nanowhiskers that grow in solder without lead, potentially leading to early failures in life-critical electronics systems. Ironically, other regulation requires manufacturers to take back such electronics components and dispose of them in an environmentally controlled manner. REACH regulations (EU regulatory framework for Registration, Evaluation, Authorization, and Restrictions of Chemicals) may cause all existing materials to be subject to lengthy and expensive tests for safety.

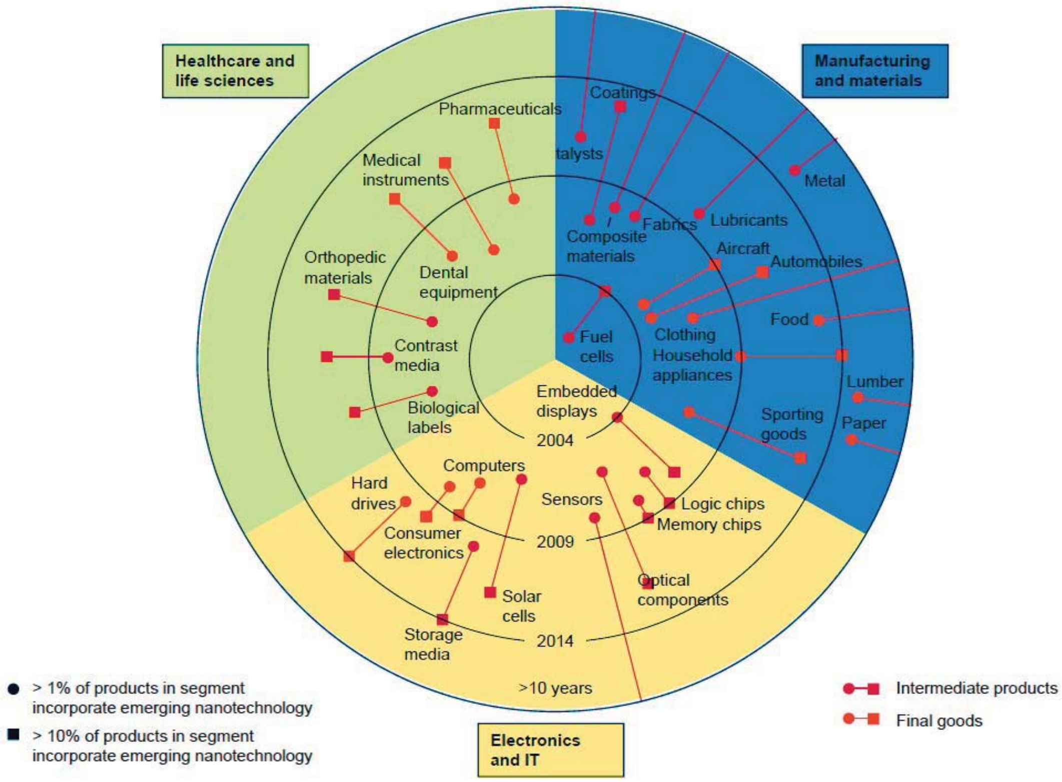

Figure 5.2. Anticipated rates of selected nanomaterials moving into the marketplace (courtesy of Lux Research).

investors. Nonetheless, angel funding remains an important source for startups.

Conventional VC funding has largely shifted from startups to later-stage deals, with larger investments made in fewer, later-stage companies. The VC industry itself is in a critical state, and overall VC returns to investors are reported to be negative since 2000, leading to shrinkage of the VC industry that is likely to continue for years. VC investors need to get a return on their investment within a short time compared to the growth cycle of a new company. With the Initial Public Offering (IPO) window effectively closed (some say partially due to Sarbanes-Oxley rules, which can cost a small public company upwards of $3 million per year in compliance costs), the opportunity for exiting via IPO is diminished. Sales to other companies or PE groups are more likely exit vehicles, but with a significantly reduced upside, because such investors are rarely as exuberant as buyers of a new IPO.

In spite of less capital being available to start a business, less chance of a spectacular liquidity event, and more friction during the critical launch phase, industry representatives still believe in the potential of nanotechnology to improve lives and create viable businesses. Business has to do its part, getting profitable by bootstrapping, but success requires that government be a good partner by fostering a stable regulatory regime under which businesses can operate.

State governments are increasingly trying to fill in for the private sector in providing early-stage funding assistance to companies. Some agencies can fund companies through programs such as the SBIR/STTR programs, but apart from these and research grants, and some Department of Defense and National Institutes of Health programs, the Federal Government does not have standardized, Government-wide funding programs to help private companies.

Case Studies for Commercialization

Focus on States

State-sponsored nanotechnology initiatives have had notable success as vehicles for commercialization. State-based initiatives are examined in case studies in Chapter 2, Models for Regional, State, Local, and

NSEC at Northwestern University: From Laboratory to the Market

Rapid commercialization of new technologies helps to ensure that key discoveries have an immediate impact. In 2000, the NSF-funded Nanoscale Science & Engineering Center (NSEC) at Northwestern University (NU) teamed with Northwestern's Kellogg School of Management to launch the Small Business Evaluation and Entrepreneurs (SBEE) program.

The idea was to give researchers opportunities to present their technologies to second-year MBA students at the Kellogg School. Students would thus gain valuable knowledge about cutting-edge nanotechnologies and also gain opportunities to work with real-world rather than theoretical test cases. Participating professors would provide assistance developing viable business plans for startup companies to present to investors.

The SBEE program has been a resounding success: 14 startup companies have been launched since 2001 based upon technologies developed at the NU NSEC, and the program has been emulated across the country.

The test case for this innovative program was a company called Nanosphere, Inc. Nanosphere was founded in the year 2000 by Dr. Chad Mirkin and Dr. Robert Letsinger, based on discoveries out of their laboratories. Among other achievements, these discoveries made possible the consistent manufacturing and functionalization of gold nanoparticles with oligonucleotides (DNA or RNA), or with antibodies that can be used in diagnostic applications to detect nucleic acid or protein targets, respectively. In October 2003, Nanosphere acquired breakthrough nanoparticle detection technology for protein biomarkers (invented by Mirkin and collaborators through the NU NSEC). This technology, when combined with Nanosphere's proprietary nanoparticle-based detection systems for DNA, positioned the company to broadly influence the fields of molecular diagnostics, genomics, and proteomics.

Since its founding, Nanosphere has made continuous enhancements to the original technology advances by coupling the gold nanoparticle chemistry and capabilities with multiplex array analysis, microfluidics, and human factors instrument engineering and software development to produce a full-solution diagnostics workstation, the Verigene® System. Designed for testing anywhere, anytime, the Verigene® System enables broader market adoption of complex tests for human inherited disease and infectious diseases, pharmacogenetic tests to support appropriate therapy decisions, and ultrasensitive protein assays for earlier detection of diseases ranging from cancer to cardiovascular disease.

The company is now a fully-integrated, healthcare company with established Current Good Manufacturing Practice (cGMP) certification, leading-edge research and development teams, and veteran customer service and support teams. Nanosphere has approximately 115 employees and is rapidly growing. As of the date of the RSL workshop, the company had licensed or acquired 44 U.S. patents (and foreign equivalents) from Northwestern University. It was valued at $164.5 million.

State initiatives vary widely in their thrusts, but typically all share common factors of targeting job creation, a focus on certain classes of industry, a competitive review process, and strict administrative requirements in terms of paperwork, mandates, and reporting. Many initiatives require university partnerships, which can help universities truly wanting to commercialize their research, but that requirement can also hinder companies partnering with universities that are only seeking increased funding and that might then spend endless months arguing over intellectual property.

International Partnerships. For the purposes of this chapter, a brief overview of two primary types of state models is provided.

The state government investment model entails significant state funds being invested in facilities, staff, and equipment for economic development reasons, i.e., to grow research, develop workforce, attract more "high-tech" industry, and attract investment in new companies. Typically, there is already a significant "nano" industry presence in such cases, e.g., in New York and Oregon.

The state government organization model includes having a paid staff, government buy-in, and support with dollars tied to state agency (public) and private partnership (e.g., state chambers of commerce). It also includes involvement of and with educational and workforce training at all levels. A successful example of this model is the Oklahoma Nanotechnology Initiative. See Chapter 2 for detailed information on the aforementioned state models and on the specific state initiatives that exemplify successful paths to commercialization through state-based programs.

Clever Models from Life Sciences

It can sometimes be helpful to look at other industries for examples of success. Looking at the life sciences field provides a number of possible models. The Massachusetts Life Science Institute (LSI) was funded at $1 billion for 10 years and created five interdisciplinary research clusters, in addition to increasing workforce and capital. On the other coast, the San Jose BioCenter provides an office and a wet lab for startups. The cluster has grown 28% per year since 2002.

Nanodistricts

A recent study from Philip Shapira and Jan Youtie and colleagues (*1*) investigated the emergence of nanodistricts across the United States (Figure 5.3). These are regional clusters of institutes and companies with a focus on nanotechnology. Their analysis shows that the 30 investigated nanodistricts have a mix of two different scenarios. In the first scenario, nanodistricts form in locations that have established expertise in high-technology areas (i.e.,

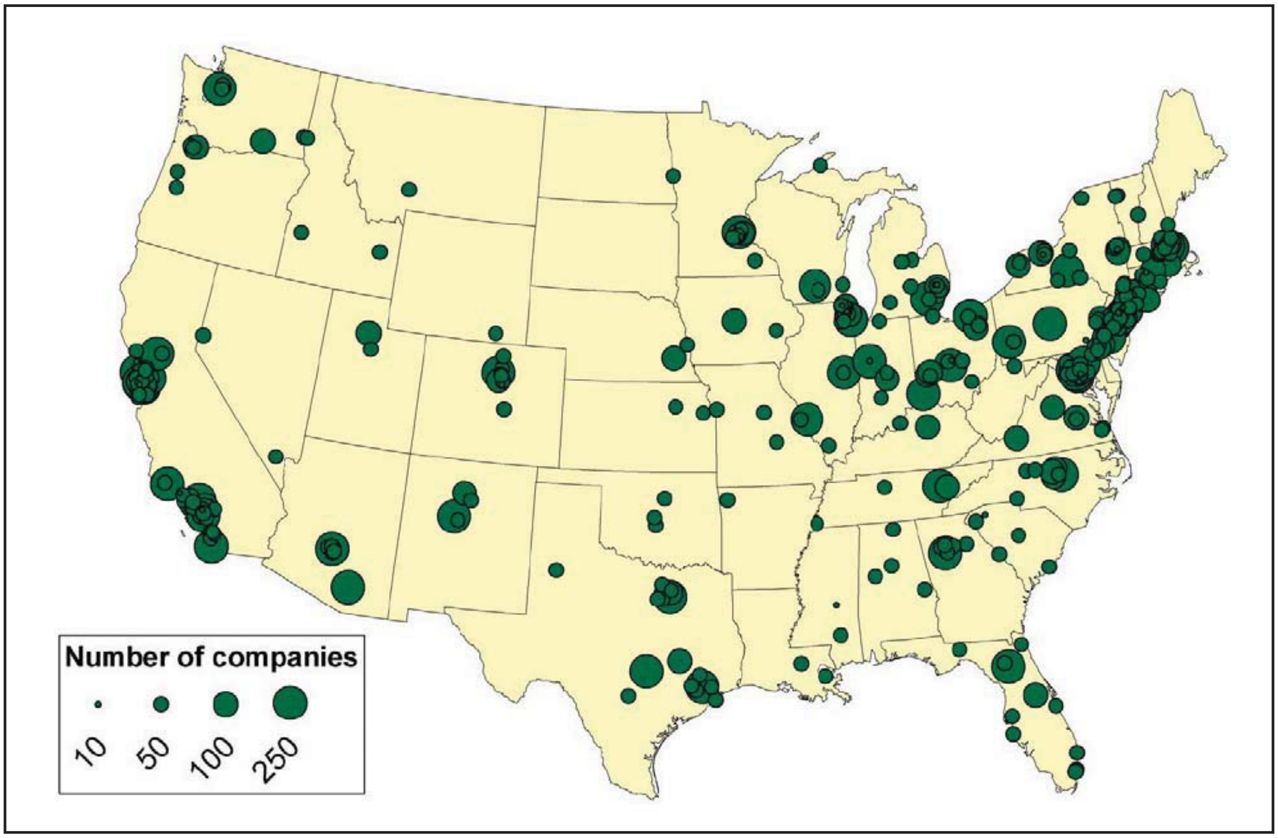

Figure 5.3. Corporate entry into nanotechnology by city: Number of establishments with nanotechnology publications or patents for cities with 10 or more nanotech establishments (courtesy Philip Shapira, Jan Youtie, and Luciano Kay; based on Georgia Tech global database of nanotechnology publications and patents; from the report, *Nanotechnology Long-Term Impacts and Research Directions: 2000–2020* [Baltimore, MD: WTEC, Inc., 2010]).

biotechnology). In the second scenario, nanodistricts get started in new locations without a historical base in high technology; however, the emerging new locations generally have formed around an existing government laboratory or university.

Where Are They Now? Startups Profiled in 2003 NNI RSL Report

Nanotechnologies, Inc. (Austin, TX) – Now NovaCentrix

NovaCentrix was established in 1999 as Nanotechnologies, Inc., by University of Texas at Austin professor Dennis Wilson. The company has developed technologies to produce nanoparticle powders and dispersions. In 2006 its name was changed to NovaCentrix, reflecting a new focus on markets such as solar power and printed electronics. Today, NovaCentrix ships processing tools and conductive inks and works with clients to perfect technologies and processes for printed electronics manufacturing. Though the company still maintains its capacity to produce various types of nanoparticles, the company has moved away from supplying "raw materials" and more toward application codevelopment with its customers. The company has successfully raised an estimated $30 million in four venture capital rounds from Air Products & Chemicals (NYSE:APD), Techxas Ventures, Convergent, Capital Conceptions, Harris & Harris Group (NASDAQ-NM:TINY), Castletop Capital, and others.

Luna Innovations (Roanoke, VA)

Luna Innovations was founded in Blacksburg, Virginia, as a spinoff from Virginia Tech. The company developed a portfolio in nanomaterials, initially for biomedical imaging applications. Luna has successfully sold two of its subsidiaries to other companies. Luna Energy developed pipeline monitoring sensors for oil and gas applications and was acquired by Baker Hughes, an oilfield services firm. Luna i-Monitoring was a developer of integrated wireless sensors for remote monitoring in the oil and gas industry, and was acquired by IHS Energy.

The company generated nearly $37 million in revenue in 2008, $10 million of which was from product sales and licensing. Luna is publicly traded on the NASDAQ exchange (LUNA). Luna filed for Chapter 11 bankruptcy in July of 2009 in response to a potentially negative litigation outcome in a case unrelated to nanotechnology. The company subsequently emerged from bankruptcy in January 2010.

Quantum Dot Corporation (Hayward, CA)

In 1998, Quantum Dot Corporation (QDC) was formed to develop and market quantum dots for biomolecular detection. The company raised approximately $40 million from top-tier venture capital and private equity funds, including Abingworth Management, CMEA Ventures, Frazier & Co., Institutional Venture Partners, MPM Capital, SV Life Sciences, and others. Markets for the company's products did not develop as quickly as anticipated, and the company was acquired by Invitrogen (NASDAQ:IVGN) in October of 2005 to support its molecular probes business.

Large-Company Perspective on Commercializing Nanotechnology

Large companies in many industries have downsized or eliminated their large, internally funded R&D organizations, which formerly developed their ideas, technology, and new products. However, there remains a pressing need to continue innovation to grow sales and market share on a competitive global scale. Depending on the industry sector, large companies have developed varying strategies to replace these R&D centers and continue feeding their new product pipelines. One model is the "open innovation model," where companies have well-developed processes for searching for external partnerships around the world for new ideas, technologies, and solutions for their new product needs. Proctor and Gamble has successfully implemented this model. Outcomes from the open innovation model are licensing of new technologies and intellectual property content, joint development agreements, investment in small companies, or outright purchase of the small entity.

Nanotechnology is viewed by many large companies as being a possible technology enabler, along with other technologies, for providing new products with enhanced features (e.g., anti-bacterial properties) or higher performance (e.g., higher-strength metals and polymers). However, some large companies have grown wary of incorporating nanomaterials into their existing products because of possible negative public backlash due to potential environmental or health issues.

Overall, large companies take a similar investment approach as private investors. They require a quick return while minimizing risk and reducing needless expenditure of technical staff resources. Other impediments to their partnering with small companies or universities for transitioning new nanotechnology R&D to the marketplace are difficulties in negotiating intellectual property rights in short time frames and the lack of focus and urgency in corporate-funded development work in university labs.

Therefore, there is a market need for other types of organizations to facilitate the commercialization of nanotechnology to meet the needs of many stakeholders. Since the return on investment to for-profit companies (users or investors alike) in early-stage nanotechnologies and nanotechnology companies is problematic, it is appropriate for NGOs to meet this need, matched to their technology-based economic development mission for regional and state development. The Pennsylvania NanoMaterials Commercialization Center is an example of such an entity.

Concluding Remarks and Ideas for the Future

Help Initiate and Support the State and Regional Initiatives

While some states devote significant amounts of their budgets to nanotechnology programs, most do not. This does not indicate a lack of activity in these regions, nor does it preclude the possibility that such states can become leaders over time. If the goal is commercialization of nanotechnology-enabled products and services, then states without initiatives should consider creating such entities with the following:

- A board of directors with significant involvement from commercial entities (e.g., not dominated by academic and/or economic development personnel)
- Charters to support economic activity (versus advancement of science by itself)
- A dedicated initial source of funding for at least two to three years (preferably more)

A vibrant state or regional initiative can survive on about $100,000/year, as proven by the Oklahoma Nanotechnology Initiative with its initial funding of $250,000 over a two-year period. Such an entity could provide a forum for making the connections that allow economic development. The Federal Government might consider instituting a one-to-one matching funds program for up to $500,000 to bolster regional and state-level initiatives in nanotechnology.

Improve Intellectual Property (IP) Benefits

Standard IP language is needed that guarantees the up-front benefits to partners. This will help to remove the barriers to university-industry-national lab partnerships and reduce the time required to negotiate research agreements.

Top 12 International Legal, Policy, and Regulatory Areas to Watch for Nanotechnology Rapid Change

1. Definitions, nomenclature, and testing methods
2. The science-innovation interface, including R&D, entrepreneurship, and commercialization
3. EHS regulations and regulatory (in)compatibility
4. Intellectual property rights
5. Risk governance, including international regulatory frameworks
6. Capital formation, investment, and tax policy
7. Human capital policies, including universities, skill sets, and training
8. Liability and stewardship issues
9. Nanotechnology innovation for grand challenges: environment, health, water, energy, climate change, and security
10. Public engagement, including ethics and outreach
11. Security balance: narrow definition (military) vs. broader one (economic and military)
12. Standards, e.g., ISO TC 229 and *de facto* standards

Focus on Commercialization

The SBIR program varies widely between agencies, but all variants are similar in one significant way. They do not require a genuine ability to commercialize in order to get Phase II funding, nor do they have a dedicated mechanism to weed out "SBIR mills" that exist solely to perform contract R&D without any real commercial intent.

While the National Science Foundation does a good job of describing commercialization activity in its grantee conferences, no organization offers detailed business training required for a technically oriented company to actually consider sales, operating margins, net profits, and sustainable growth paths.

Some state and regional initiatives have recognized this disconnect and applied state funding to connect business schools with emerging technology companies. If the Federal Government truly wants commercialization to be a priority in the SBIR and other programs, then it should consider emplacing a more streamlined review process that is transparent, quick, and balanced between commercial and technical reviews. A 100% funding focus on great, new science will continue to create science without any clear paths to commercialization.

Continue Federal Funding of Basic and Translational Research

Federal funding of basic and translational research provides a foundation for growth and economic development of nanotechnology.

Cluster Regionally to Build upon Strengths where an Industrial Base Exists

Regional, state, and local clusters have been shown to be an effective and efficient form of resource sharing to support industry.

Support Smart Use of State Resources

States could perhaps use tax incentives to encourage commercial interests and facilities to build and grow in their regions. They can also support commercialization-oriented professors and other

The Center for Innovation Management Studies at North Carolina State University

Early in 2005 a research team from North Carolina State University (NCSU) began working with NNI centers to determine how to efficiently and effectively connect emerging nanoscience and technology developments with the commercial marketplace. Five years and ten workshops later, the NCSU team at the NCSU Center for Innovation Management Studies (CIMS) has developed a set of tools and processes that have helped NNI centers improve the dialogue between university scientists and their industrial counterparts as they search for an "impedance match" between the forces that characterize their respective working cultures.

NCSU/CIMS workshop organizers believe that if academic and industrial scientists could engage in precommercial dialogues about possibilities, it would potentially increase the overall yield from the NNI investments. They reached the following conclusions based on the workshop series:

- Industry needs to engage faculty if it wants to exploit science at an early/upstream stage; faculty definitely needs help in understanding how to talk to industry about industry needs.
- Workshops are much more efficient than unstructured discussions in promoting understanding of the "middle ground" between faculty interests and business needs.
- Faculty scientists found that the workshops enriched their perspectives on applications and commercial potential and created excitement about new ideas for research.
- Valuable ideas emerged from the facilitated workshops that were often followed up by direct discussions between research groups and companies.
- Industry participants found that the workshops provided a good basis for comparing the capabilities of different centers and for forming judgments about selecting future alliance partners.
- Finally, center directors learned a great deal about the uniqueness of their various capabilities, which helped in valuing their intellectual assets relative to those of other contributors.

entrepreneurs. On a related note, marshalling resources to capture stimulus funds, and seeking short-term opportunities locally, should help to hold on to (and create) talent and resources.

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6. Resources for RSL Partnerships, Exchanges, and Continuing Information Systems

Moderators: Mark Tuominen, University of Massachusetts, Amherst
Sean Murdock, NanoBusiness Alliance

Introduction

The goal of regional, state, and local partnerships, ultimately, is to optimize the U.S. nanotechnology enterprise for research, development, education, commercialization, and governance to achieve the best outcomes for sustained economic and societal benefit. Achieving that goal requires the effective cooperation of stakeholders from industry, universities, government, and nongovernmental organizations. A robust nanotechnology enterprise, especially one that builds a thriving national system of nanomanufacturing, requires a long-term strategic view while simultaneously providing mechanisms for the fast-paced pursuit of near-term commercial opportunities. A long-term strategy should serve to identify and fill gaps in the value/supply chain for an array of future nanomanufactured products through public-private partnerships.

Advancements in nanotechnology already provide proof-of-concept scientific evidence for a feasible future with a wide-range of nanotechnology-enabled products that benefit society. However, since nanotechnology is still an emerging area, the pathway from a lab demonstration to a specific commercial product has a considerable amount of uncertainty and unmet needs. These missing pieces currently hinder the implementation of nanotechnology and nanomanufacturing. For instance, gaps exist in nanomaterial properties data; scalable nanomanufacturing process tools; suitably trained workers; knowledge cyberinfrastructure; environmental, health, and safety (EHS) best practices; nanomanufacturing design science; and the network of research, development, and commercialization partners. These gaps can be filled through partnerships that build the physical and intellectual infrastructure in targeted high-priority areas of nanotechnology development.

This chapter serves to identify catalytic mechanisms for innovation and progress—to build new value/supply chains with direct partnerships between industry, universities, government, and other organizations. These follow from the discussions and findings of the participants in the workshop breakout session on partnerships, exchanges, and continuing information systems.

Of high importance to this group was the issue of how best to structure resources to advance manufacturing and commercialization in the United States. Following up on this, participants discussed efficient models for partnership between regional, state, and local groups and Federal resources. They also enumerated information assets needing to be connected to support research, education, and development. Finally, they made recommendations on how to proceed quickly and immediately—at the speed of business.

Three key needs emerged from the breakout discussion:

1. Using pilot projects to advance strategic development
2. Building a more comprehensive and deeper information infrastructure
3. Establishing a more robust system for workforce training and education

Communities of Interest and Pilot Projects

A community of interest (COI) is a nucleating, precompetitive entity that serves to identify needs and objectives in the presence of great uncertainty. Examples include industry consortia, the National Nanomanufacturing Network (NNN), the NanoCollaboratory, and the GoodNanoGuide wiki (http://www.goodnanoguide.org) of the International Council on Nanotechnology (ICON).

COIs also help to guide standards development. The development of both documentary standards and standard reference materials is essential to trade as well as to research, development, and commercial partnerships. COIs should cultivate and spin out fast-paced, funded pilot projects. This could be in the form of public-private partnerships with tightly focused objectives that foster subsequent commercial development, or alternatively in the form of support for the feasibility phase of a long-term enabling nanotechnology enterprise infrastructure project. The COIs and pilot projects must have mechanisms to keep small- and medium-sized companies engaged throughout the development process.

It would be effective to establish pilot projects that build tangentially off of initiatives already underway, in order to fill gaps that currently limit the economic and societal impact of these initiatives. This not only uses previous investments in nanotechnology R&D, but also, by clearly identifying needs in the value/supply chain, creates new opportunities for both small and large ventures.

It is desirable to have an efficient system for pilot project support that avoids sparse proposal deadlines incommensurate with the speed of business. Waiting too long for funding can result in lost opportunities. Furthermore, everyone should have “skin in the game”—that is, contribute to the funding match. Otherwise, the drive to succeed is not as compelling.

The funding for pilot projects can be leveraged 2-4 times by matching combinations of Federal, industry, state, and university support.

These pilot projects can create foundational contributions to the nanotechnology enterprise such that Federal, state, or regional investment, together with a private stake, is likely to produce a considerable return on investment through economic activity and taxes.

Pilot Projects

Pilot projects will determine stakeholder requirements and realistic follow-up program goals, plans, and stakeholder roles based on experience and lessons learned.

- Example: Provide thorough characterization using standard protocols for a small number of specific nanomaterials; use national state-of-the-art facilities to determine their structure (initiating user service for sample preparation and remote access); develop structure activity relationships (SARs) using resultant data and computation; and evaluate if all stakeholder requirements have been met and if new requirements are needed.
- Emphasize the science: Involve collaborations among a large number of stakeholders, entities, and disciplines to provide robust requirements for the pilots, and evaluate the pilot results prior to initiating the next stage.
- Informatics should federate existing databases, concentrating on common metadata and ontologies, and using examples of (precompetitive) shared data to show the utility in developing SARs. Systems should be built to provide secure storage of private data for limited sharing, sharing of public data developed using government funds, and exploring the use of anonymous data. Regulators must be involved.
- Public-private partnerships should be used for broad involvement in development of instrumentation, standard software, and standards for software as well as the above projects.

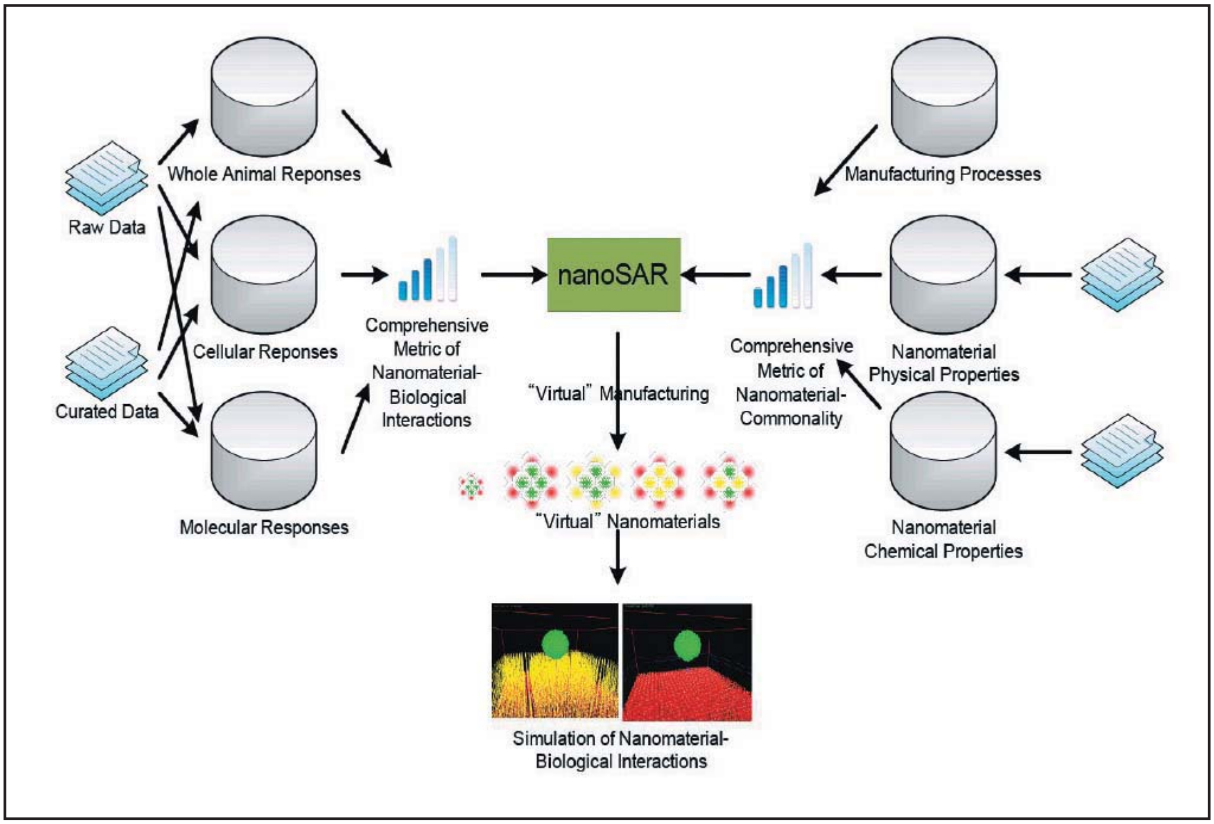

Figure 6.1. Operational schematic for the Nanomaterials Interactions Database (courtesy of Stacey Harper).

Development of Information Infrastructure: Databases

The goal for development of information infrastructure is to transform data into information and then into knowledge. Information infrastructure is vital to RSL groups and the entire U.S. nanotechnology enterprise, to support continuous advancements. It is essential to designing nanotechnology-enabled products that are part of the value chain. Several nanotechnology information (e-science) resources are already established, while others are emerging. Currently these are clustered around specific subject domains, such as simulation & modeling (nanoHub); manufacturing (InterNano); and environment, health, and safety (ICON, the Nanotechnology Characterization Laboratory, and the Nanomaterial-Biological Interactions database, as shown in Figure 6.1). These are curated by their respective expert communities of interest.

In order to build on the existing infrastructure, greater depth of information is needed on who is doing what and where in the field of nanotechnology. This includes gathering information from industry, universities, and government. In other words, it is still difficult to find experts and potential partners who can fulfill specific needs. More information of this type would help RSL development significantly by identifying partnership opportunities, enabling access to tools and instrumentation, and facilitating communication with experts on all dimensions relevant to nanotechnology advancement.

The depth of information available on centers and shared-use facilities needs to be increased. Their services and modes of access should be clearly identified (e.g., fabrication and measurement capabilities, simulation and modeling, and other services). NSF, DOE, and NIST presently have user facilities with a range of services, but the full extent of these services needs to be more easily accessible.

Nanomaterials properties databases are crucial to the implementation of nanotechnology. The initial focus of data gathering and aggregation should be on high-priority materials and properties. Standards for metadata and measurement protocols are an essential component for the most useful properties. A centralized access point for these resources within a data management infrastructure would be beneficial. This is conceivably a role that the National Nanotechnology Coordination Office (NNCO) should play.[1] Perhaps the best way to accomplish this is via federation of topical/regional resources—to be able to access data from a common dashboard but still preserve local emphasis and subtopics.

For federation, some software utilities or website services already exist that may help develop networked information resources. These include Ibridge, common APIs, FlintBox, Twine, LinkedIn, citeseer, Rexa, and others. Many of these are designed as tools for social or professional networking (also known as Web 2.0 applications). Building on existing systems, an "e-extension" model could be implemented to serve all sizes of companies, facilitated in conjunction with an information resource. E-extension can be thought of as a modern-day version of the university agricultural extension infrastructure launched through the Morrill Act in 1857. The National Nanomanufacturing Network (NNN), Network for Computational Nanotechnology (NCN), Nanotechnology Characterization Laboratory (NCL), and other organizations already perform this function to a limited extent but not yet at the scale needed for a comprehensive U.S. nanotechnology enterprise.

It is critical to note that one cannot, and should not, attempt to develop databases and cyberinfrastructure independent of the COIs that desire them. Rather, those COIs should design, curate, and maintain them.

Skills and Resources

Skills and resources are an essential part of the nanotechnology enterprise. Again, since nanotechnology is new, many pieces necessary for commercial implementation are not in place. Especially important are skilled human resources for nanotechnology innovation and manufacturing.

The value/supply chain needs to be developed and supported. This includes information, tools, suppliers, know-how, and roadmaps. Workforce training needs range from the student to the professional levels. Building a skilled workforce may involve constructing a national training network, providing training rotations, and various kinds of professional development (see also Chapter 3). One possible solution would be to identify necessary skills for a nanotechnology professional development certification, and to ensure that universities and community colleges have appropriate programs. It is also important to develop a strong innovation and technology management education culture in the United States. This includes a focus on managing emerging technologies under uncertainty, as well as utilizing experienced "front-line" experts from industry (e.g., industry innovators, IRI members) to complement university training.

U.S. manufacturing know-how is at great risk. It is in decline and must be addressed with great urgency. Emphasis must be placed on reinvigorating advanced statistical design, informatics, process control, manufacturing automation design, and manufacturing science in university curricula, combined with supporting close industry-academic relations. Also at risk is the development of tools and instrumentation to be conducted at government and academic institutions. These are key enablers of nanotechnology and nanomanufacturing advancement, and they should not be solely the domain of industry to develop.

Ways to Better Utilize Existing Infrastructure and Activity

To better utilize existing infrastructure, continuous evaluation and accountability is needed in simple, bottom-line form. External evaluators should be trained specifically for this mission. Federally and state-funded centers should respond to the needs of private customers and be strongly service-oriented. Some of the existing resources such as National Nanotechnology Infrastructure Network (NNIN) and NNN may benefit by asking their communities what they can do differently to serve them better. For example, NCN readjusted its strategy after surveying its users and became far more successful with them.

To realize the potential of many nanotechnology-related discoveries, universities need to reorient their practices to better accommodate a culture of innovation. One sees the disparity in comparison to the innovation focus in Asian and EU countries. In terms of Federal agencies, a better extension

1 The NNCO provides technical and administrative support to the NSET Subcommittee, serves as a central point of contact for Federal nanotechnology R&D activities, and provides public outreach on behalf of the National Nanotechnology Initiative.

to industry is especially needed with regard to the mission-oriented agencies. It would be helpful if they could recognize the value of people, including support staff for industry liaison.

Federal Recommendations

There should be more than one mode of access to Federally supported facilities, not simply collaboration or proposal-based access (e.g., the NIST CNST facility provides a fee-for-access option). Along these lines, implementing best practices for cost structure and standardized user agreements and fee structures is encouraged. A best-practices litmus test would be to ask the question, Can one settle an agreement in one day or online?

A national system/network for testing and characterization to produce useful nanomaterials property data (e.g., United States Measurement System, Nanotechnology Characterization Laboratory, regional efforts) needs to be implemented. This should include inter-laboratory studies, which add validity to data. It is critical to identify and fill needed data gaps. We cannot—and should not—fill the entire data space but rather focus resources and efforts on high-priority materials and properties. High-throughput screening will reduce the costs and increase the richness of the data set. The network effect of expertise can also be built on an investment in network cyberinfrastructure and community of interest activities that can help RSL experts and partners find each other.

Best Practices and Future Opportunities in Building Partnerships

The nanotechnology R&D community needs to be open to the possibility that the best practices for moving nanotechnology research to application development are still in the future. The impulse to fit nanotechnology into one or more existing frameworks is enticing, because it suits past experiences and present expectations and expertise. However, at the level that research is reduced to abstract production of new knowledge, the reasoning from a model (such as a linear model of research to commercialization) is far removed from circumstance-dependent, on-the-ground practice. The best currently known practices may not in fact represent leading-edge practices.

Venture capital funding and other standard entrepreneurial fare may not operate well in support of nanotechnology commercialization. If nanotechnology development time exceeds 20 years, then use of the patent system may also be less effective. University research contracting and industry procurement best practices are not well suited to nanotechnology research in which an economic interest is a central focus of various stakeholders. Direct effort is needed on reframing points of research and entrepreneurial engagement in research organizations. Doing this, rather than complaining about pace or restrictions, would be a more productive route to effective collaborations. This would move beyond cooperative research and development agreements (CRADAs) and “work for others” agreements; it considers new strategies such as limited contracting, basic agreements, frame agreements, and the development of memberships, subscriptions, and other low-threshold and overhead relationship-framing arrangements.

Future opportunities for partnerships need to take into account local financial models for the stakeholders as individual organizations. While the overall engine of knowledge production and economic activity may churn on in fine form, it may also grind down or waste the assets available to various stakeholders. It is to be expected that some organizations are going to benefit more than others, and at different times in the development of nanoscale technologies, it is not helpful if stakeholders are broken financially even before local success is realized.

Partnerships that provide space for specialized intermediary organizations can develop resources that aggregate, stage, and validate clusters of research technologies into useful platforms. Much more emphasis is needed on the roles and financing of these intermediate organizations. Such organizations can include companies such as Intellectual Ventures or economic development initiatives such as the Orange County Technology Action Network (OCTANe) in California. This approach means inserting other players between research and commercialization of products to develop industry-grade tools that enable both rapid access to resources and effective assessment of risks and development

A Case for Sharing: NanoEHS

An integrated approach is needed for the responsible development of nanomaterials. Enabling technology innovation and application while identifying and addressing potential nanotechnology-related environmental, health, and safety ("nanoEHS") concerns requires an oversight system that utilizes all viable options in an integrated manner. Such a system should include:

- Workplace safety and product stewardship initiatives
- Voluntary and mandatory agency programs
- Collaborative efforts between multiple stakeholders

Workshop participants recommended consideration of the following points:

1. *Consortia should be formed to pool resources in order to accelerate responsible development of nanotechnology.*

   One model is the Nanomaterial-Biological Interactions knowledgebase. It includes curated and raw data on three levels, combined with information on chemical and physical properties and manufacturing processes, which inform structure activity relationships and enable simulation of nanomaterials-biological interactions. See Figure 6.1 for a schematic.

   Another model is a planned inter-operable, federated system of data/knowledge bases for nanoEHS information using a framework like the Cancer Nanotechnology Laboratory portal (caNanoLab) or the community-built nanoHUB; participants are expected to include:

   - National Toxicology Program at NIEHS
   - Nanotechnology Characterization Laboratory at the National Cancer Institute (NCI)
   - DOE's Pacific Northwest National Laboratory (PNNL)
   - InterNano
   - Nanoparticle Information Library at NIOSH
   - Advanced Biomedical Computing Center at NCI
   - National Center for Computational Toxicology at EPA

2. *Assessments are critical.*

   - Perform nanomaterials toxicology assessments of common-interest nanomaterials
   - Perform nanomaterials exposure assessments
   - Publish results from common nanomaterials

3. *Full participation is needed in the standards development process.*

4. *Technical expertise should be communicated at public forums, professional conferences, and workshops, and through organizational tools such as the ICON Best Practices wiki.*

5. *Fund nanoEHS research and publish results.*

   For example, the University of California's Center for Environmental Implications of Nanotechnology has a breadth of activities comprised of seven interdisciplinary research groups. These all fall into a larger framework designed to expand the knowledge base of nanomaterials' toxicity and other properties.

6. *Look forward.*

   It is imperative to be proactive about disposal and recycling of nanomaterials and products containing nanomaterials.

These initiatives, programs, and efforts would support development of science-based policies.

requirements to achieve an economic payoff for further investment.

Open innovation for economic development may be best enabled through the creation of "science commons" in various forms. A commons is characterized not by indifference to intellectual property rights and provenance, but a "some rights reserved" approach that makes all other rights clearly and routinely marked for easy access. Open source software provides some of these attributes. For patents, a commons that enables easy access to "make" and "use" rights while reserving for various reasons "sell" and "sublicensing" rights serves both widespread access, including research and internal commercial operations, and regional economic development interests.

Appendix A. Workshop Agenda

NNI Regional, State, and Local Initiatives in Nanotechnology

1-3 April 2009
Skirvin Hilton Hotel
1 Park Avenue
Oklahoma City, OK 73102

Speaker presentations are available online at
http://nano.gov/html/meetings/nanoregional-update/workshop.html

Wednesday, April 1, 2009

PM Joint tour activities for the NNI Regional, State, and Local Initiatives Workshop and the Oklahoma Nanotechnology Initiative workshop (which took place March 30–April 1, 2009):

1:00 Oklahoma City, Presbyterian Research Park: briefings on applications of nanotechnology by OrthoCare/Martin Bionics, NanoBioMagnetics, and Charlesson LLC

3:00 Norman, Oklahoma, Southwest Nanotechnologies, Inc. (SWeNT), carbon nanotube production facility near the University of Oklahoma (OU), followed by a meeting at OU with representatives of Ekips Technologies, Inc.

5:30 Welcoming reception for Regional, State and Local Initiatives in Nanotechnology Workshop (poster sessions begin, with posters remaining on display for the duration of the workshop)

Thursday, April 2, 2009

8:15 Welcome from Jari Askins, Lt. Governor, State of Oklahoma

8:25 Welcome and charge to the workshop (Mike Roco and Jim Mason)

Keynotes

8:35 Federal role in industrial support
Marc Stanley (Director, NIST Technology Innovation Program)

9:00 Involvement of states in nanotechnology partnerships
Skip Rung (ONAMI)

9:25 University-based nanotechnology partnerships
Mauro Ferrari (University of Texas)

9:50 Involvement of industry in nanotechnology partnerships
Sean Murdock (NanoBusiness Alliance)

10:15 Coffee break

Keynotes (Chair: **Warren Ford**, Oklahoma State Univ.)

10:30 Industry-university-government partnerships in nanotechnology
Mike Roco (NILI/NSET)

10:55 Nanoelectronics Research Initiative and other models
Ralph Cavin (SRC/SIA)

Case Studies

11:20 Case study: State-corporate partnership for economic development
Ed Cupoli (CNSE-SUNY Albany)

11:40 Case Study: ONI and regional impact
Jim Mason (ONI)

12: 00 Lunch Break

Keynotes (Chair: **Clark Cooper**, NSF)

12:30 Nanotechnology and Life Sciences
Mostafa Analoui (The Livingston Group)

12:55 Organization and business preparation for introducing nanotechnology
Rich Chapas (Battelle)

Topical Panels (overview presentations followed by discussions)

1:20 *Panel: NNI Infrastructure and Funding*
Moderator: **Minoo Dastoor** (NASA)

Short statements:
Mike Roco (NSF funding)
Marty Fritts (NIH funding)
Dianne Poster (NIST funding)
Bill Mullins (DOD funding)
Stephen Streiffer (DOE research centers)
Krish Mathur (DOEd activities)

2:05 *Panel: International Models*
Moderators: **Phil Lippel** and **Richard Johnson** (Arnold & Porter)

Short statements:
Scott Bryant (MANCEF)
Gary Albach (nanoAlberta)
John Cowie (Technology Manager for Agenda 2020)
Jaime Parada Avila (Instituto de Innovación y Transferencia de Tecnología de Nuevo León)

2:40 Break

3:00 *Panel: Fostering Nanotechnology Innovation*
Moderators: **James Rudd** (NSF) and **Rich Chapas** (Battelle)

Short statements:
Alden Bean (CIMS, North Carolina State Univ.)
Les Alexander (A123 Systems)
Edward Ahn (Pioneer Surgical)
Charlie Gause (Luna Nanomaterials)
Doug Schulz (North Dakota State U. CNSE)

3:35 *Panel: Nano-EHS*
Moderator: **Terry Medley** (DuPont)

Short statements:
Steve Brown (Intel)
Arturo Keller (UCSB/CEIN)
Stacey Harper (Oregon State University)
Golam Mustafa (EPA)

4:10 *Panel: State Models for Supporting Emerging Nanotechnology*
Moderator: **Skip Rung** (ONAMI)

Short statements:
Ed Cupoli (CNSE-SUNY Albany)
Jim Mason (ONI)
Philip Shapira (Georgia Tech)
Griffith Kundahl (Colorado Nanotechnology Alliance)

4:45 *Panel: Industry Groups Partnering in Nanotechnology*
Moderator: **Hratch G. Semerjian** (CCR)

Short statements:
Brent Segal (Lockheed)
Dave Arthur (SWeNT)
Ralph Cavin (SRC/SIA)
Richard Johnson (Arnold & Porter)
Daniel Rardon (PPG industries)

5:20 *Open forum: New Partnering Methods*
Moderators: **Mike Roco** (NSF) and **Mike Moradi** (Charlesson LLC)

Open contributions from the participants

Response to comments from the public

6:00 Closing comments

7:00 Networking Dinner at the Science Museum, followed by premiere presentation of IMAX RPI movie on nano, "Molecules to the Max"

Friday, April 3, 2009

8:15 Welcome and overview of program (**Mike Roco** and **Jim Mason**)

Keynote (Chair: **World Nieh**, USDA Forest Service)
8:25 Nanotechnology in U.S. Industry
Matthew Nordan (Lux Research)

Panels on Future Activities (overview presentations followed by discussions)

9:00 *Panel: Nanotechnology Workforce Development and Education*
Moderators: **Bob Chang** (Northwestern U.) and **Carl Batt** (Cornell U.)

Short statements:
Steve Fonash (PSU - NACK)
Sheryl Hale (OK Dept. Career & Tech. Education)
Srinivas Sridhar (Northeastern IGERT with NIH)

9:45 Break

10:00 *Panel: Nanotechnology Research and Manufacturing Infrastructure Development*
Moderators: **Mark Tuominen** (U. Mass Amherst) and **Sean Murdock** (NBA)

Short statements:
Mike Postek (NIST)
Dave Arthur (SWeNT)
Marty Fritts (NCL)

10:45 *Panel: Focus on Economic Development and Commercialization*
Moderator: **Mike Moradi** (Charlesson LLC)

Short statements:
Jim von Ehr (Zyvex)
Michael Carolina (OCAST)
Alan Brown (Pa NMCC)
Mostafa Analoui (The Livingston Group)

11:30 *Open Forum: Focus on Best Practices and Future Opportunities for Partnerships*

12:00 *Working Lunch: Report Synthesis; Breakout Sessions for Five Structural Themes:*

1. *Models for regional, state and local, and international partnerships*
   Skip Rung and **Jim Mason**
2. *Workforce development and education*
   Bob Chang, Krish Mathur, and **Phil Lippel**
3. *Research and development infrastructure*
   Ralph Cavin, Mostafa Analoui, and **Marlowe Epstein**
4. *Economic development and commercialization*
   Mike Moradi, Jim von Ehr, and **Geoff Holdridge**
5. *Resources for RSL nanotechnology partnerships: partnerships, exchanges, continuing information systems*
   Mark Tuominen, Sean Murdock, and **Heather Evans**

3:30 Closing Remarks and Next Steps (Moderator **Mike Roco**)

4:00 Adjourn

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

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Jim Von Ehr
Zyvex Labs, LLC

Appendix C. List of RSL Nanotechnology Initiatives in the Report of the 2003 Workshop

Albany NanoTech

Arizona Nanotechnology Investments

AtomWorks

Center for Accelerating Applications at the Nanoscale (South Dakota)

Colorado NanoTechnology Initiative (CNTI)

Massachusetts Nanotechnology Initiative

Michigan Small Tech Association (MISTA)

NanoSig

The NanoTechnology Group, Inc

The Nanotechnology Institute

Nanotechnology in Oklahoma

The New Jersey Nanotechnology Consortium (NJNC)

North Dakota State University Center for Nanoscale Science & Northwest Nanoscience & Nanotechnology Network (N4)

South Carolina NanoTechnology Initiative

Texas Nanotechnology Initiative

Virginia Nanotechnology Initiative (VNI)

The Washington Nanotechnology Initiative

Appendix D. List of RSL Nanotechnology Initiatives in 2009

North Alabama Nanotechnology Organization (Alabama)
http://aamuri.aamu.edu/Nano/organization/index.htm

Arizona Nanotechnology Cluster (Arizona)
http://www.aznano.org/

California NanoSystems Institute (California)
http://www.cnsi.ucla.edu/

Northern California Nanotechnology Initiative (California)
http://www.ncnano.org/

Colorado Nanotechnology Initiative (Colorado)
http://www.coloradonanotechnology.org/

Connecticut Innovations (Connecticut)
http://www.ctinnovations.com/

High Technology Development Corporation (Hawaii)
http://www.htdc.org/

Birck Nanotechnology Center (Indiana)
http://www.purdue.edu/dp/

Kansas Technology Enterprise Corporation (Kansas)
http://www.ktec.com/index_Flash.htm

Maine Technology Institute (Maine)
http://www.mainetechnology.org/

Maryland Technology Development Corporation (Maryland)
http://www.marylandtedco.org/

Massachusetts Nanotechnology Initiative (Massachussetts)
http://www.masstech.org/mni/index.htm

Massachusetts Technology Transfer Center (MATT Center) (Massachussetts)
http://www.mattcenter.org/

Mississippi Technology Alliance (Mississippi)
http://www.technologyalliance.ms/index.php

MN Nano (Minnesota)
http://www.mnnano.org/

Albany NanoTech (New York)
http://cnse.albany.edu/

North Carolina Nanotechnology (North Carolina)
http://www.ncnanotechnology.com/public/root/home.asp

North Dakota Centers of Excellence (North Dakota)
http://www.governor.state.nd.us/init/ce-init.html

The Nano-Network (Ohio)
http://www.nano-network.org/

Ohio Third Frontier (Ohio)
http://www.development.ohio.gov/ohiothirdfrontier/

Oklahoma Nanotechnology Initiative (Oklahoma)
http://www.oknano.com/

Oregon Nanoscience and Microtechnologies Institute (ONAMI) (Oregon)
http://www.onami.us/

Pennsylvania Nanomaterials Commercialization Center (Pennsylvania)
http://www.pananocenter.org/

Texas Emerging Technology Fund (Texas)
http://members.texasone.us/site/PageServer?pagename=tetf_homepage

Texas Nanotechnology Initiative (Texas)
http://www.texasnano.org/

Utah Science, Technology and Research Initiative (USTAR) (Utah)
http://www.ustar.utah.edu/

nanoSTAR Institute (Virginia)
http://www.virginia.edu/nanostar/

Northern Virginia Technology Council (Virginia)
http://www.nvtc.org/index.php

Washington Tech Center (Washington)
http://www.watechcenter.org/

Greater Washington Nanotech Alliance (Washington, D.C.)
http://www.nanotech-alliance.org/

WV Nano Initiative (West Virginia)
http://wvnano.wvu.edu/

MidAtlantic Nanotech Alliance (MANA) (Pennsylvania, New Jersey, and Delaware)
http://www.midatlanticnano.org/

NanoBusiness Alliance National (HQ in Chicago)
http://www.nanobsiness2009.com/

Southwest Nano Consortium (Arizona, Colorado, Oklahoma, New Mexico, Texas, and northern Mexico; HQ in Albuquerque)
http://www.mancef.org/nnnm

Nanoelectronics Research Initiative (NRI) (National HQ in Durham, NC)
http://nri.src.org/

Appendix E. NNI Agency Mechanisms for Industry and States

A NILI Survey of Partnership and Funding Opportunities

(See http://www.nano.gov/html/funding/businessops.html for updates.)

A main objective of the NNI is developing interactions with industry and state organizations in order to support nanotechnology development and technology transfer. The Nanomanufacturing, Industry Liaison, and Innovation (NILI) Working Group surveyed NNI member agencies to create a central list of the different agency programs that work toward this goal, and to detail the current or planned activities that support this goal of the NILI charter.

Defense Threat Reduction Agency/JPEO Chemical & Biological Defense Program (DTRA/CBDP)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Chem-Bio Detection Capability Area Research	as available	Nano-PCR: Rapid, Accurate, and Portable Full Genomic Amplification (Nanobiosym, Inc.)
CBD/ SBIR Chem-Bio Small Business Innovation Research program	as available (total CBD SBIR FY09 budget = $12.7M); these funds are for Phase I & Phase II contract awards across the Physical S&T and Medical S&T Capability Areas. Some topic areas have addressed nano-technology applications.	Participation in the annual DOD Beyond Phase II program; this annual outreach conference was established to facilitate one-on-one interactions between small businesses and potential industry partners to commercialize SBIR developed technologies. http://www.beyondphaseii.com

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
CBD/ SBIR Chem-Bio Small Business Innovation Research program	as available	State operated Small Business Development Centers (SBDCs) serve as liaison between SBIR programs (e.g., the Government) and small businesses, and potential industrial partners. The U.S. Small Business Administration (SBA) established the SBDC network to foster relationships with small business and industry. http://www.sbtdc.org/technology/sbirsttr.asp http://www.floridasbdc.com/ http://www.idahosbdc.org/ CBD SBIR has periodically interacted with Florida, North Carolina, Colorado and Montana SBDC organizations.

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Participating at outreach conferences such as the **DOD Beyond Phase II** conference	N/A	See info presented above

Department of Agriculture, National Institute of Food and Agriculture (USDA/NIFA) (formerly Cooperative State Research, Education, and Extension Service, CSREES)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Providing competitive grants, including **SBIR, formula funds,** and **Congressional earmarks for research, education and extension activities**	Approx. $6M combined total for nanotechnology, nanomanufacturing is a small fraction of it.	National Research Initiative (NRI) competitive grants, currently funded projects http://cris.csrees.usda.gov/cgi-bin/starfinder/0?path=nrinselink.txt&id=anon&pass=&search=CG=*-35603-*%20not%20PS=TERM*&format=WEBTITLESG

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Facilitating broad stakeholder interactions with Land Grant universities, other research institutions, the food industry, and agricultural producers through workshops, conferences, grantees' annual meetings, multistate research committees	varies	Nanoscale Science and Engineering for Agriculture and Food Systems – National Planning Workshop, http://www.nseafs.cornell.edu/

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
CRADA - Cooperative Research and Development Agreement		
SBIR - Small Business Innovation Research		http://www.csrees.usda.gov/business/pdfs/sbir_programs.pdf
USDA Extension system/ Extension Communities of Practice (CoP)		http://www.csrees.usda.gov/Extension/
Some large grants with industry direct involvement in project planning, executive, and sharing results, sometimes through an industry board.		
Special research grants aiming at solving industry problems, and may require industry matching fund.		

Department of Labor, Employment and Training Administration, Business (DOL/ETAB)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
High Growth Job Training Initiative	N/A	The High Growth Job Training Initiative is a strategic effort to prepare workers to take advantage of new and increasing job opportunities in high growth, high demand and economically vital sectors of the American economy. The High Growth Initiative targets worker training and career development resources toward helping workers gain the skills they need to build successful careers in these and other growing industries.
Community Based Job Training Grants	N/A	Community Based Job Training Grants serve to build the capacity of community and technical colleges to train workers and develop skills needed in local industries and occupations that are expected to experience high growth. California Nanotechnology Collaborative NanoCenter

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Global Issues in Nanotechnology (GIN) Working Group, NSTC-CT-NSET Subcommittee	None	Participation in GIN meetings Contributions to GIN projects related to OECD activity Connection of NILI and NSET conferences and meetings to DOL-ETAB nanotech talent development investments

Department of State

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
OECD Working Party on Nanotechnology	N/A	Project on Nanotechnology Impacts on Companies and Business Environments http://www.oecd.org/sti/nano
OECD Working Party on Nanotechnology	N/A	Project on Nanotechnology Indicators and Statistics http://www.oecd.org/sti/nano

Food and Drug Administration (FDA)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Meeting with product sponsor	Part of FDA responsibility—no specific budget	For all products that FDA regulates, product sponsors request regular meetings.
Public meetings to hear from industry on requirements for "nano" products	Part of FDA responsibility—no specific budget	Two public meetings to hear from public on requirements for nanotechnology-enabled products

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Developing guidance for industry for "nano" products	No specific budget—part of FDA business	FDA Task Force Report

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
While FDA typically does not develop technology for transfer to industry, FDA does serve as a facilitator of technology to bring new technology to enhance public health.	None	N/A

National Institute for Occupational Safety and Health, Centers for Disease Control (NIOSH/CDC)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Facilitating nanotechnology innovation indirectly by reducing safety concern barriers through the NIOSH nanotechnology program	$6M in FY08	NIOSH nanotechnology program http://www.cdc.gov/niosh/topics/nanotech/ NIOSH Approaches to Safe Nanotechnology http://www.cdc.gov/niosh/topics/nanotech/safenano/ NIOSH Nanotechnology Field Team (NIOSH Publication No. 2008-121: NIOSH Nanotechnology Field Research Effort; http://www.cdc.gov/niosh/docs/2008-121/

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
NIOSH eNews	N/A	http://www.cdc.gov/niosh/enews/default.html
NIOSH Science Blog	N/A	http://www.cdc.gov/niosh/blog/

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Research to Practice (r2p), a NIOSH initiative focused on the transfer and translation of research findings, technologies, and information into highly effective prevention practices and products which are adopted in the workplace.	N/A	http://www.cdc.gov/niosh/r2p/
CDC Technology Transfer Office		CRADAs, Material Transfer Agreements (MTAs), etc. http://www.cdc.gov/od/ads/techtran/us.htm

National Institutes of Health, National Cancer Institute (NIH/NCI)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
CCNE - Centers of Cancer Nanotechnology Excellence		http://nano.cancer.gov/programs/ccne.asp
CNPP - Cancer Nanotechnology Platform Partnerships		http://nano.cancer.gov/programs/nanotech_platforms.asp
UIP – Unconventional Innovations Program		
SBIR/STTR – Small Business Innovation Research / Small Business Technology Transfer		http://sbir.cancer.gov/
NCL – Nanotechnology Characterization Laboratory		http://ncl.cancer.gov

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Maintaining web site, includes information about awardees, funding opportunities, scientific bibliography		http://nano.cancer.gov
NCL- Nanotechnology Characterization Laboratory		http://ncl.cancer.gov http://ncl.cancer.gov/working_input-nanomaterials.asp
NanoWeek		(Series of events sponsored by NIH in 2009, designed to bring the excitement of nanotechnology to the broad NIH biomedical community)

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
SBIR/STTR- Small Business Innovation Research / Small Business Technology Transfer		http://sbir.cancer.gov
UIP- Unconventional Innovations Program		http://ncl.cancer.gov/working_application-process.asp#submission-ncl
NCL- National Characterization Lab		http://ncl.cancer.gov/working_intellectual-property.asp
Public-Private-Partnership		http://ppp.od.nih.gov/pppinfo/focusareas.asp

National Institutes of Health, National Heart, Lung, and Blood Institute (NIH/NHLBI)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
PEN – NHLBI Programs of Excellence in Nanotechnology		http://www.nhlbi-pen.net/default.php
SBIR/STTR – Small Business Innovation Research / Small Business Technology Transfer		http://www.nhlbi.nih.gov/funding/sbir/index.htm
BRP - Bioengineering Research Partnerships		http://grants.nih.gov/grants/guide/pa-files/PAR-07-352.html

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
PEN – NHLBI Programs of Excellence in Nanotechnology		http://www.nhlbi-pen.net/default.php
NanoWeek		(see abover under NCI)

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
SBIR/STTR- Small Business Innovation Research/ Small Business Technology Transfer program		http://www.nhlbi.nih.gov/funding/sbir/index.htm
BRP - Bioengineering Research Partnerships		http://grants.nih.gov/grants/guide/pa-files/PAR-07-352.html
Public-Private-Partnership		http://ppp.od.nih.gov/pppinfo/focusareas.asp

National Science Foundation (NSF)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
GOALI - Grant Opportunities for Academic Liaison with Industry	Open pool of funds	http://www.nsf.gov/pubs/2010/nsf10580/nsf10580.htm
I/UCRC- Industry/University Cooperative Research Centers	Open pool of funds	http://www.nsf.gov/eng/iip/iucrc/
FRP - Fundamental Research Program for Industry/University Cooperative Research Centers	Open pool of funds	http://www.nsf.gov/funding/
SBIR - Small Business Innovation Research	Open pool of funds	http://www.nsf.gov/eng/iip/sbir/index.jsp
STTR - Small Business Technology Transfer	Open pool of funds	http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5527
PFI – Partnerships for Innovation	Open pool of funds	http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5261
NSEC – Nanoscale Science and Engineering Centers	19 centers	http://www.nsecnetworks.org/
NNN - National Nanomanufacturing Network	Network with 4 main nodes	http://www.internano.org/
NNIN – National Nanotechnology Infrastructure Networks	Network with 14 nodes	http://www.nnin.org/
NCN – Network for Computational Nanotechnology	Network with 7 nodes	http://www.ncn.purdue.edu/
NRI – Nanoelectronics Research Infrastructure	Open competition	http://nri.src.org/member/about/default.asp http://nri.src.org/member/centers/nsf-nri/about.asp
MRTC – Materials Research Science & Engineering Centers	17 centers with main focus on nanotechnology	http://www.nsf.gov/funding/
STC – Science and Technology Centers, and **ERC** - Engineering Research Centers	2 centers on nanotechnology	http://www.nsf.gov/funding/
NIRT – Nanoscale Interdisciplinary Research Teams - No competition in 2009	Nanomanufacturing area in FY 2011	http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf07521
NEB - Nanoelectronics for 2020 and Beyond	Open competition	http://www.nsf.gov/funding/
AIR - Accelerating Innovation Research	Open competition	http://www.nsf.gov/funding/

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Maintaining website with abstracts and funding opportunities, with search engine	about 4,000 awards posted (keyword: nano*)	http://www.nsf.gov/nano http://www.nsf.gov/awardsearch/ http://www.nsf.gov/funding/
Supporting workshops	About 10 per year	Workshop with forestry industry; see below

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Publishing papers	N/A	N/A
Patents	N/A	N/A
Funding **SBIR/STTR** companies	$18 million (grants)	http://www.nsf.gov/eng/iip/sbir/diversity/2003sbirII.xls
Matching **SBIR/STTR** companies to industry	$5 million (supplements)	http://www.nsf.gov/eng/iip/sbir/matchmaker.jsp

Department of Agriculture, United States Forest Service (USFS)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Nanotechnology for the Forest Products Industry-**Vision and Technology Roadmap**		USFS participated in forest products industry nanotechnology roadmapping workshop. Roadmap published by the Agenda 2020 Technology Alliance. http://www.agenda2020.org/PDF/fp_nanotechnology.pdf
SBIR		SBIR project with NanoDynamics to develop mold-resistant building materials

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
American Forest & Paper Association Agenda 2020 Technology Alliance		Regular interaction and review of pre-commercial nanotechnology for application in the forest products industry
Chemical Industry Vision 2020 Technology Partnership		Regular interaction discussing nanotechnology in the chemical industry. Provide input into chemical industry roadmapping activities.
American Forest & Paper Association/Technical Association of the Pulp and Paper Industry Industrial Liaison Meeting		Annual review (2 days) of USFS nanotechnology R&D program with industry
Annual International Conference on Nanotechnology for the Forest Products Industry	$5,000 sponsorship plus staff time and travel costs to plan , conduct and participate in the conference	Research conference on nanotechnology specific to the forest products sector—involves industry and universities in the U.S. and worldwide
USFS-Purdue University collaboration	$45,000 plus salary and benefits of employee (~$90,000)	USFS has placed a nanotechnology scientist at the Purdue University Birck Nanotechnology Center with joint academic appointment.

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
American Forest & Paper Association Agenda 2020 Technology Alliance		Review of pre-commercial nanotechnology and assess readiness for technology deployment
Publishing research in scientific and industry technical journals		
SBIR project - NanoDynamics and other cooperative R&D agreements as opportunities arise		Develop mold-resistant building products

National Institute of Standards and Technology (NIST)

Mechanisms to facilitate nanotechnology innovation, nanomanufacturing advancement, and interactions with industry, medical, or other economic sectors:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Center for Nanoscale Science and Technology (CNST) **NanoFab Facility**		http://www.nist.gov/cnst
NIST / SRC-NRI Partnership		http://www.nist.gov/public_affairs/releases/src.html
TIP - Technology Innovation Program		http://www.nist.gov/tip
NIST Construction Grant Program		http://www.nist.gov/director/ncgp/index.cfm
Measurement, Science, and Engineering Research Grants Program		http://www.nist.gov/director/ocfo/grants/upload/2010_MSE_FFO120809.pdf
Hollings Manufacturing Extension Partnership (MEP)		http://www.nist.gov/mep
SBIR - Small Business Innovation Research		http://tsapps.nist.gov/ts_sbir

Mechanisms to enable transfer of technology to industry:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Publishing papers		NIST Publications Portal http://www.nist.gov/publication-portal.cfm
Developing standards		Characterization, Nanometrology, and Nanoscale Measurements Portal http://www.nist.gov/characterization-nanometrology-and-nanoscale-measurements-portal.cfm
Develop Standard Reference Materials (SRM)		Examples: Examples (additional nanoscale RMs will be released in 2010 and 2011): RM 8011, Gold Nanoparticles, Nominal 10 nm Diameter RM 8012, Gold Nanoparticles, Nominal 30 nm Diameter RM 8013, Gold Nanoparticles, Nominal 60 nm Diameter http://www.nist.gov/srm/

Mechanisms to exchange information and stimulate interactions related to nanotechnology with other industry, state, and local organizations:

Title or name of each activity	Amount and budget of annual activity	Example of activity
Sponsor/co-sponsor nanotechnology-related workshops	Approx. 3 per year	**2008-2010 Examples:** Extreme Manufacturing – What are the technology needs for long-term U.S. Manufacturing Competitiveness? http://www.nist.gov/el/extrememanu.cfm The 4th Carbon Nanotube Workshop: Measurement & Control of Chirality http://www.nist.gov/mml/polymers/complex_fluids/carbon-nanotube-workshop.cfm Washington Metro Region Nanotech Partnership Forum http://www.eventbrite.com/event/734215057 Grand Challenges for Advanced PV Technologies & Measurements http://www.nist.gov/director/grand_challenges2010.cfm Nano-Optics Plasmonics http://www.nist.gov/cnst/nrg/nopam_conf.cfm Calibration and Standards for Nanomechanical Measurements Workshop http://www.nist.gov/mml/ceramics/calibrations-and-standards.cfm Nanoscale Measurement Challenges for Energy Applications Global Workshop http://www.asmeconferences.org/NanoMeasurement09/index.cfm Enabling Standards for Nanomaterial Characterization http://www.nist.gov/msel/ceramics/nanomaterial-characterization-workshop.cfm The Tri-National Workshop on Standards for Nanotechnology http://www.mel.nist.gov/trinat.htm International Workshop on Documentary Standards for Measurement and Characterization in Nanotechnologies http://www.standardsinfo.net/info/livelink/fetch/2000/148478/7746082/index.html
Participate in national and international technical and standards committees		Examples: IEEE Nanotechnology Council Standards Committee http://ewh.ieee.org/tc/nanotech/ ASTM Committee E56 on Nanotechnology http://www.astm.org/COMMIT/COMMITTEE/E56.htm International Organization for Standardization (ISO) Technical Committee 229 (TC 229) http://www.iso.org/iso/iso_technical_committee?commid=381983 International Electrotechnical Commission (IEC) Technical Committee 113 (TC 113) – Nanotechnology standardization for electrical and electronic products and systems http://www.iec.ch/dyn/www/f?p=102:7:0::::FSP_LANG_ID,FSP_ORG_ID:25,1315 OECD Working Party on Nanotechnology http://www.oecd.org/document/30/0,3343,en_2649_34269_40047134_1_1_1_1,00.html
Maintain website with links to research focused on nanotechnology		NIST Nanotechnology Portal http://www.nist.gov/nanotechnology-portal.cfm

Appendix F. List of Acronyms

AAAS	American Association for the Advancement of Science
ATE	Advanced Technology Education (NSF)
CBAN	Consultative Board for the Advancement of Nanotechnology
CCR	Council for Chemical Research
cGMP	Current Good Manufacturing Process
CIMS	Center for Innovation Management Studies (North Carolina State Univ.)
CMOS	Complimentary Metal-Oxide Semiconductor
CNSE	College of Nanoscale Science and Engineering (State University of New York)
CNST	Center for Nanoscale Science and Technology (NIST)
COI	Community of interest
CPSC	Consumer Product Safety Commission
CRADA	Cooperative research and development agreement
CSREES	Cooperative State Research, Education, and Extension Service (USDA); as of October 2009, the National Institute of Food and Agriculture (NIFA)
DHHS	Department of Health and Human Services
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DOEd	Department of Education
DOL	Department of Labor
DOJ	Department of Justice
DOT	Department of Transportation
EHS	Environment(al), health, and safety
EPA	Environmental Protection Agency
EPSCoR	Experimental Program to Stimulate Competitive Research
EU	European Union
FDA	Food and Drug Administration
FHWA	Federal Highway Administration (DOT)
ICON	International Council on Nanotechnology
IGERT	Integrative Graduate Education and Research Traineeship
IP	Intellectual property
IPO	Initial public offering
IRI	Industrial Research Institute
ISO TC229	International Standards Organization Technical Committee on Nanotechnologies
ITRS	International Technology Roadmap for Semiconductors
MANCEF	Micro and Nanotechnology Commercialization and Education Foundation
MARCO	Microelectronics Advanced Research Corporation (a subsidiary of SRC)
NACK	Nanotechnology Applications and Career Knowledge Center
NAICS	North American Industry Classification System (codes)
NASA	National Aeronautics and Space Administration
NBA	NanoBusiness Alliance
NCI	National Cancer Institute (NIH)
NCL	Nanotechnology Characterization Laboratory
NCLT	National Center for Learning and Teaching (in Nanoscale Science and Engineering)
NCN	Network for Computational Nanotechnology

NGO	Nongovernmental organization
NIH	National Institutes of Health (DHHS)
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology of the Department of Commerce
NILI	Nanomanufacturing, Industry Liaison, and Innovation Working Group of the NSET Subcommittee
NINE	National Institute for NanoEngineering (Sandia Laboratory)
NISE Net	Nanoscale Informal Science Education Network
NMCC	National Manufacturing Competitiveness Council
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network
NNN	National Nanomanufacturing Network
NRI	Nanoelectronics Research Initiative
NSEC	Nanoscale Science and Engineering Center
NSET	Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council's Committee on Technology
NSF	National Science Foundation
NYSTAR	New York State Foundation for Science, Technology and Innovation
OCAST	Oklahoma Center for the Advancement of Science and Technology
OCKED	Oregon Council for Knowledge and Economic Development
OECD	Organisation for Economic Co-operation and Development
ONAMI	Oregon Nanotechnology and Manufacturing Initiative
ONI	Oklahoma Nanotechnology Initiative
OSTP	Office of Science and Technology Policy (Executive Office of the President)
PaNMCC	Pennsylvania Nanomanufacturing Commercialization Center
PCA	Program component area
PE	Private equity
PSU-NACK	Pennsylvania State University Nanotechnology Applications and Career Knowledge Center
RSL	Regional, state, and local (nanotechnology initiatives)
SAR	structure-activity relationship
SBIR	Small Business Innovation Research programs
SEMATECH	Semiconductor Manufacturing Technology Consortium
SRC	Semiconductor Research Corporation
STEM	Science, Technology, Engineering, and Mathematics
STTR	Small Business Technology Transfer programs
SUNY	State University of New York
SWeNT	SouthWest NanoTechnologies, Inc.
TIP	Technology Innovation Program (NIST)
USDA	U.S. Department of Agriculture, including the Forest Service (USFS) and the National Institute of Food and Agriculture (NIFA)
VC	Venture capital
WTEC	World Technology Evaluation Center

National Science and Technology Council; Committee on Technology; Subcommittee on Nanoscale Science, Engineering, and Technology

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