Annual Report of the National Nanotechnology Infrastructure Network

March 1, 2007 through Dec 31, 2007

Cooperative Agreement: ECS-0335765

ABRIDGED

***Participating Institutions**:* Cornell University, Georgia Institute of Technology, Harvard University, Howard University, Triangle Lithography Center (NCSU/UNC; affiliate), Pennsylvania State University, Stanford University, University of California at Santa Barbara, University of Michigan, University of Minnesota, University of New Mexico, University of Texas at Austin, and University of Washington.

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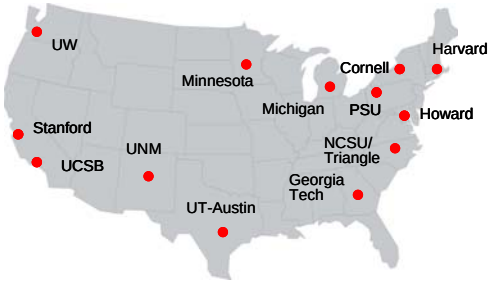
1.0 Executive Summary

National Nanotechnology Infrastructure Network (NNIN)
NSF Grant ECS-0335765
PI: **Sandip Tiwari**
Cornell University

Figure 1: Member institutions of NNIN.



The National Nanotechnology Infrastructure Network (NNIN) is a partnership of 13 university based nanotechnology laboratories (Figure 1), providing open access to nanotechnology resources and expertise to researchers across the country. NNIN provides the infrastructure that is an important means to achieving the objectives of the National Nanotechnology Initiative (NNI). It serves the critical objectives of facilitating research of the academic community as well as of industry and government. Nanotechnology spans the breadth of science and engineering disciplines and is a frontier research and development area for electronics, optics, materials science, physics, chemistry, and life sciences. NNIN provides the tools, training, knowledge, and affordable access for all of these areas so that new and existing researchers can pursue new nanotechnology research ideas without impediments. Each of the 13 NNIN facilities has significant equipment resources and expertise in one or more of the areas of nanotechnology. These resources are made available in an open environment with support from expert technical staff and an operating culture which encourages openness and sharing of resources (Figure 2). The network also has in place a national and local effort in support of education, public outreach, safety, and a thrust in examining the societal and ethical implications of nanotechnology and developing a consciousness of societal impact of science and technology in our user community.

Key to NNIN is its network-based strength that allows the assemblage to have an impact much larger than that possible from same sites operating separately. Because of the breadth of nanotechnology and its rapid expansion, no one site can provide the equipment or expertise over more than a fraction of the nanotechnology landscape. Within NNIN, each site has a particular area of responsibility and expertise based upon the needs of the network and its local technology interests and strengths, and is expected to provide

Figure 2: NNIN equipment, staff, and information resources in a network structure and a user-centric culture enable broad based support for users.

leadership through judicious use of the funds towards staff, equipment and the knowledge in support of the area of responsibility. Cornell and Stanford have the broadest scope and provide extensive support across the entire range of nanotechnology disciplines and applications. In addition, due to their larger resources they are most often best suited for wider interdisciplinary project and projects requiring complex integration. For biology and life-sciences, Georgia Tech and Washington; for chemistry at the nanoscale, Penn-State, Harvard and Texas; for Geosciences, New Mexico and Minnesota; for integrated systems, Michigan; for tool development and manufacturing research support, Texas; for remote use and characterization, Minnesota and New Mexico provide the focus technical area leadership. There is also considerable technical overlap between many of the sites. This provides backup technology and geographical diversity. By working together, the 13 NNIN sites are able to provide coherent nanotechnology resources across the entire geographic and technical landscape. Users who find that their requirements exceed the capability of the site they are working at can get assistance and support from other sites in the network. Similarly our facilities grow by taking advantage of the expertise available at other sites to expand their own scope. These characteristics derived from collectivism also benefit the broader activities that the network pursues and where geographic diversity brings additional strengths. The range of technology resources available within NNIN are summarized in Figure 3.

Approximately 200 new research users per month are being trained by the network. The network is also employed as a precious resource by more than 250 small companies. One of the key challenges to nanotechnology, as a multi- and inter-disciplinary area where many of the exciting ideas require cross-discipline use of techniques, is finding an efficient way for cross-training. As an infrastructure network, an efficient continuous transfer and cross-fertilization of the knowledge of these techniques and new developments is an important task for us. Our Technical Liaison staff (domain experts) support research at the boundaries of disciplines by day-to-day interactions, hosting site visits, and organizing regular workshops. Examples of areas where this has been very successful include the interface between life-sciences, chemistry, and the major disciplines of engineering. Use of soft-lithography, tools and techniques of biology and chemistry, and connecting them to electronics, optics, and MEMS are some examples where the staff provides strong support.

The NNIN website (http://www.nnin.org) is a major link and store-house of information to technical and non-technical community. It provides, technical know-how to the national community, provides detailed information of our resources (processes, tools, training media for users, technical talks, a search engine) and is a web-portal for

Figure 3: Major technology capabilities available from NNIN.

outreach activity for education and social and ethical discussions. It features a number of links, including recent examples of research made possible through the network. A number of these examples, which have received extensive recognition as important contributions, came about due to the ability of bringing diverse techniques together through the staff and through focus on user service.

Education, Development and Outreach: Education of the public, the workforce, and students at all levels is critical to the societal adoption of nanotechnology development. NNIN conducts a broad range of education and outreach activities at national and local levels addressing the needs of the public and of the education community. Our national activities take advantage of the visibility and national scope of NNIN, and of the critical mass created by 13 sites working together. Our local activities address needs and opportunities unique to each site. Together, they make a significant impact on nanotechnology education.

As part of our education and research support program, we organize local and national workshops and short courses that tie technical areas to research and to practical knowledge. Our web-site features a number of multi-media offerings related to education and outreach, discussion groups, lectures on the practice of nanotechnology, graduate-level lectures, and how-to lectures related to mentoring (art of scientific presentation or writing of scientific papers), as well as instructional material related to social and ethical considerations. The network also conducts a very successful Research Experience for Undergraduates (REU) program and a Research Experience for Teachers (RET) program. During 2007, 70 REU interns from institutions across the United States participated in the program. Sites also have activities focused on local needs, ranging from attracting underrepresented high school students to the field through enrichment experiences to support for the local teaching community – high school, community college and other small colleges. We are also active in workforce development through hands-on practical training, entrepreneurial workshops, speaking engagements at economic development events, and nanotechnology roadshows.

Societal and Ethical Implications: Integrated into our network activities are activities fostering the awareness of societal and ethical issues for practicing researchers, as well as creation of the archives and collection of data for future studies as the nanotechnology area evolves These activities are centered at Cornell, Stanford, Washington and Georgia Tech. During this year, the findings of an extensive survey of attitudes spurred a new user training module for ethical consciousness within the user community.

Example Research: With over 4500 users annually, the research output of NNIN is enormous and not easily digested. A collection of highlights from NNIN projects are attached as an appendix to this report. Other examples of research from NNIN are available on the web-site. A few brief examples related to engineering are provided in Figure 4

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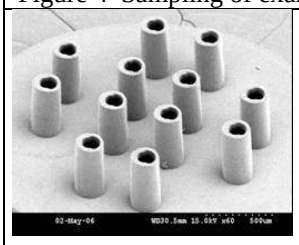
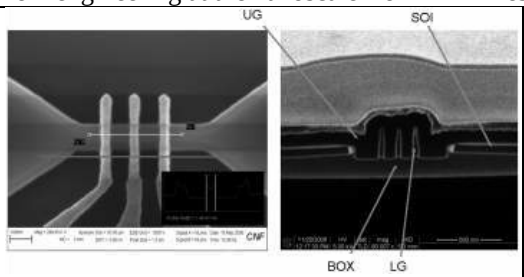
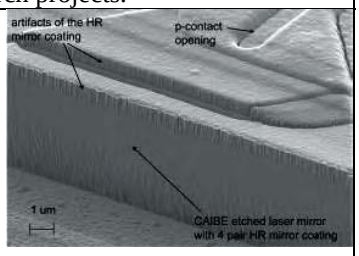
Figure 4 Sampling of examples from engineering at the nanoscale from NNIN research projects.

		
Microfluidic electrode arrays for biological recording. M. Allen, Georgia Tech	Silicon single electron transistor for sensitive electrical measurements. N. Zimmerman, NIST	Etched facets of a blue laser. Binopics, Ithaca, NY.

Summary: NNIN, nearing the end of its fourth year of operation, is now reaching out to nearly ~4600 research users nation-wide, ~250 small companies, has trained ~1600 new users during 2007 alone, and has been instrumental in several major recent successes in research – ranging from observation of quantum back-action in a superconducting single electron transistor, to ultra-small electronics to biological characterization. The educational, health and safety, and societal and ethical consciousness efforts of NNIN also continue to reach a wide audience.

2.0 National Nanotechnology Infrastructure Network

2.1 Introduction

NNIN is a network of open university-based laboratories organized to provide state-of-the-art infrastructure in support of nanotechnology research and development activities. Network resources span the broad fields of nanotechnology enabling users from universities, small and large companies, and state and federal laboratories to have access to state of the art facilities and expertise.

The network is focused on providing infrastructure to support nanotechnology research by "outside users" —students and professionals from institutions outside of NNIN. In NNIN's view, infrastructure consists of much more than advanced equipment (Figure 5). While an extensive set of state-of-the-art equipment is a necessary condition it is not sufficient for the operation of an effective user facility. Key to NNIN operation and thus a key part of the "infrastructure" are the culture and committed staff resources to enable effective use of nanotechnology equipment and the focus on service. NNIN's group of facilities are committed to this culture and operate as an organization supporting and complementing each other so that together, the network can be more effective.

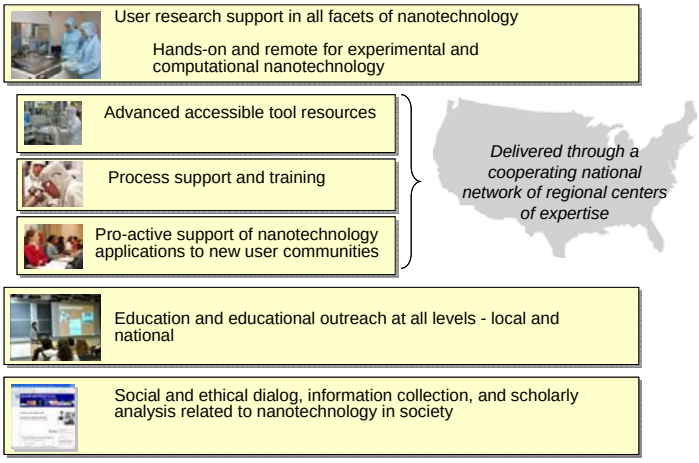


Figure 5: The scope of NNIN programs and impact.

NNIN enables researchers, experienced and novice, to make significant contributions to nanoscale science and technology without having to worry about the availability of equipment, the expense of maintaining equipment, the intricate development of knowledge for use of equipment, and knowledge of integrated processing where numerous materials and environmental interactions occur. Projects can be simple, requiring only one step or access to one advanced instrument; others can be very complex, requiring integration of multiple process steps and the use of novel materials. Openness to new materials is also a key feature on NNIN facilities. Nanotechnology extends far beyond semiconductors, soft and hard materials, and fabrication technology. Additional facilities and processes must be made available to handle this broader materials mandate. The ability and willingness to process new materials is critical for many emerging applications of nanotechnology to biology, materials science, chemistry, and quantum physics.

Within its 13 sites, NNIN supports both top-down processing (e.g. via advanced lithography) and bottom-up processing (e.g. synthesis, growth, etc). Increasingly, interesting applications of nanotechnology require simultaneous use of both approaches, for example, fabricated electrodes for measurement of macromolecules, assembly of molecular-scale films onto fabricated devices or surface-mediated molecular processes such as in block copolymers and selective binding. NNIN has the resources and expertise to support users in all of these approaches.

NNIN was established in March 2004 as a result of an open national competition for a nanotechnology infrastructure network to succeed the former National Nanofabrication Users Network (1993-2002). While funded through the ECCS division of NSF, funds for the network are drawn internally at NSF from most major NSF divisions. Primary NSF funding for NNIN is currently $14.0 M per year. Individual sites are funded, by sub-award, at levels ranging from $500,000 per annum to $2.5M per annum. Additional operational funding at each site is obtained in various amounts from university and state sources, from user fees, and from industry. The network also competes separately for funds from various NSF equipment and educational programs (e.g. MRI, REU, RET). A breakdown of budgeted NNIN funds is given in a later section.

NNIN is a network of "resource facilities" providing open access to state-of-the-art equipment and expertise. Personnel funded by NNIN are paid to assist others in research, not to perform research themselves. This assures that they are viewed by users as helpers not competitors, a critical tenet for effective user facility. The only research supported directly supported by NNIN is the research and exploration that occurs in the SEI activities (Social and Ethical Implications of Nanotechnology).

The vision of a nanotechnology future is also critically dependent upon the availability of appropriate human resources. Education, human resource development, and outreach activities are thoroughly integrated throughout the network. Our goals to spread the benefits of nanotechnology to new disciplines, to educate a dynamic workforce in advanced technology, and to become a teaching resource in nanotechnology for people of all ages and educational backgrounds, are served through a number of local and national educational programs.

As part of both its education and training programs, NNIN conducts workshops, develops educational tools, promotes and researches social and ethical dimensions of the technology, and engages in other activities of broad reach to help establish long-term social gains derived from discoveries and inventions from nanoscale science, technology and engineering. The network thus is a resource center for technology transfer and the sharing of new techniques, and provides a foundation for the education and technical training of new users who will be the leaders in the coming decades, and the network serves to educate the public about the opportunities and challenges of nanotechnology, and promote research in the social sciences so that future developments lead to the greatest possible societal benefits.

The network began operation on Mar. 1, 2004. This is the report of most of the 4th year of operation of NNIN — 10 months — March 1, 2007 – Dec, 2007. During the 10 months reported here (March 2007- Dec 2007), the network supported the research objectives of 4185 users from academia, industry and the national research laboratories. More than 250 small companies employed the network resources to reduce their ideas to practice. In addition, more than 14,000 students and professionals participated in NNIN educational activities, many of them gaining their initial hands-on experience with tools and techniques of nanotechnology. Details of NNIN operations are covered in the following sections.

2.2 Mission and Approach

NNIN's mission is to enable rapid advancements in science, engineering and technology at the nanoscale through efficient and affordable access to nanotechnology infrastructure (Figure 6). Our approach to accomplishing this goal is based upon:

- A cultural commitment of openness that focuses on external users,

- State-of-the-art equipment resource, distributed across sites, supported by a high level of technical staff expertise
- A commitment to technical excellence that focuses on bringing key instrumentation and knowledge to users
- Effective and leveraged use of scarce resources, enabled by the critical mass of users engendered by the user facility concept and the scope and visibility of the network,
- Geographically distributed resources with distributed technical responsibilities, building upon the research and technology strengths of each site while serving the broadest community, and
- A synergistic set of local and national educational activities to support education of users, potential users, the human resource pipeline, and the public.

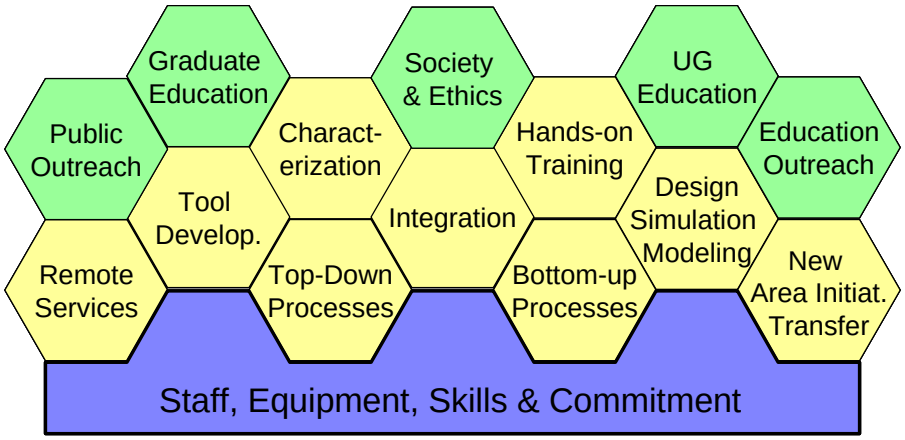


Figure 6: Interlocking NNIN Infrastructure and Activities

Accomplishing this mission requires that we place the highest priority to the needs of external users; each NNIN facility is focused on this aspect, with significant equipment, staff, and training resources devoted to accommodating both new and ongoing users from other institutions. Accommodating large numbers of new users arriving weekly and training them to operate safely and creatively in a shared-facility environment is the most critical aspect of network operation. With a high level of training and process support delivered by a dedicated professional staff, complex technologies such as e-beam lithography and complex multi-step integrated processing procedures can be made available to a large user community in an efficient and timely manner. At the same time, new techniques and processes, developed either by the staff or by the user community, can be efficiently and effectively made available for the mutual benefit of all users, at the site and across the network. This is a continuing improvement process that builds on experience, expansion of areas and emergence of new directions. This process rewards long term commitment by aggregating these gains over time.

The network is a distributed set of laboratories, each with distinctly local flavor, but all working to a common goal and with a common approach. This shared vision is critical to the operation of the network. To achieve this visison, all sites have committed to these common principles:

- Open and equal access to all projects independent of origin
- Single-minded commitment to service of external users
- Commitment to support interdisciplinary research and emerging areas
- Commitment to deepening social and ethical consciousness

- Facility control, not individual faculty ownership, of instruments and other resources
- Openness to new materials, techniques, processes, and applications
- Commitment to maintaining high equipment uptime and availability
- Commitment to comprehensive training and staff support
- Facility governance independent of interference from other local organizations
- Commitment to no intellectual-property barriers

These principles have served NNIN well, making it a uniquely successful national infrastructure resource.

Network activities are also directed towards encouraging underrepresented groups in the scientific disciplines and in propagating successful models across the network. Our outreach and educational activities are both national and local in scope. National activities are supported at all sites and take advantage of the critical mass and visibility afforded by the network as well as the diverse sets of resources we can bring towards a major effort; local activities are developed or implemented at specific sites in response to local interests and needs. Local activities supplement the national activities. For example, with participating universities located strategically in areas with large under-represented communities,(Howard in Washington DC, U. New Mexico in Albuquerque in the South West, Georgia Tech in Atlanta, and UCSB in Santa Barbara) we have strong programs for local outreach to specific minority communities. In all cases, sharing of activities and experience between sites provides significant leverage to our efforts. As these programs continue to develop, the successful efforts become models for development of across the network. Details of our education programs at both the local and national level are discussed later.

Together, these practices have established NNIN as a model shared laboratory environment that embraces interdisciplinary research and builds upon the nanoscience and nanotechnology expertise resident at each of our member sites. This infrastructure support for nanotechnology research enables NNIN to play a leading role in the development of the scientists, engineers and high-technology work force of the future. Through these activities and a thrust in examining the societal and ethical implications of nanotechnology, we directly impact the national scientific landscape that extends beyond the scope of nanotechnology itself.

2.3 Technical Expertise Responsibilities of Network Sites

The breadth of nanotechnology can not be covered by any one facility or by a set of identical facilities. NNIN sites are all different, for geographical, cultural, historic, and scientific reasons, but all operate within NNIN under the same guiding mission, vision and open approach. Each site has been assigned different responsibilities within the network, some with responsibilities in traditional areas and others with primary responsibilities in emerging areas such as geosciences and life sciences. Some sites have been assigned leadership positions in certain thrust areas, while others are contributors. This ensures that leading state-of-art resources are available at these sites directed towards these areas. Similarly, responsibilities for education and SEI activities are distributed across the network. We obtain efficiencies in the use of the scarce financial resources by leveraging the individual sites' research strengths to provide network technical leadership in each major technology area. This provides a path for new developments, knowledge and ideas to become nationally available in a timely manner.

The network consists of 12 funded sites and one unfunded affiliate. In order to address the broad scope and to provide the most advanced technical capabilities within limited financial means,

sites are assigned specific specializations based on internal research strengths (Figure 7). All sites have responsibilities towards education and outreach activities, with major efforts at Howard University, University of New Mexico, Georgia Institute of Technology, and University of Washington towards under-represented communities. Figure 5 provides a summary view of these responsibilities as viewed from focus areas; here these are described with an institutional view:

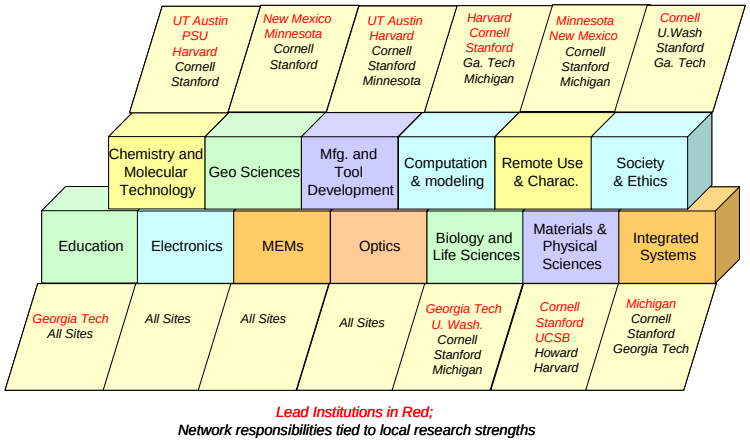


Figure7: Technical responsibilities of NNIN sites.

- **Cornell:** The Cornell Nanoscale Science and Technology Facility, CNF, along with the facility at Stanford, has the task of providing broad capabilities across biology, chemistry, MEMS, characterization, electronics, materials, and optics, with special focus on complex integration. Leadership of the network SEI activity (Prof. Douglas Kysar) resides at Cornell, and Cornell also has responsibility towards nanoscale scientific computation support. Management of the network also resides at Cornell within the NNIN management office.
- **Stanford:** The Stanford Nanofabrication Facility is broadly responsible for user support across the entire range of nanotechnology, including capabilities in biology, chemistry, MEMS, characterization, electronics, materials, and optics, and complex integration. Stanford is also responsible for providing computation and modeling support and to participate in scholarship activities in social and ethical investigations. The network's health and safety efforts are coordinated from Stanford with Dr. Mary Tang as the network coordinator for these activities.
- **Georgia Tech:** Georgia Tech is responsible for leadership in the Biology and Life Sciences efforts for research and applications of nanotechnology. Georgia Tech also provides expertise in electronics, MEMS, and optics, and participates in SEI activities. In addition, the network's efforts in education and outreach are coordinated from Georgia Tech with Dr. Nancy Healy leading the effort.
- **University of Michigan:** The Michigan Nanofabrication Facility provides technical leadership within the network in integrated systems with particular focus on integration of MEMS, micro-fluidics in order to create systems for biological sensing and other applications. Michigan also contributes to computation effort of the network.
- **University of Washington:** NNIN services at the University of Washington are provided through the Nanotech User Facility. U. of Washington has specific responsibility for serving the biology, medicine, and life sciences communities in their

needs for nanotechnology, participates in the SEI activities and has leadership responsibilities for outreach activities.

- **Penn State:** Penn State has specific NNIN leadership in the area of chemical nanotechnology with a particular focus on molecular-scale science, engineering and technology support.
- **UCSB:** The laboratory at UCSB has network leadership responsibilities towards support of electronic materials and physics applications of nanotechnology, and to provide outreach support towards underrepresented community locally.
- **Texas:** The University of Texas has responsibilities to support chemistry and chemical nanotechnology. U. Texas also has responsibilities for tool development for nanotechnology and through related activities support of manufacturing research.
- **Minnesota:** The Minnesota NNIN Node (MINTEC) consists of the capabilities of three laboratories: the characterization facility, and the particle technology lab and the fabrication facility and takes quite a different form the other NNIN sites which are under a single umbrella and primarily a clean-room centered operation. Through the former two laboratories, the Minnesota site is expected to provide NNIN leadership in remote access characterization and in particles and nanomaterials, an area of concern for health and safety in our society. Particles, characterization and nanoporous materials are also the primary current areas of effort in NNIN towards the Geology community.
- **New Mexico**: Similar to Minnesota, Nanoscience at the University of New Mexico provides expertise in nanomaterials and materials characterization, again with strong interactions with the Geology community. U. of New Mexico also has leadership responsibility in outreach to underrepresented community in the southwest area.
- **Harvard:** The Harvard node is located within the Harvard Center for Nanoscale Systems. Primary responsibilities for Harvard are leadership of the network in chemical nanotechnology, including synthesis and soft lithography, and the network leadership in computational effort in support of nanotechnology. The network computation activities are coordinated from Harvard and are led by Dr. Mike Stopa.
- **Howard**: The facility at Howard supports a variety of specialized materials activities and has major educational and outreach responsibilities towards underrepresented community in the Washington DC area.
- **Triangle National Lithography Center (NCSU/UNC):** The Triangle Lithography Center is an affiliate member of NNIN with the objective of providing access to 193 nm deep ultra-violet lithography. They receive no funding from the network for participation but agree to operate the DUV facility on an open basis, consistent with NNIN principles, and NNIN commits to redirect users who can gain from this resource to TNLC. TNLC has decided to withdraw from the network, effective Jan. 15, 2008.

Site specific reports are contained in Appendix 1 as submitted by sites and describe the progress of the sites towards their objectives.

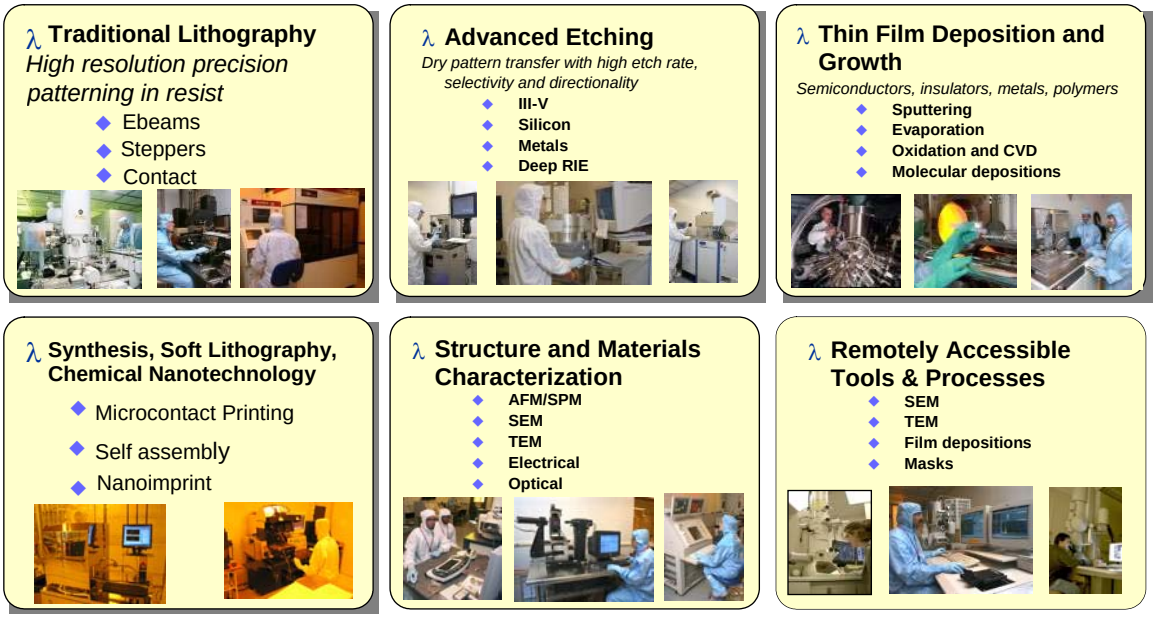
2.4 NNIN Technology Resources

Critical to any user facility or network of facilities is modern state-of-the-art equipment and broader technology resources including the knowledge experience that is part of the “art of new technology” that precedes the comprehensive understanding and robustness derived from experience and careful theory. The equipment must be well characterized and well maintained,

and users must be trained and supported in its effective use. NNIN's tool set is worth many hundreds of million dollars with significant resources available to support all the facets of nanotechnology research. Some of the available technologies are highlighted in Figure 8.

In most cases, a number of other nanotechnology resources and capabilities also exist at each site, outside of the NNIN-defined scope. In many cases these resources are part of other NSF funded centers. These resources, in most cases, are made available to the user community through the NNIN program if their use can help with completing the task, but they are not part of the program itself and funds are only employed within the NNIN-defined and NNIN-committed areas. Our goal is to provide service and help the user rapidly accomplish tasks with the highest level of technical support.

Figure 8: Major technology capabilities available from NNIN.



The network plays a vital role in identifying nascent disciplines and interdisciplinary research programs that can make use of nanotechnology. To be a "national resource" for knowledge and information related to nanoscience and nanotechnology and activities aimed at developing interest and understanding of science in the society, NNIN utilizes workshops, dissemination at professional societies, user exchanges, and other participatory activities. These activities plus \feedback from the advisory board and users keep sites abreast of new research in nanoscale science. This feedback sets the agenda for the development and utilization of resources required to rapidly exploit these advances – through equipment, knowledge and training for the emerging directions and fields. In turn, this feedback helps decide the direction of future investment in staff, processes, and equipment.

The replacement cost of equipment resources (excluding buildings) of NNIN facilities is many hundreds of million dollars. Over 900 major fabrication and characterization tools are listed on the tool database of the NNIN web site. While some of this equipment is new, acquired within the last few years, much of it is five or ten years old, or even older. It is a testament to the facilities that they remain effective resources. Only a very small fraction of the NNIN funding (average < 10%) at each site is available for equipment purchases and upgrades. This is

inadequate to cover even the depreciation on existing equipment. The equipment facilities have been built up over the years, predominantly by a variety of other means including state funding, university funding, gifts, research center awards, faculty grants, and equipment competitions such as MRI. The strength of the local faculty research programs at each site in the assigned technical areas is to a large extent responsible for the ability to obtain new equipment resources for the NNIN facilities. All users of NNIN facilities benefit from this leverage.

Despite the fact that there are hundreds of users each week using hundreds of pieces of major equipment, equipment damage is rarely an issue. This is a testament to the training the users receive, their appreciation of the resource, the quality and robustness of the equipment, and the skill of the staff in providing effective preventative and corrective maintenance.

2.5 Practices for User Support

There is both an art and a science to the task of supporting users in a user facility, practices which have been developed by NNIN sites over the last 30 years. While simple to explain, they are difficult to implement in a traditional university environment. Through the leadership of NNIN, the participating sites in NNIN have adopted, implemented, and embraced these methods. This section summarizes the NNIN practices and mechanisms implemented by NNIN to enable effectice research and development support.

The User Facility Concept

The facilities of NNIN are resource facilities, i.e., the primary mission of NNIN and its individual sites is to facilitate the research of others. This is accomplished by providing equipment, processes, staff support, and instruction to all feasible projects. The NNIN sites are specifically not research centers and NNIN is not a research program. This is an important distinguishing characteristic from the large array of STCs, NSECs, MRSECs and other research centers supported by NSF and others. While the facilities of these research centers may be available to some collaborators, they are primarily maintained to support the research mission of the center; furthermore, such research centers rarely have the staff or user support mechanisms in place to assist users from other unaffiliated research programs. The NNIN facilities thus do not have a particular research thrust or a portfolio of research thrusts. As a result, NNIN does not fund research at the site by resident faculty or staff. Similarly NNIN does not directly fund user projects from outside users. The user base thus defines the direction of their research in NNIN, and we avoid the variety of conflicts that arise between research itself and research support through this clear distinction.

That being said, at most NNIN universities there are resident research programs —NSECs, MRSECs, NIRTs, etc, as well as non-NSF centers — which use the facilities heavily and provide critical knowledge and information. These programs, related “research centers”, and their associated students provide much of the technology base, process development, and process characterization at each site. A prime tenet of NNIN is, however, that all users are equal and the facility is equally open to all. NNIN sites are expected to clearly separate research tasks from the user facility tasks so that even researchers from competing research programs have fair access to all site technology. The NNIN facility staff is distinct from any associated research staff. This separation is a cornerstone of NNIN operation and distinguishes the NNIN from other organizations.

NNIN sites operate as user facilities, not dependent upon research collaboration. Access by “collaboration”, the common mode at other centers for accessing equipment and expertise,

comes at a heavy price, paid by intellectual freedom and intellectual property, which many users are unwilling to pay. NNIN grants open access to all without strings. Our users come for a short period of time (days, weeks, and months depending on the task) for access to our laboratory facilities without disclosing their intellectual property. They have open access to the instruments, the staff, and the knowledge infrastructure of the "user facility". The researcher can use the facility quite independently, having learned the instruments, or can seek extensive help offered by the staff. The NNIN staff is available to assist but not to take control of a project. The user can, and often is working in direct competition to local researchers. Access is on an equal basis and the intellectual direction of each project remains with the user, and the beauty of this openness is that the research community at large can leverage broader or complementary knowledge to focus specifically on their ideas and interests for best and timely results.

NNIN User Access Process

The process for gaining access to NNIN labs can be brief, spanning as little as a week or two from initial contact. It is intentionally kept brief and unencumbered to facilitate access by users with new and exciting ideas. It begins when a potential user calls or sends email to an NNIN site or to NNIN management with a brief project outline. A discussion ensues with the site user coordinator to clarify the requirements. Depending on the level of sophistication of the user and the proposed process flow, a subset of the NNIN staff may enter the discussions to work out an acceptable process plan. At any time a project may be referred, in whole or in part, to an alternative NNIN site which is better suited to the task, and NNIN coordinates efficient conduct of the tasks across sites.

After it is agreed that a project is feasible, a brief proposal, one or two pages, is written to document the agreed upon scope. It is extremely critical by this point that the user expectations are consistent with staff expectations, and that the project is manageable within the resources of NNIN. A brief standard memorandum of understanding is signed between the NNIN facility and the outside institution. This is not treated as sponsored research contract, merely a purchase of services. Limited administrative burden is imposed by the NNIN site. If the user is ready and able he/she is assigned the next available slot, which can be as soon as the next week but should always be less than a month away. New users are accepted into the NNIN facilities weekly. Some of the larger NNIN sites can accommodate 10 new users each week, and through special efforts, more than that during the summer period Almost 1400 new research users were trained and entered NNIN facilities in 2007 (10 months, Mar-Dec).

User projects are accepted without further scientific peer review, predicated on the assumption that the funding process of the research has taken care of this essential task. The projects, however, are "reviewed" by the site staff to assure that they are appropriate to the available toolset and that the proposed materials are compatible with the available processes.

All NNIN facilities have well developed orientation methods to familiarize users at all levels with our expectations for use and safety. Safety and rule compliance is extremely critical in a multi-user facility, and even more so when users come at a variety of skill levels from varied institutions and backgrounds. NNIN staff is assigned to provide user support for each outside user. Training is provided by staff for all the necessary tools and processes to complete the project, and some level of process integration support is provided. All this training must be delivered efficiently and expediently as the user is resident for a short period of time and needs to keep making progress. NNIN sites are well accomplished at this.

NNIN's procedures and operation that a user sees can thus be summarized as follows:

- First contact is through the web, email or by phone
- Project is discussed with user program manager. Project may be redirected to an alternative site if appropriate. Multi-site task, if necessary, is coordinated through Network Access Committee.
- User consults web resources (process libraries, on-line training, …)(Figure 9) to define first impression of how a project may be accomplished. User also talks by conference phone at a regular weekly meeting with a group of technical staff to refine the approach.
- User submits a 2 page maximum technical description of work and signs a memorandum of understanding. User's responsibility includes not disclosing their intellectual property.
- User visits site (typically 2 week, or as appropriate) to begin work
    - User has a staff host for the first visit
    - User receives safety training
    - User receives consultation and support to further refine the practice of the project
    - User receives equipment training
    - User performs fabrication and characterization with staff support during the first visit
- User evolves to be an independent user who can come and go and use the facility without any further permission for equipment and processes that the user is trained for.

For NNIN users this process addresses the key issues —getting access to equipment expediently, having access to the right equipment to do the job, receiving adequate equipment training, and receiving adequate project and process support from experts, all enabling rapid research program. And lastly, it assures that once fully trained, the user is not dependent upon anyone but can work at his/her own pace. This plateau is attractive for both graduate students and professionals and can be achieved in a relatively short period of time (weeks to months). A side effect is that the equipment training and process support received are portable; the student can return to his/her own university better prepared to use existing resources available there.

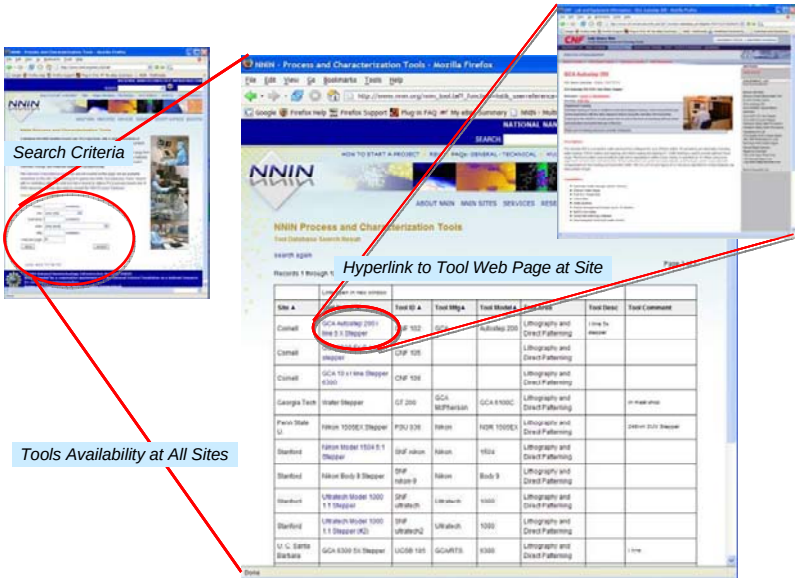


Figure 9: NNIN equipment database with links to tool information at appropriate site.

As nanotechnology reaches into new fields and brings new researchers into existing fields, many users have little or no relevant laboratory experience. It is NNIN's task to provide them the necessary support to be successful. Other users may have significant processing experience. They already know what they want to do and they come to NNIN looking only for equipment

access and basic tool instruction. NNIN support mechanisms are flexible enough to handle both of these extremes.

Users may visit for a week, or a month, or longer. A duration of a few weeks is most typical for first time visits. There are also many users who are permanently resident at the facilities, i.e. technically they work for another institution but they live at the NNIN site and use it everyday. They "reverse commute" to their home institution when necessary. To facilitate the out of town user visits, some sites provide low cost housing for daily rental. In some areas this is not practical, however. Nonetheless, travel costs are generally small compared to other costs of research.

NNIN Project Support , Process Support, and Training

NNIN facilities are primarily hands-on facilities. Users are trained by the staff to become self sufficient. Some processing can be performed remotely (staff working for the user), but this is generally limited to simpler process sequences, i.e. we do not operate as a foundry of complex integration. The execution of a complex multi-step process sequence is itself a research project, and must be performed by the user and not by the staff working remotely. Most users, from academia or industry, are performing research and development and wish to be part of the hands-on process of research - to learn from the staff, and become self sufficient.

Each site is responsible for providing sufficient staff resources to enable comprehensive training and support for external research projects. Currently, NNIN trains approximately 1800 new users per year, with a total of over 4500 different users taking advantage of NNIN facilities each year. Safety training is mandated for all users prior to any activity. Each external user project is assigned to a staff mentor who is the primary contact for the technical support. This is particularly important for new users and for users from outside the domain of electronics. Instruction in all phases of nanotechnology is provided as necessary in addition to direct equipment instruction. The NNIN staff act only as facilitators; the technical and intellectual direction of each project remains with the user. As projects progress, users become more independent of NNIN staff support, many to the point of being self-sufficient. NNIN staff remains available, however, to provide support as necessary.

Training protocols vary by site and by instrument. Equipment training is provided hands-on, either one on one or in a group, and on the web via multimedia. Some training is provided on a fixed schedule, others on demand. Every effort is made to provide both expeditious and effective training. New users are accommodated into NNIN facilities every week, and training sessions on individual tools are conducted daily.

In addition to normal support staff, NNIN has a small set of technical liaisons called "Domain Experts." These are senior staff members, typically Ph.D.s, who are scientists and experts in nanotechnology applications in a particular field and who can be non-competitive peers of potential users. They are particularly valuable in establishing the interface to new technical communities, as they have the necessary scientific background, but also have sufficient academic training and standing to converse in the specifics of the potential user's field. They perform an important matching function to new user communities. Even these technical liaisons, while interacting at a high scientific level, are careful not to take ownership of the user's project. NNIN maintains technical liaisons in the life sciences, in chemical nanotechnology, in geosciences, and in materials characterization. Details on these individuals are available on the NNIN web site.

Critical mass

For the effective operation of user facilities, a critical mass of users as well as a critical mass of equipment is necessary. A large diverse state-of-the-art equipment set is obviously critical to a successful user facility. But a facility can only afford to have a large set of equipment if it has a large set of users, i.e. a critical mass of research support. Similarly it can only afford to maintain a large set of equipment with high availability if it has a large set of users. Complex integration tasks also bring very interdisciplinary knowledge-intensive demands which benefit from the process knowledge developed by a large set of users. The critical mass of users enables a large equipment and knowledge base, and is in turn necessary to continue to attract and maintain the critical mass of users. NNIN, through its networked operation, makes this easier to achieve and in turn influences the research of a larger community of users enabling the spread of the technology knowledge on a wider basis. Also, in the face of equipment failure, through the network and its critical mass of users and distributed sites, high availability can be maintained through redundancy within sites and between sites.

Typical university laboratories have less than a critical mass of equipment, at least with respect to the most demanding applications across a broad area. Very specialized facilities can be very successful but are limited to a small niche. Research often drives projects outside of those niches, however. Certain necessary processes are impossible or at least unreasonable, thereby limiting the expansion possibilities of the research. Such a facility often has less than a critical mass of users to support an expanded tool set. NNIN plays an important role in supplementing and supporting these facilities. In some cases, for users from quite small institutions, NNIN facilities provide the entire research resource. In most cases, however, the home institutions of NNIN users have some facilities; the availability of NNIN resources allows this research to expand outside its normal limits by providing supplemental resources. The impact of NNIN thus expands far beyond just counting the number of hours in each NNIN facility. Not only are NNIN facilities productive, they enable other facilities to be more productive. NNIN seeks to cooperate not compete with such home facilities. We realize that eventually many of our current users will acquire adequate resources at their home institution to no longer need NNIN. There will, however, continue to be a stream of new users with new, more advanced, technical demands to replace them.

Access to Process and Technology Information

The staff and the prior users of NNIN facilities have developed and characterized large number of processes and process sequences. One of the powerful aspects of open user facilities is that this information can be shared among a larger group of researchers. While not all users are able or willing to share, a considerable amount of technical expertise is available. For many projects, the staff is the conduit for this technology exchange. In other cases, training sessions and written documentation are used. For on-site users as well as users planning visits, the NNIN website documents the array of tools and technology available from NNIN and is updated regularly. It provides the means to analyze and understand the resources of individual sites, where specific resources are available within the sites, and a variety of the process and training knowledge necessary in the use of many of the instruments.

While there is a large array of tools and technology listed here, nanotechnology is broad and has continuous stream of new approaches, new tools, and refinements of older techniques ongoing. Many tools, available for donation, are not suitable for the smaller-scale NNIN lab operations. This is particularly the case for wafer-based manufacturing tools where the wafer sizes are now

well beyond the size appropriate to our facilities. In addition, installation and facilitization costs can be prohibitive. Renewal of the capital resource and its expansion to meet new technology demands remains a critical and continuing issue within NNIN and we work on it through judicious use of resources and by following multiple acquisition paths.

A major portion of NNIN support goes to employ staff, as the major NNIN tasks are staff intensive. For example: maintenance of equipment to high up-time is staff intensive; user support (training and process assistance) is staff intensive; and process characterization is staff intensive. While some process characterization can be supplied by local users, for the most part, these tasks must fall to the professional staff. Our technology liaisons (domain experts) are a critical element in the knowledge transfer in the newer areas where instruments and techniques cross disciplines. Biology, chemistry, computation, biomimetics, mechanics, electronics, geology, etc. all have a variety of exciting projects that take advantage of new developments in another of these areas. In addition to the technology through the tools, the knowledge of practice available through our staff is a critical resource provided by NNIN to our user community.

2.7 NNIN Promotion Activities

NNIN's activities aimed at supporting information dissemination and utilization of the technology resources take a large number of forms ranging from physical presence, talks and instruction such as in professional society meetings or workshops, to use of internet and communication based resources such as the web-site, monthly newsletter, and training and instruction media (Figure 10).

Direct Contact

These activities are planned in order to reach the professional communities that would benefit from the infrastructure resource. Primarily they take two forms: (a) participation in professional society meetings and (b) NNIN-organized workshops that bring professionals to NNIN sites. Our presence at professional society meetings includes invited talks, booths at which our informational material is dispersed and where our staff can talk individually with potential users. We have two booths that can be used in exhibiting at conferences together with supporting posters and literature. During 2007, NNIN participated in the American Chemical Society Spring Meeting; the Materials Research Society (Fall and Spring); Electron, Ion Photon Beams and Nanostructures; Society of PhotoInstrumentation Engineers-Microlithography; American Vacuum Society; and National Science Teachers Association. Our presence at these events allows us to have an extended conversation with potential users leading to discussions of how the network resources can be brought to bear for the users' needs.

Figure 10: NNIN advertises itself through multiple ways including brochures and presence at professional meetings for interactions with users.

Workshops that are held at individual sites allow us to interact with the community for an extended period of time. Many of the people who attend these workshops are interested either in

learning more about a specific area, or are using the opportunity to advance their learning and in many instances checking through hands-on experimental experience the viability of trying their ideas at NNIN sites. For all sites, this mechanism is perhaps the most powerful mechanism for building trust in the user regarding the capabilities of the sites and the user's ability to complete a project effectively. During 2007, significant hands-on training workshops were conducted at Cornell University, Harvard University and Georgia Institute of Technology, for example..

One example of tremendous success of workshops is the computation and modeling effort from NNIN. This effort, started in 2004, has rapidly expanded to a large community because of workshops conducted at Cornell University and Harvard University that brought together a large group of interdisciplinary users who were interested in modeling transcending their own disciplines. At this point, as a result of the national user community that has been built up accessing a large variety of codes related to nanoscale science, we are now encountering resource-limitations. The effort however, has provided a very powerful mechanism for the computational science community as well as for experimentalists who want to take advantage of the theoretical tools from their own and from other disciplines in defining new directions. This success has been an example similar to that in experimental research with an entirely different type of networked resource where staff assistance and open availability has allowed wider use.

Web, Electronic Resources and Contact

NNIN's website and electronic newsletter to an expanding community are an indirect resource for promotion of NNIN. The newsletter summarizes the coming period's activities including workshops and new offerings for research and education. The website also announces activities on its main page. The website itself is very extensive. Our website located at http://www.nnin.org is a portal for users and the public to NNIN activities. The site is database driven to allow easy updating and permission based editing of selected sections by each site and is organized as the main technology and overview site for both users and the public. This is accomplished through a series of sub-sites, or Portals, that can be viewed as standalone sites or as part of the larger NNIN universe.

NNIN's main webpage (Figures 9 & 11) emphasize research user support services offered by NNIN. Care is taken to explain to new visitors the mode of operation of NNIN as an open user facility and to explain the scope of services available. Extensive information is then given to allow a potential user to assess the capabilities of NNIN to meet his/her needs. Major functions include:

- How to start a Project
- Frequently Asked Questions
- Site Information
- Searchable Tool Database
- Process Capabilities Table
- Mailing Lists and Contact Info
- Multimedia Seminars and Instruction
- Technical Liaisons
- Events

Figure 11: NNIN Web Site

The entire site is searchable, via free text or assigned keywords.

Extensive multimedia and instructional content is available within the NNIN web site. These resources have dual appearance, appearing both as instructional materials for users in the main NNIN web site and as educational media within the NNIN Educational Portal. The linked web pages from this main webpage include portals (education, society and ethics, computation, children's magazine *Nanooze*) which are extensive gateways to a large body of information, and the technology information infrastructure of the central research and development support mission of NNIN.

The NNIN education portal is a self-contained site within the main NNIN site designed to appeal to mixed and generally less technical audiences—students, teachers and the general public. It is thus more easily navigable than the NNIN site, with more emphasis on graphical display of information and events (Figure 12). Events and activities and information that would be of appeal to a wide audience are presented on the front page. Additional information and events are sorted into separate sections for the main audiences: K-12, teachers, undergraduates, graduates and professionals and public. The site is a repository of all the training materials, lesson plans, and activities developed by NNIN sites that have been found useful. In addition, content generated outside NNIN may be distributed by mutual agreement. The site features a custom back-end tool for managing content on a rotating basis.

Figure 12: NNIN Education Portal

In addition to network content, the site contains summaries of educational activity at each site.

Nanooze, NNIN children's science web magazine, is a separate "kids" site within this umbrella, or directly accessible at http://www.nanooze.gov. Nanooze was developed at Cornell University in collaboration with Prof. Carl Batt This magazine is also featured at http://www.nano.gov, the NNI web site. The target group for Nanooze is grades 3 through 8 and it is written at a level and style appropriate for this age group. Nanooze is organized into four main sections: a primer, original articles, Web blog on interesting science topics in the news, and interviews with scientists and engineers. The original articles address interesting topics in nanotechnology, often taken from current events. Interactive science learning games are also available. An Editorial Board of teachers and a testing group of children advise the developers on matters of content. Nanooze is also available in Spanish and Portuguese on the web, and in print in English only.

Figure 13: NNIN SEI portal

The NNIN SEI portal (located at sei.nnin.org) is the central face for SEI efforts within NNIN (Figure 13). The site is intended as an archive of all materials related to Social and Ethical Implications of Nanotechnology and act as a resource and a research tool for the SEI community.

3.0 NNIN User Research Accomplishments

The success of NNIN's research infrastructure efforts are ultimately shown by the research results of its users, by their publications and patents, and by the contracts won and products developed. Digesting the research output of more than 4000 individuals each year is a daunting task. Even collecting publications is challenging as it demands response from users and because of the delay between the research and the publications. None the less we have collected over 4300 publications and presentations from the period July 2006-June 2007 resulting from work of NNIN users. These are included as an appendix in this report. We expect that due to collection efficiency the number of outside user publications is significantly undercounted. Even more significant example of NNIN impart are those publications cited on the journal covers particularly high impact publications.. Some of these are highlighted in Figure 14.

Research highlights (nuggets) have been collected from each NNIN site, a total of more than one hundred forty examples of NNIN impact. These are included in an appendix to this report. Because of issues related to the release of intellectual property, the examples are more heavily weighted toward academic projects than our industrial projects.

Figure 14. A sampling of some of NNIN projects features on major journal covers.

4.0 Education and Human Resources

4.1 Objectives and Program Challenges

In completing its fourth year of operation, the NNIN Education and Outreach (NNIN E&O) program has grown dramatically from offering just a few activities at local sites to having numerous activities that are offered at the local and network level. The graphs below (Figures 15 & 16) demonstrate how the program has grown since we began collecting data on events in 2005.

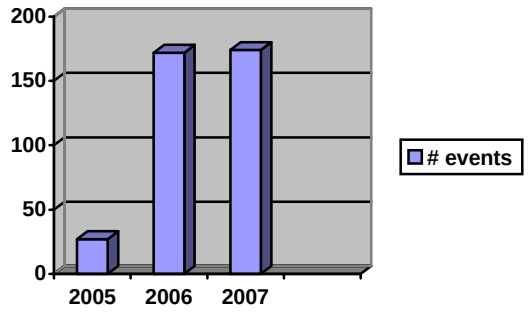


Figure 15. Number of NNIN educational Events annually (calendar year).

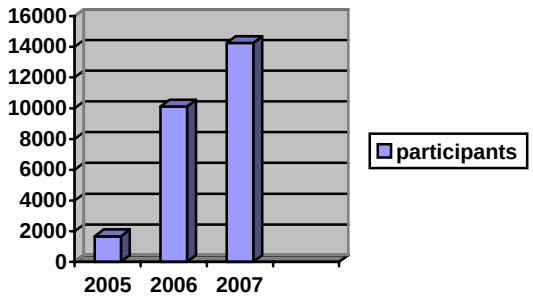


Figure 16. Number of annual participants in NNIN educational events and activities.

To set the framework of our activities, it is important to understand our goals and objectives. NNIN seeks to provide a wide variety of educational outreach that spans the spectrum of K-gray, i.e. school aged children through adult professionals.

NNIN has established the following goals for its network-based educational outreach and training:

- Expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering;
- Train teachers about the discipline of experimental sciences, provide additional teaching tools, and enhance their enthusiasm for having students pursue careers in science and engineering;
- Create and distribute educational materials for children, college students, technical professionals, teachers and the general population, as well as improve the understanding of and involvement with science, technology, engineering, and mathematics;
- Focus these efforts on population segments having disproportionately low employment and education in sciences, including women, disadvantaged minorities, and the economically disadvantaged.

From these overarching goals, specific programmatic objectives have been established that impact national or local efforts. These include:

- Developing and distributing activities to encourage K-12 students to enter science and engineering fields;
- Developing resources to inform the public about nanotechnology;

- Developing activities and information for undergraduates regarding careers in nanoscience;
- Developing tools and resources for undergraduates and graduate students that focus on teaching and learning and research;
- Designing programs to ensure the inclusion of underrepresented groups;
- Developing programs for technical workforce development; and
- Developing programs and resources for K-12 teachers.

This report provides updates of our accomplishments and current programs that are both local and national in focus. This report does not fully describe the breadth of activities that are occurring in our education and outreach programs but does provide an overview of our activity during the past year. Our programs reached approximately 14,000 individuals during the past twelve months.

To attain each of the NNIN's education objectives, a variety of innovative activities have been defined, developed, and implemented. NNIN E&O components include network-wide programs to address needs at the national scale and more specific efforts for communities that are local to network sites. Table 1 illustrates the type of programs offered by NNIN and their scope across the network. The various facets of the NNIN E&O program are reviewed in the following sections.

Table 1. Local and National NNIN education activities and programs

	Site Specific Activities	**Network Wide Activities**
Local Scope	Site Activities-Local Scope	Network Activities-Local Scope
	Facility tours Community days Open house Seminars/Public lectures School programs	User support & training Diversity K-12 education- school programs Summer & after school camps
National Scope	Site Activities-National Scope	Network Activities-National Scope
	Workshops Technical Training Teacher Training Research Experience for Teachers (initial program) K-12 instructional materials Hands-on demos & experiments Undergraduate education	National Conferences & Meetings Research Experience for Undergrads RET (NSF award) NNIN Education portal User support Diversity Open Textbook Nanooze

4.2 Coordination and Collaboration

The challenges of any large-scale activity center on coordination and communication. Each NNIN site has a full-time or part-time education coordinator. The NNIN Site education coordinators have established a communications network which effectively allows us to refine our work plans, establish short and long-range plans, and ensure continuous communication and collaboration among the sites. The network coordination of NNIN E&O occurs from the Georgia Institute of Technology and consists of phone, e-mail, and face-to-face meetings. Dr. Nancy Healy serves as the Network Education Program coordinator.

The education site coordinators meet one to two times per year at one of the NNIN sites for a minimum of two days. The NNIN E&O program has reached a point where sharing of ideas, approaches, and materials is a regular practice among the sites and occurs outside our scheduled meetings. During the past year, the coordinators met at the University of California Santa Barbara (January 17-19, 2007) and will meet at Georgia Tech February 27-29, 2008. They also meet informally at the NNIN REU convocation and at various professional meetings and conferences.

An additional challenge with a large, distributed program is keeping accurate records and conducting thorough assessments of our activities and resources. Because of the wide variety of activities across the sites, it is important to track the types of activities, the duration, the impact in terms of numbers served, etc. The NNIN Education Coordinator and Program Manager worked with the NNIN web service provider to develop a custom activity/event database with user interface, the Education Events Manager, which was implemented in 2006. This tracking system for education efforts is regularly updated by individual sites with Georgia Tech and Cornell monitoring the entries and using the system to generate reports.

4.3 NNIN REU Program and RET Programs

NNIN REU Program

The NNIN has developed, operated, and managed a highly successful Research Experience for Undergraduates (REU) Program in nanotechnology since 1987. It is a cornerstone of our education effort and a model for coordinated network activity. Our program hosts 60-80 students each summer distributed among the 12 participating NNIN sites. This program enjoyed separate support from the NSF REU Program from its inception until 2005, with supplemental support from NNIN sites. The program was entirely supported by NNIN for the summer of 2006. In 2007, NNIN was again awarded support from the NSF REU program for 25 students. This was well below what we believe to be the critical mass for this program estimated as a minimum of 5 students per site. Because of the priority which NNIN attaches to this program and the success and popularity of the program, additional funds from the NNIN management budget were allocated to sites to assure a minimum of 5 students at each of 12 sites. Ten additional students were supported by site or industrial funds to make a total of 70 students.

Our program offers a well-supervised independent research project for a 10 week summer period. While individual sites are responsible for daily project supervision, there is strong network coordination to assure a uniform program with high expectations. Our program features a central on-line application process for the entire network program.

Our program draws top quality participants from a diverse applicant pool. Due to the size and visibility of our program, we have been successful in recruiting a large number of women, minorities, and students from non-research institutions (non-doctoral granting). Our program remains a popular choice among students with 403 applications received in 2007. We have been committed to providing research opportunities to students who have the most to gain from the NNIN REU experience—67% of the 2005, 53% of the 2006, and 75% of the 2007 participants had no prior organized research experience. Table 2 shows the demographic make-up of applicants, participants, and their type of home institution for 2005, 2006, and 2007. Women and minorities are well represented in the applicant pool but more importantly at an even higher level of participation.

Table 2 : Demographics of NNIN REU applicants and participants

	Applicants			Applicant Pool (%)			Participants			Application Success Rate			Participation (%)		
Year	'05	'06	'07	'05	'06	'07	'05	'06	'07	'05	'06	'07	'05	'06	'07
Overall	500	354	403				81	64	70	16%	18%	17%			
Gender															
Women	148	97	134	30%	27%	33%	33	28	24	22%	29%	18%	41%	44%	34%
Men	352	257	269	70%	73%	77%	48	36	46	14%	14%	17%	59%	56%	66%
Race/Ethnicity*															
Minorities	74	68	57	15%	19%	14%	19	15	21	26%	22%	37%	23%	23%	33%
Non-Minorities	426	259	346	85%	73%	86%	62	45	43	15%	17%	12%	77%	77%	67%
Institution Type															
Ph.D. Level	343	231	258	69%	65%	64%	49	39	43	14%	17%	17%	60%	61%	61%
Master's Level	82	71	72	16%	20%	18%	28	12	13	21%	17%	18%	21%	19%	19%
Bacc. Level	63	40	60	13%	12%	15%	13	11	11	21%	28%	18%	16%	17%	16%
Assoc. Level	12	12	13	2%	3%	3%	1	2	3	8%	17%	23%	2%	3%	4%

** Race/Ethnicity is only for students who reported this information;*

***Carnegie Ratings: The Carnegie Foundation ratings of high education institutions are used as the measure of institutional diversity. Some Ph.D. institutions may not offer advanced degrees in the sciences and engineering*

Figure 17: 2007 NNIN REU Convocation at UCSB

The NNIN REU program culminates with the NNIN REU Convocation where all participants and the site coordinators travel to one NNIN site for a "mini" scientific conference. The 2007 convocation was held August 8-11, 2007 at University of California Santa Barbara (Figure 17). At the convocation, each student presents his/her research results to fellow NNIN REU participants. For many of our students, this is their first scientific presentation. We also simultaneously webcast these presentations which allows faculty, graduate student mentors, and staff from the sites as well as any other interested viewers to view the convocation. To finish the program, all students write a research report that is published as the *NNIN REU Research Accomplishment*s (Figure 18). The archived webcasts and the *Accomplishments* are online at www.nnin.org/nnin_reu.html.

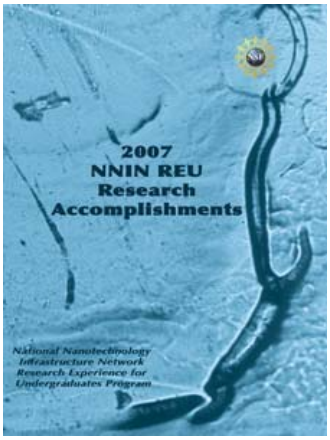


Figure 18: NNIN REU Research Accomplishments

Each year we contract with an external evaluator to assess the impact of the REU convocation and provide feedback on the overall program. Dr. Susan Crowther, Department of Mathematics, Engineering, and Science Achievement at College of the Canyons, Santa Clarita, CA served as the evaluator for 2007. Dr. Crowther attended 36 student presentations and conducted 29 interviews with the interns. Her report indicates that the NNIN REU program meets

its goals and objectives including offering well-designed research projects, exposing interns to the breadth of nanotechnology, providing career and education information on nanotechnology and developing competencies in both technical writing and research presentation. She notes, "The NNIN REU is a large, well-organized program engaging a diverse population of students in meaningful research experiences at well known universities with robust programs in nanotechnology."

Many of our interns go beyond our program requirements by presenting at regional and national conferences and by publishing in refereed journals. This further attests to the quality of the projects completed by our interns. Examples of such achievement for the 2007 interns include, so far: **Co-authored papers** - Ashley Colletti (PSU REU) "Focusing Microparticles in a Microfluidic Channel with Standing Surface Acoustic Waves", *Lab on a Chip*; Will Roman (GT REU) "On-Chip Integration of Microfluidic Channels with Ultra-high Q Silicon Microdisk Resonators for Lab-on-a-chip Sensing Applications" *Lasers & Electro-Optics Society*; Myriam Alexandre (U. Mich. REU) "Increasing the Length of Single Wall Carbon Nanotubes in a Magnetically Enhanced Arc Discharge" *Applied Physics Letters*; Kylee Korte (U. Washington REU) "Rapid Synthesis of Silver Nanowires by at CuCl- or $CuCl_2$ Mediated Process" Journal of Materials Chemistry; **Presentations at meetings and conferences** – Andres Baisch (Cornell REU), "Interfacing Methods for Fluidically-assembled Microcomponents" *Proceedings of IEEE International Conference on Micro Electro Mechanical Systems*; Alexander Luce (Stanford REU), Atomic Force Microscopy Method for Nanostructure Characterization of Perpendicular Magnetic Recording Media" Four Corners Zone Meeting of the Society of Physics Students and 2007 University of Arizona Student Showcase. As it is only five months since the end of the 2007 program, we expect more to be submitted in the upcoming months.

One of our 2006 REU students, Kaylie Young of Brown University, recently was awarded the 2007 McKnight Prize for Undergraduate Chemistry Research. While this was for work not done within the NNIN REU program, it shows the caliber of students that participate in our program and the level of their accomplishments.
(http://www.chem.brown.edu/undergraduate/kyoung.html)

Each year we survey our interns as part of our program evaluation. We consistently receive very high ratings for our program including the quality of the research experience, the support offered by faculty and graduate student mentors, and the level of technical training and support. Table 3 summarizes the evaluation of the technical components of our 2007 program :

Table 3. NNIN Participant post-program survey

NNIN REU Post Survey 2007				
Likert scale of 1-5 with 5 being the highest rating				
Question	**Avg.**			**Avg.**
Did the program offer you a substantial independent research project with a strong intellectual focus?	4.14		How well did the program provide you with an understanding of the graduate research life?	4.51
Were you able to execute the research project using the available equipment and facilities?	4.25		How well did the program provide you with an understanding of careers in nanotechnology?	4.08
Did you consider your project a "good" project- interesting, right scale, right complexity, etc.	4.14		Did the program assist you in making future educational & career choices?	4.36
Were you reasonably able to complete the project?	4.06		How likely is it that you will choose a career in nanotechnology?	3.77

Were you satisfied with how much you were able to complete, given the time constraints?	3.86		How likely is it that you will go to graduate school in science/engineering?	4.48
Did you receive significant scientific interaction with the faculty member/ senior staff in charge of your project?	3.69		Did the program assist you in developing presentation and writing skills?	4.25
Were you included in group meetings and seminars?	4.27		Was the Convocation a worthwhile experience?	4.42
Did the program provide you with experience that allowed you to see the breadth of nanotechnology applications?	4.22		Would you recommend the program to a friend?	4.66
How well did the program assist you in learning to use advanced equipment and processes in nanotechnology?	4.16		How likely is it that when you return to your home campus that you will share your experiences with fellow students and faculty?	4.63
How well did the program assist you in understanding the scientific basis of nanotechnology equipment & processes?	4.03		How do you rate the overall quality of the program?	4.54
			Did you think that your experience with the program was positive. Would you do it again?	4.60

The most common "complaint" from students is that they needed more time, but we are constrained by the calendar. The NNIN staff do make every effort to expedite training and project support so that students can be maximally successful. The level of training and support and the quality of the student participants allows most participants to have an extremely successful research experience. This is particularly important when, as is often the case in our program, it is their first research experience.

Since its inception in 1997, the NNIN REU program has had over 500 participants. As noted above, the program expanded to twelve sites with the inception of the NNIN. REU is a long term investment in human resources. The plans of those students who choose to go on to a research career will play out 5 or even 10 years after participation. Because of the long history of our REU program and its large number of participants, NNIN is uniquely situated to gather some fundamental data on the effect of REU programs on career choices. In 2006 we began a longitudinal study to determine the educational and career paths of interns who participated in the 1997- 2003 period of the program.

Table 4

NNIN REU Longitudinal Study	
Degree/Career	**1997-2003**
Doctorate	42%
Master's	31%
Baccalaureate	12%
J.D.	4%
M.D.	5%
Science Career	89%
Nano Career (broad definition)	47%

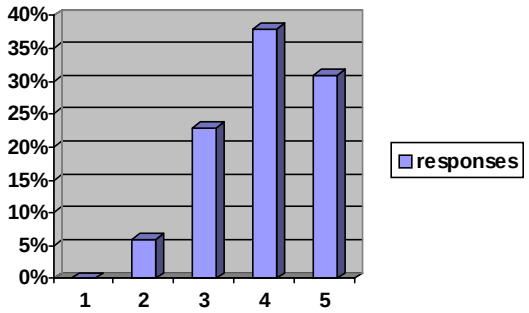
We have chosen the 1997-2003 time period because participants most will have graduated from their home institutions and will either have entered or completed additional education and/or entered into the workforce. This study is a labor intensive process as participants have often moved, changed names, and even home addresses may no longer be valid due to family moves. It is thus time consuming to locate them and to get responses. *(The advent of universal cell phones may help alleviate problem this in the future).* However, of the 250 participants nearly 100 have completed the online survey. Academic and career results to date are shown in Table 4.We are continuing this study and believe the highly positive results are not only of

importance for the NNIN program but also for other undergraduate research programs in general. Particularly striking from the data in Table 4 is the percentage of PhD and MS degrees, as well as the number who remained in "science" careers.

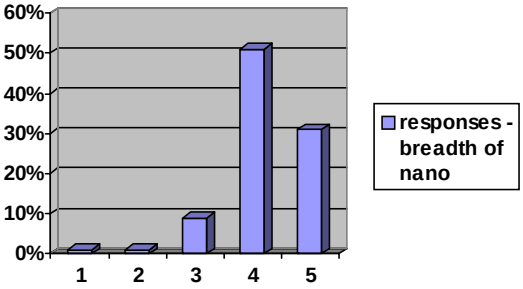
Below are results for some of the questions that allow us to see how the NNIN REU program has played out over the years for past participants. For responses on a Likert scale, the response choices are as follows: 1) not at all; 2) limited; 3) somewhat; 4) significantly; 5) very significantly.

- Did the program assist you in making future educational and career choices (Figure 19)?

Figure 19: Post REU survey; Assist in making educational and career choices.



- Did the program provide you with experiences that allowed you to see the breadth of nanotechnology applications (Figure20) and possible careers in nanotechnology(Figure 21)?



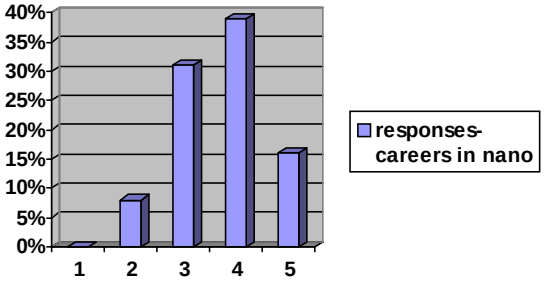


Figure 20: Exposure to breadth of nanotechnology Figure 21: Exposure to Nanotechnolgy careers

- Did the program influence you (or reinforce your choice) to pursue education or a research career in science, mathematics, engineering or technology (Table 5)?

Table 5: Post REU Suvey Eduation and careers in STEM

Response choices	Answer
Yes, influenced me to pursue/continue to pursue a science/technology research career	69.5%
Influenced me NOT to seek a science/technology research career	5.3%
Influenced me to NOT seek any type of science/technology career	0.0%
Did not influence my career choice significantly	14.7%
Other – influenced to get a Ph.D., influenced positively but not for research career, influenced engineer/application career.	10.5%

iREU* IRES/IREE and *2REU

Each summer NNIN provides an introductory research experience for approximately 70 select students. The training and experience these students receive is excellent and they are highly sought by employers, graduate schools, and other internship programs. While they almost all perform very well, from our direct observation over the summer, it is clear that 10-25% of them are exceptional students and have exceptionally bright career prospects if mentored properly.

In 2007, we sought to establish several programs within NNIN to further the nanotechnology experience of these exceptional performers. We sought and received supplemental funding from the NSF International Research Experience for Students program (IRES) and the NSF International Research Experience in Engineering Program (IREE) to establish a 2nd summer international research experience for the most select of the previous year's NNIN REU participants. We call this iREU, for international REU. It is established under the maxim that educating globally aware scientists should be a priority in the 21st century and the observation that US students are particularly ill prepared for the global research environment. This program is only open to our prior year REU students; we are effectively using our REU program as a filter to select only the very best students for this enhanced research experience. We have partnered with the **National Institute of Materials Science** (NIMS) in Japan and the **Forshungzentrum Julich** (FZJ)(a Helmholz Research Institute) in Germany to host 5 and 3 students respectively in the summer of 2008 for a 10 week advanced research experience, similar to REU experience but more advanced and more challenging, with the kicker that it is in a unique cultural environment (Figure 22). This program will not only provide an excellent career growth opportunity for the participants but it also establishes important international linkages for NNIN. Our arrangement with NIMS, for example, includes the reciprocal hosting of 5 graduate students from NIMS into NNIN facilities (at no cost to NNIN). In this program the iREU participants will receive stipend, travel, housing and food allowance via our NSF award and supplemental NNIN funds. This opportunity was extremely well received by the 2007 REU participants and we expect that it will further enhance recruitment into our REU program. The first participants for this program have been selected for participation during the summer of 2008. We expect to continue and even expand this program in future years.

Figure 22: NNIN partner institutions for iREU

Building up on the same theme that our REU participants are highly valued, we have established similar opportunities for two of our best past REU participants to complete a second summer at Sandia National Laboratory (CINT) and 5 others to work at NIST, on nanotechnology related projects. We call this program 2REU. This program is at no direct cost to NNIN; the student participants are supported by the federal laboratories. In both these programs (***iREU*** and ***2REU***) we believe that providing the NNIN REUs with a second nanotechnology research opportunity will enhance and sustain their interest in pursuing graduate school in science and engineering. The international experience will allow interns to gain a global perspective of research while the national lab experience will provide insight into government-sponsored research facilities. We

expect both these programs to be especially popular and to draw additional applicants to our REU program.

NNIN RET Program

Five sites participate in an NSF-funded Research Experience for Teachers (RET) Program which began in March 2006. In 2007, Georgia Tech (lead), Harvard, Howard, Penn State, and UCSB hosted 20 teachers who conducted research with faculty mentors and developed instructional units for their classroom. During the school year for each teacher participant, each site supports the teachers in their classroom to help introduce nanotechnology into their courses. The program culminates at the National Science Teachers Association (NSTA) annual meeting which will be held at Boston March 25-30, 2008 (Figure 23). At the 2007 Convention in St. Louis, the NNIN RETs presented an hour-long workshop for attendees. All of the sites meet for a half-day session (NNIN RET Share-a-Thon) where materials are shared and critiqued. Teachers interact with their fellow NNIN RETs which builds a sense of community. We hope this experience will create a cadre of teachers who will support nanotechnology education in their classroom and schools as well as continue to support our education efforts by participating in NNIN education outreach activities. Georgia Tech participants have been active in providing such outreach. Two teachers provided support for the summer NanoCamps and a third is now working part-time with the NNIN Education Office. Each participant develops instructional units for their classrooms, which are then reviewed and field tested before placement on the NNIN education portal (http://www.education.nnin.org). Penn State's 2007 RETs have submitted their instructional materials for publication.

Figure 23: NNIN staff member and RET participant distributing nanotechnology information at NSTA 2007.

In addition, the University of Washington uses NNIN funds to provide a two week summer program for teachers. The NNIN program combines its effort with the MRSEC at UW, the Genetically Engineered Materials Science and Engineering Center (GEMSEC). They engaged 13 middle and high school teacher (2 NNIN) participants in a week-long immersion in nanoscale research. In addition, the teachers participate in a Bio-Nano workshop (1 week) which focuses on bionanotechnology and molecular biomimetics. Classroom modules are developed some of which are on the NNIN education portal. Stanford University supported one teacher to do nanotechnology research who was part of the Industry Initiatives in Science and Math Education (IISME) eight week program for teachers.

4.4 Development of Materials for Education and Training

Providing education and outreach across the entire K-gray spectrum is a major goal of the NNIN Education and Outreach program In connection with our camps, after school activities, and RET programs, we (the NNIN sites) have developed materials suitable for use with elementary grade students through adult professionals (teachers, industry and government personnel, etc.). These materials are shared among the sites providing significant leverage. The underlying philosophy that guides the development of our K-12 instructional materials is that they should support the teaching of currently taught science concepts and meet the National Science Education Standards (NSES). Teachers we have worked with indicate that nano-focused education materials must

connect to required concepts (state standards) taught in the science classroom. The pre-survey of participants in a Georgia Tech workshop demonstrate that teachers teach "facts," cover the district's curriculum, and prepare students for standardized tests (Table 6).

Table. 6

Georgia Tech Workshop				
In the courses you teach, how much emphasis did you give to each of the following	**None**	**Minor**	**Moderate**	**Major**
Integrating the course with other subjects or fields of study		25%	50%	25%
Teaching facts, rules, or vocabulary		5%	5%	90%
Encouraging students to explore alternative explanations or methods for problem solving			65%	35%
Preparing students for standardized tests in the subject			25%	75%
Fully covering the course curriculum as prescribed			35%	65%
Understanding the theoretical concepts and ideas underlying scientific or mathematical applications		5%	70%	15%

Most of our materials relate to basic science concepts taught in the classroom but with a "nano" twist. For example, NNIN instructional units teach polarity, hydrophobic-hydrophilic properties, phase transformations, chemical reactions, forces, magnetics, among others.

The NNIN RET program has been important in the development of materials suitable for students in middle and high school. Units developed by our RETs undergo review, refinement, and field testing before posting on the education portal for use in other classrooms. A subgroup of sites (UCSB, UW, and GT) formed the NNIN Education Activities Development Committee (EADC) which focuses on the development of inquiry-based middle school activities. The group is on schedule for the collection, refinement, and testing of materials that have been developed by NNIN sites. These materials have been correlated to NSES and are ready to be placed on the education portal for testing by teachers nationwide. Sites will also use these materials in teacher workshops as part of the field testing. We use a field testing evaluation instrument adapted from one used by Cornell's Center for Nanoscale Systems' Institute for Physics Teachers. Table 7 shows the timeline for the testing and distribution of these materials:

Table 7

Theme	**Year**	**Month**	**Goal**
Assemble	**2006**	Feb	Solicit nanotechnology activities From NNIN Sites
		April	Collate initial set of activities from sites
		Dec	Initial set of activities formatted into templates Pilot/beta test activities in nanocamps, workshops, & classrooms
Test & Evaluate	**2007**	Jun	Activities correlated with NSES Publish nanotechnology activities on NNIN website in draft form Publish activity assessment form for classroom use feedback
		Dec	Teachers/classrooms selected for testing & external evaluation; Activity testing begins
Publish	**2008**	Jun	Publish activities refined based on assessment feedback
		Dec	Publish assessed & refined activities in a workbook

Stanford, in collaboration with Mid-continent Research for Education and Learning (McREL) and Aspen Associates, has developed two high school curriculum modules that address nanoscale science and national standards. The program is funded by an NUE award to McREL, with Stanford's assistance supported by NNIN. NanoLeap consists of two modules: one for physical science and one for chemistry (http://www.mcrel.org/nanoleap). NNIN actively recruited teachers to be part of the second year of field testing which is occurring this school year. As part of the NanoLeap program, Stanford has developed the use of NNIN remote access tools and capabilities for use with the units. The idea is to bring students into the nanofabs through the web, for a live and interactive experience, and to include and make real many of the concepts in the NanoLeap modules. University of Minnesota and Georgia Tech provided, with Stanford, remote access demos/activities for three classrooms in 2007.

For education support at the university level, the University of Minnesota site, under the direction of Dr. Steve Campbell, is the lead site for the NNIN Open Textbook. This web-based textbook for nanotechnology is geared towards upper undergraduate and beginning graduate student level courses. The majority of the chapters have been completed and posted on the web. Table 8 shows a list of the chapters and the status of each. The NNIN Open Textbook can be viewed at http://www.nano.unm.edu/nnin_opentext/index.jsp

Table 8

Chap.	Title	Lead Site	Online
1	Atoms, Molecules, & Molecular States	Howard	Yes
2	Biochemistry Fundamentals	UW	Yes
3	Solids, Energy Bands, Optical Processes	UNM	
4	Charge Transport & Quantum Confinement	Cornell	
5	Advanced Lithography	GT & UTA	Yes
6	Self Assembly	Harvard	
7	Growth of Nanoparticles, Tubes, Wires, Belts, etc.	Minnesota	Yes
8	Applications of Carbon Nanostructures	Stanford & Harvard	Yes
9	Nanoelectronics	Cornell	
10	Optical and Magnetic Nanodevices	UCSB	Yes
11	Molecular Devices	PSU	Yes
12	Nano-Bio Systems	Michigan	Yes
13	NMEMS	Stanford	Yes

Penn State and the University of Minnesota continue to offer their nationally recognized community college programs in nanotechnology. Steve Fonash, Penn State, presented a webcast seminar for Northwestern's National Center for Learning and Teaching Nanoscale Science and Engineering (NCLT; February, 2007) on the statewide program offered in Pennsylvania. Both of these programs provide capstone semesters which use the NNIN facilities and staff to provide hands-on training and lectures. The University of Washington's collaboration with North Seattle Community College has led to the development of a similar associate's degree program in nanotechnology. The two institutions have been awarded NSF funding and have launched the undergraduate program called UNIQUE. UCSB continues to offer its Technician Internships in NanoTechnology (TINT) which brings 4 foreign undergraduate students each year to the UCSB nanofabrication facility for a 6-month apprenticeship.

4.5 Education Workshops

NNIN sites develop and provide teacher workshops on nanotechnology. The intent of these activities is to give teachers the background and tools necessary to increase student awareness and interest in science and technology in general and nanotechnology in particular. We believe it is very important to provide professional development training for teachers in order to move nanotechnology into classrooms. Survey results of NSTA attendees indicate that teachers are not knowledgeable about nanotechnology (65% knew nothing or very little about nano), similar to survey results of the general public. A pre-survey of science teachers attending a Georgia Tech workshop indicated that 25% knew nothing and 75% knew very little (had heard about it but did not know what it meant) about nano and 75% believed a nanometer was $1x10^{-12}$ m.

Penn State offers the *Hands-On Nanofabrication Workshop for Educators* which provides information on the growing applications of nanotechnology and teaches the basics of nanofabrication processes and tools through a combination of classroom lectures and hands-on processing labs in their NNIN class 10 clean rooms.

Georgia Tech offered a one-day workshop on nano for teachers attending a two week Math and Science course at East Georgia College. During the past few months, Georgia Tech has established relationships with Gwinnett County School Districts' Science & Math magnet school (offering a nano strand), Georgia's Regional Education Service Agencies, and McREL's NanoLeap project. Two-day workshops are scheduled for summer 2008 with these groups. Three of Tech's RETs presented a workshop on their summer experience and nan-instructional materials at the Georgia Science Teachers Association annual meeting (02/2007) and four others will repeat this session at the upcoming GSTA.

As noted above, the University of Washington provides its RETs with a weeklong workshop focused on bio-nanotechnology. The University of New Mexico provided demonstrations and information on upcoming workshops at the Teachers' Open House sponsored by area museums and The University of Texas provided a 1.5 day Nanoscience Academy for Teachers.

4.6 Other K-12 Outreach

Numerous outreach activities have occurred in 2007 which include K-12 field trips to facilities, visits to schools, summer/weekend camps, workshops, and demonstrations. In order to provide these activities, the NNIN sites have developed hands-on activities, demonstrations, and presentations on nanotechnology. These resources have been posted or are being compiled for inclusion on our website. We also adopt and adapt activities developed by other centers and programs such as University of Wisconsin-Madison MRSEC & NSEC, Nanosense (SRI), NBTC (Cornell), among others.

Hands-on summer, weekend, or after-school camps/programs to engage students in nanotechnology are offered by Penn State, UCSB, Georgia Tech, University of Washington, University of Minnesota, Howard University, U. of Michigan, and NC State University. These camps/programs focus on middle and high school students and have a variety of formats (1day to one week) and content (chip camps, introduction to nano, biomedical, etc.). **Examples** of some of these programs include:

- UCSB "Chip Camps" provided hands-on nanofabrication to students from area high schools.
- Georgia Tech's *Nanotechnology Explorations* camp for high school students and *Explore Nanotechnology* for GT's Women in Engineering middle school girls camp

- Penn State's *NanoCamps* hosted 10 groups during summer 2007 and reached over 225 students and chaperones.
- U. of Minnesota and Dakota Technical College offer NanoScience Class for High School Students.
- University of Washington provides one week of nanotechnology activities as part of a four week summer science program for underrepresented minorities – *Science for Success.*

In addition, several sites provide on-site activities for visiting school groups. These typically involve hands-on activities, demonstrations, lab tours, and cleanroom tours. Most include discussions on career and educational opportunities to encourage students to consider careers in STEM and in particular nanotechnology. Sites are also involved in career days at schools, family science nights, and science fairs. The University of Michigan judged local science fairs and provided awards for the best experiment in nanotechnology. Besides receiving a plaque for the achievement, the students were special guests for a day at the MNF.

4.7 Other Community Outreach

Howard University launched the NanoExpress in summer 2006. This is a mobile laboratory which presents the world of nanotechnology to the general public from K-Gray. The NanoExpress is a mobile van with 208 square feet of lab space designed to facilitate hands-on experiments but also capable of doing nanotechnology research. Experimental areas include: Introduction to Passive Nanoparticles, Introduction to Self Assembly, Introduction to Micro and Nanofabrication, "Chips are for Kids", Instruments for NanoScience, Shape Memory Alloys, and Soft Lithography. Undergraduate and graduate lab assistants help supervise experiments. The NanoExpress has visited D.C. area schools, the Museum of Science Boston, and industry (United Technologies)

The NNIN education portal serves as another avenue in reaching a variety of audiences by offering information for children and adults. Cornell has developed a children's science magazine related to physical sciences and particularly nanotechnology. *Nanooze* is a web based magazine, with kid-friendly text, topics, and navigation. *Nanooze* is available in English, Spanish, and Portuguese. Tens of thousands of *Nanooze* "postcards" (advertising material) were distributed during Ithaca Science Center's *Too Small to See* exhibition at EPCOT in Spring 2007. *Nanooze* has developed a special edition to go along with the exhibit which discusses Richard Feyman, biomimetics, quantum dots, and other topics. Print editions are now available for use by schools.

Community and open house activities are also part of the efforts of the NNIN education and outreach programs. For example, the University of Washington has developed five roll out carts for use at the Pacific Science Center with graduate students providing support for these carts. The Stanford site provides activities for Stanford's Annual Community Day. The University of New Mexico had nanotechnology booths (with demos) at the New Mexico State Fair's "Celebra la Ciencia" Day, Native American Day, and Pathways to College Day.

NNIN has also reached out to professional organizations by developing symposia for national meetings. The NNIN has been preparing for a two-day symposium on nano education at the Materials Research Society spring 2008 meeting. This is co-chaired with NISENet, NCLT, and the European Commission. NNIN participated in the Fall 2007 MRS Showcase by providing tabletop demonstrations for the high school participants of the Hybrid Fuel Cell Car Race

Competition and the Education Outreach Showcase. NNIN provided a workshop on nanotechnology at the NSTA in St. Louis (spring 2007) and had its third annual exhibit booth at the conference. We have been the only nano-education exhibit at the NSTA; our materials were very popular. We will have our booth at the upcoming NSTA conference in Boston in March 2008.

4.8 Technical Workshops

The NNIN is committed to workforce development through a variety of training and development activities which have been developed and implemented across the network. Training and development activities focus on undergraduate and graduate students, industry and government personnel, and faculty from other institutions. These workshops do double-duty, as both educational/workforce development activities and as an avenue to introduce the capabilities of NNIN to potential users. Information on these workshops is found on the NNIN website and upcoming events are advertised on the home page so that individuals can find quick links to the technical workshops. A variety of multimedia are available on the website including talks, symposia, short courses, and equipment training - http://www.nnin.org/nnin_multimedia.html. Individual sites also offer online training materials which are downloadable. Many of these video demonstrations and lectures are downloaded by individuals worldwide for use in classrooms and training activities.

Figure 24: Participants in lecture and laboratory sessions at the TCN short course at Cornell

Technology and Characterization at the Nanoscale is a 3 day laboratory based workshop(short course) offered twice a year by Cornell (Figure 24). Leveraging of the Cornell experience, Georgia Tech offers a similar workshop each summer for three days titled *Technology, Fabrication, and Characterization at the Nanoscale*. The content of the these short courses is designed to encompass all nanotechnology techniques relevant to current research in the field. While traditional topics in nanotechnology - thin films, lithography, pattern transfer (etching), and characterization - provide the basic structure of the course, we include emerging technologies and new approaches in nanotechnology. Nano-imprint lithography, bottom-up nanofabrication, carbon nanotubes, soft lithography, and surface preparation for biology applications are among the topics addressed.

The University of Minnesota provided several workshops during the past year. Some of the topics addressed include aerosol and particle measurements, surface and thin-film characterization, and BioMems and microfluidics for the life sciences. The University of Michigan presented a one day workshop on Nanotechnology and Microfabrication for Small Businesses. The University of Texas offered workshops on Fabrication of < 100nm Geometries with Nano-imprint Lithography Technique and Imprint Lithography Processes.

In October 2007, CNF conducted its third hands-on Computational Nanoscience workshop. This year's offering, Defining the Interface between Nanoscience and Geology , covered applications of nanoscale computation to the geological sciences. These are representative of just some of the

workshops held during 2006. Further information on all of the workshops held plus information on upcoming workshops can be found on the NNIN website.

4.9 Diversity

A primary focus of NNIN E&O is inclusion of underrepresented populations; his theme runs throughout the education goals and objectives of the NNIN. While there are specific outreach activities that focus on underrepresented populations, inclusion is an underlying objective of all of our outreach programs. Discussed below are some of the specific programs that are occurring which **highlight some** of our inclusion activities.

Our REU program places a special emphasis on providing research opportunities for women and minorities. Specifically, the program requirements indicate, "Sites are encouraged to select applicants who are female, minority members, or from non-research institutions." The REU program has quantifiable benchmarks regarding participants which include 50% women participants, 20% from underrepresented minorities, 50% from schools with no Ph.D. program in science and engineering, and 50% from outside the 100 largest research universities. The results reported in the REU section of this report demonstrate that women and minorities have a higher participation rate in our program in comparison to the applicant pool but that we need to do more in recruiting women to the program to reach the 50% target rate.

The NNIN RET program recruits teachers who are themselves from underrepresented groups or teach at schools with a high percentage of underrepresented students or low socio-economic status. Since inception in 2006, there have been 39 RETs: 51% were male, 49% were female, and 36% were underrepresented minorities. Equally important are the demographics of the schools where the teachers teach. The tables below(Tables 9-11) indicate the student demographics of **some** of the schools in which our RETs teach.

Table 9

GT High School Demographics	Duluth	South Gwinnett	Chattahoochee	Cedar Grove	North Springs
White	39.8%	45.5%	64.4%	0.2%	42.5%
African-American	15.5%	42.7%	9.8%	98%	44%
Hispanic	17.6%	5.9%	5.0%	0.3%	6.8%
Asian Pacific Islander	24.3%	2.6%	18%	0.2%	3.2%
American Indian	0.3%	0.2%			.2%
Other					

Table 10

Howard High School Demographics	Flowers	McKinley Tech.	Shabach Christian	DC Prep
White				
African-American	97%	99%	99%	97%
Hispanic/Latino	1%	1%		3%
Asian Pacific Islander				
American Indian				
Other	2%		1%	

Table 11

Harvard High School Demographics	Dover-Sherborn	Brookline	Cambridge Rindge & Latin School	Kennedy-Longfellow Middle	Tyngs-borough
White	92.4%	62%	34.4%	32%	91%
African-American	1.6%	8.3%	40.4%	35%	1.1%
Hispanic	1.6%	8.1%	14.7%	17.4%	2.7%
Asian Pacific Islander	4.0%	17.8%	8.9%	12.4%	4.8%
American Indian	0.2%	0.1%	0.4%	0.8%	0.4%
Other	0.3%	3.6%	1.2%	2.3%	

While these results vary significantly by site, they demonstrate that the NNIN RET program has a significant penetration into a diverse student population.

Individual sites make every effort to ensure participation by underrepresented groups in the K-12 programs. With our new data management system, gender and ethnicity is being tracked for all activities when possible. Sites that are located in diverse areas of the country have the best opportunities for recruiting underrepresented participants to the events. However, all sites make an effort for reaching out to diverse populations. Listed below are some examples (Table 12):

Table 12

Institution/Activity	Diversity Participation
UCSB Chip Camp	55% White 34% Black 11% Hispanic 50% Female
USCB Chip Camp	100% Hispanic 57% female
Georgia Tech - South Atlanta High	100% Black
Georgia Tech – WIE TEC Camp	48% White 16% Asian 25% Black 5% Hispanic 100% Female
U. of New Mexico Celebra la Ciencia – Atomic Museum	82% Hispanic 18% White 52% Female
U. of New Mexico Upward Bound	59% Hispanic 27% White 5% Native Amer.
U. of Michigan - SCEEP	19% White 13% Asian 42% Black 26% Hispanic
Penn State NanoCamp	100% Black 48% Female
U. of Washington – Science for Success	64% Black 22% Asian 14% Hispanic 36% Female

NNIN has developed the **Nanotechnology Showcase for Students** which is a one day workshop on nanotechnology with morning lectures and activities and demonstrations in the afternoon.

NNIN has acquired portable nanotechnology equipment including a tabletop SEM, AFM, STM, and various optical microscopes. Sites have developed demonstrations and activities showing various nanotechnology concepts and applications which can be conveyed to a group in 5-10 minutes. The afternoon session consists of 10-15 demonstration stations, with activities designed to engage the students and broaden their career horizons. The focus is on undergraduate students who attend conferences sponsored by under-represented professional science and engineering organizations. The first event was held at the Society of Hispanic Professional Engineers (SHPE) Annual Conference in Philadelphia (October 2007). We had approximately 300 attendees for the SHPE event and survey results indicate that the program was well-received by the attendees (Table 13). The SHPE organizers were so pleased with the response of students that we have been asked to repeat the workshop in February 2008 at the Hispanic Eastern Technical Career Institute (February 2008). We will be proposing the same workshop to other professional organizations with significant exposure to undergraduate students..

Table 13

NNIN Nanotechnology Showcase for Students – Post event survey					
SHPE Sessions Evaluation	**Ratings**				
	5*	**4**	**3**	**2**	**1**
Nanotech concepts & Applications	81%	19%			
Nanotech Tools	69%	31%			
Nanotech Education	73%	18%	9%		
Nanotech Careers	56%	33%			11%
Nanotech Future	64%	27%		9%	
NNIN & REU	43%	57%			
Afternoon Demos/Activities	81%	19%			

*Likert Scale 1-5 w/ 5 highest

In fall 2007, NNIN introduced a new program, the NNIN Laboratory Experience for Faculty. The program focuses on supporting underrepresented faculty or faculty from minority serving institutions to perform research at one of our facilities. In some cases, the participants may become NNIN users in the future; in others, they will relate their experience to their students. Either way NNIN has an impact on participation of underrepresented populations in nanotechnology. For the summer of 2008, Five awards of $12,000 each were made to Georgia Tech, Cornell, NCSU, and U. Texas(2). Faculty will spend 8-10 weeks in the summer of 2008 undertaking their own research project in nanotechnology.

4.10 Evaluation

NNIN has evaluation instruments for its major programs that include the REU, RET, workshops, and camps. Results from some of these surveys have been presented throughout the E&O report. Evaluation of some activities is more difficult because of the shorter duration of the event (1-4 hours) or the large number of participants.. However, we have developed a simple and quick survey instrument to gauge student reaction to and understanding of activities they participate in during a visit. Results from a recent high school visit at Georgia Tech can be seen in table 14

Camps provide a better opportunity to asses the program and associated student learning because they are typically of longer duration (3-5 days). UCSB has been offering Chip Camps to high school students who wish to learn about nanofabrication. The camp also encourages the students to consider education and career opportunities in STEM. Results from the UCSB surveys (tables

15, 16)) indicate that they are reaching their goal in terms of encouraging education and careers in STEM.

Table 14

Questions	Average
Familiarity w/ nano prior to camp	**2.1**
Familiarity w/ nano at end of camp	**3.7**
Camp helped you to understand the science behind nano	**3.8**
Camp helped you to understand how nano research relates to the real world	**3.8**
Camp helped you to understand how nano applies to your life	**3.6**
Camp encouraged you to learn more about nano	**3.3**
Camp made you consider studying nano in college	**2.7**
Camp helped you understand about career opportunities in nano	**3.4**
Nano is likely to pose societal and ethical issues	**3.5**

*Likert Scale 1-5 w/ 5 the highest

Georgia Tech's summer NanoCamp provides another example of determining if the students are gaining knowledge while participating in a variety of activities during the one week program. Presented below are some of the results from the survey of the 2007 participants which indicate increased awareness of various aspects of nanotechnology.

Table 15			
UCSB Chip Camp			
I have the abilities necessary for a career as a scientist or engineer			
Pre-Camp		Post-Camp	
No	7%	No	2%
Somewhat No	14%	Somewhat No	2%
Neutral	36%	Neutral	22%
Somewhat Yes	43%	Somewhat Yes	41%
Yes	0%	Yes	29%
N/A	0%	N/A	3%

Howard University has recently developed an exit survey for the NanoExpress. The objective of the survey is to determine what visitors thought of the van as well as to determine what they learned at the various stations. This instrument will be used during the van's 2008 visits and will provide us with valuable information on the impact of mobile labs.

Table 16			
UCSB Chip Camp			
I have or can get the training that will prepare me for a career as a scientist of engineer			
Pre-Camp		Post-Camp	
No	7%	No	2%
Somewhat No	14%	Somewhat No	2%
Neutral	36%	Neutral	22%
Somewhat Yes	43%	Somewhat Yes	41%
Yes	0%	Yes	29%
N/A	0%	N/A	3%

Table 17

Georgia Tech NanoCamp 2007 – Sample Questions		
Questions	**Average score***	
Familiarity w/ nano prior to camp	**2.4**	
Familiarity w/ nano at end of camp	**4.0**	
Camp helped you to understand the science behind nano	**3.8**	
Camp helped you to understand how nano research relates to the real world	**4.0**	
Camp helped you to understand how nano applies to your life	**4.1**	
Camp encouraged you to learn more about nano	**3.6**	
Camp made you consider studying nano in college	**3.3**	
Camp helped you understand about career opportunities in nano	**4.1**	
Nano is likely to pose societal and ethical issues	**3.4**	
Can you see yourself doing the kind of work of the faculty and grad students you met during camp?	**79% yes**	**21% no**
Do you think nano should be included in your science classes?	**100% yes**	

*Likert Scale 1-5 w/ 5 the highest

NNIN has developed evaluation instruments for a variety of activities offered at the local level. The goal now is to distribute these throughout the sites so that they can be adopted and adapted by each site for similar activities, i.e., school visits, open house, camps, etc. With standardized questions for similar events we will be able to generate a database that will provide information on the positive and negative aspects of NNIN E&O activities. Such results, combined with results from our evaluation of the major education programs will allow NNIN to continuously assess and improve its E&O offerings at the local and national level.

4.11 Program Summary

NNIN has and will continue to offer and develop a variety of education and outreach activities at the local and national level. Table 18 below summarizes the major new and ongoing network wide programs.

Table 18: Major NNIN Network Education Programs

Program	Participants	Purpose	Status
REU	Undergraduate	Research experience for a diverse population of undergraduates; Introduce to nanotechnology research careers	upcoming 12th summer
iREU	Undergraduates-Former NNIN REU Participants	Developing globally aware scientists from the most successful REU participants	new summer 2008
2REU	Undergraduates-Former NNIN REU Participants	Develop ehnaced nanotechnology interest by placeing superior students in national laboratory positions	new summer 2008

iREG	Graduate students from Japan	International outreach; reciprocity for iREU Japan; No cost to NNIN	new summer 2008
RET	High School and Middle School Teachers	Introduce teachers to nanotechnology; develop nanotechnology classroom activities	Completed 2 summers; 5 participating sites
LEF- Laboratory Experience for Faculty	Underrepresented faculty and faculty at institutions serving underrepresented populations	Increase diversity in NNIN user base and in nanotechnology pipeline	new summer 2008
iSFS- Nanotechnology Showcase for Students	Undergraduates	Expose diverse population of undergraduates to education and career opportunities in nanotechnology	new 2007
Nanooze	Primary and Middle School Students	Stimulate and maintain interest in science at a young age.	Print edition added in 2007

5.0 Computation

5.1 Objective

The central objective of the National Nanotechnology Infrastructure Network Computation Project, NNIN/C, is to leverage existing scientific computation codes for the benefit of the broader nanoscience community. Computation is of increasing importance in all areas of science but nowhere more so than in the science of the nanoscale world. Research into nanoscale systems that span multiple length and energy scales can be accelerated by numerical models that account for complex interactions. Often, the objective of the numerical work is to further an experimental or theoretical investigation. Consequently, unlike experiment and theory, many researchers who engage in computational nanoscience are not specialists; that is, they are not dedicated to *creating* computational codes but rather are interested in *using* them. A wide array of potentially useful codes exist, some of which have been well-supported for years and some of which find themselves consigned, after a brief life, to code mortuaries. The task of NNIN/C is to identify computational scientists and their codes (either widely available or in development) and port those codes to NNIN/C computational clusters. This enables NNIN users to have access to a wide range of codes that addresses different aspects of nanoscale investigations. In addition, NNIN/C holds workshops and posts material to help reduce the steep learning curve that non-specialists often face when applying a particular code to their problem of interest. Finally, where possible, NNIN/C serves as a feedback conduit to the code creators to suggest modifications and generalizations of their code which could be of specific benefit to the user community.

5.2 Technical Scope

NNIN/C has, through support from NSF and with funds from local NNIN sites, acquired hardware resources in the form of computer clusters which it has made widely accessible to the nanoscience community. The hardware that is currently installed is described below.

Software resources are divided according to NNIN site. Harvard, Cornell and Stanford maintain user-accessible codes (described below) while the University of Texas has a set of codes which can be downloaded to the user location (but not executed on UT computers). Georgia Institute of Technology performs in-house simulations and the University of Michigan will provide hardware resources only, during the coming year.

In addition to the NNIN/C-maintained codes, nanoscience researchers with their own codes are encouraged to use NNIN/C hardware resources and, where possible, to make versions of their codes available to the NNIN/C community. Some of those efforts are described below.

5.3 Timeline

A timeline of NNIN/C activities, highlighting major events such as workshops and conferences, is displayed in Figure 25. The principal events which have occurred during the last two years are the NNIN/C conference entitled: *Synergy between experiment and computation in nanoscale science*, held at Harvard University from May 31 to June 3, 2006; and the two user workshops *Building nanostructures bit by bit*, and *Defining the Interface between Nanoscience and Geology* held at Cornell University from October 23-25, 2006 and November 12-13, 2007, respectively. Additionally, NNIN/C participated in the workshop on Nanoinformatics organized by the National Science Foundation during the summer of 2007 and the Workshop on Predictive Modeling also organized by NSF as well as by the NCN nanoHUB in Fall 2007.

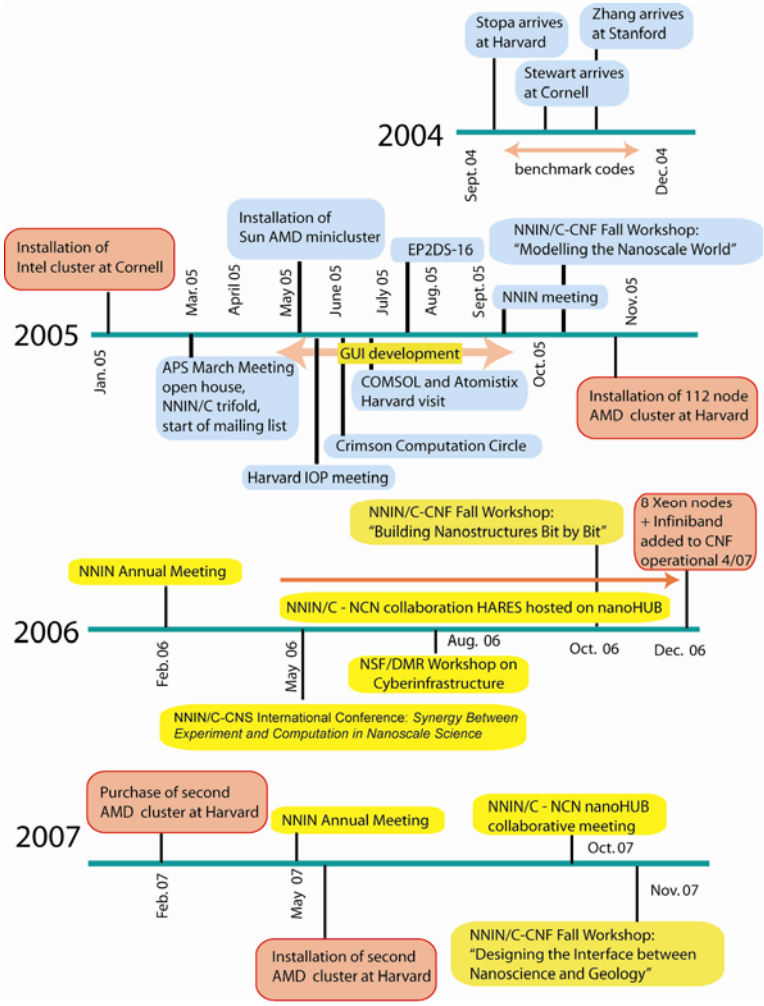


Fig 25: Timeline of major NNIN computation activities.

4.4 Hardware facilities

Hardware facilities for NNIN/C users exist at four of the participating institutions. Dedicated machines (for NNIN users) are available at three of those locations (Harvard, Cornell and Stanford).

At *Harvard University* – NNIN/C Twin AMD Opteron cluster: each with 112 processors, 56 connected with Infiniband, 56 with gigabit ethernet. SUN large memory suite: 4 units of 4-way Opterons from SUN Microsystems, two with 24 GB memory, two with 32 GB memory for a total of 112 GB RAM. Second cluster of AMD Opterons currently being installed (02/16/07). NNIN users additionally have access to the Crimson Grid resources of the Harvard School of Engineering and Applied Sciences (HSEAS), comprised of 48 dual 32 bit Xeon blades (~3 GHz) each with 2 ½ GB of RAM with gigabit ethernet. P655 IBM Power 4 Plus processors, total of 20 processors with 80 GB RAM.

At *Cornell University* – A computational cluster donated by Intel consisting of 48 node dual processor Xeon (3.06 GHz) nodes with an additional 8 dual core dual processer nodes and Infiniband connectivity for 24 nodes. In addition 15 sixty-four Bit Opteron workstations are available through a donation by AMD Corporation.

5.5 Software facilities

NNIN/C continues to identify and host codes that are of interest to the nanoscience community. Several of these are "home-grown" codes originating in the sites of NNIN. Others are general open source codes of wide popularity and still others are codes in development where NNIN/C has recruited an advance version for our users. A important aspect of NNIN/C is the support at a high scientific level provided by staff to users to help them choose the proper approach and to assure that the codes are being applied in a scientifically valid fashion. A partial list of codes that are available from NNIN/C (in most cases to be run on the hardware of one site or another, in some cases for download only) follows (Table 19) :

Table 19

NNIN/C Software Resource Availability

Software	Site/Support
MIT Photonic Bands is a free (*http://www.gnu.org/philosophy/free-sw.html*) program for computing the band structures (dispersion relations) and electromagnetic modes of periodic dielectric structures, on both serial and parallel computers. It was developed by Steven G. Johnson (*http://math.mit.edu/~stevenj*) at **MIT** (*http://web.mit.edu/*) along with the Joannopoulos Ab Initio Physics (*http://ab-initio.mit.edu/*) group	Cornell *Supported by Derek Stewart*
MEEP is a open source finite difference time domain (FDTD) code developed by the MIT Ab Initio Physics group for modeling transmission of electromagnetic waves through wave guides and photonic crystals.	Cornell *Supported by Derek Stewart*
SETE (pronounced *seet*) employs density functional theory to solve for the electronic structure of GaAs-AlGaAs heterostructure-based surface gated nano-devices such as quantum wires and quantum dots.	Harvard *Supported by Michael Stopa*
Siesta (Spanish Initiative for Electronic Simulations with Thousands of Atoms). -This code using numerically truncated orbitals (single and double zeta approach) to build an order-N density functional code. This code is ideal for modeling large scale nanostructures (*i.e.* nanotubes, nanowires, molecules).	Harvard *Supported by Michael Stopa*
Socorro is a computer code for performing density-functional theory (DFT) calculations on high-performance, parallel computers. Socorro was developed under the auspices of the **Accelerated Strategic Computing Initiative** at **Sandia National Laboratorie**s. Ongoing development efforts are in collaboration with **Vanderbilt University** and **Wake Forest University**.	Harvard *Supported by Michael Stopa*
LAMMPS is a classical molecular dynamics code with various runtime configurations (single processor, MPI, etc.) and a wide variety of physical applications.	Cornell *Supported by Derek Stewart*
Elmer is an open source multiphysical simulation software developed by **CSC-Finland**. Elmer development was started 1995 in collaboration with Finnish Universities, research institutes and industry. Elmer includes physical models of fluid dynamics, structural mechanics, electromagnetics, heat transfer and acoustics, for example. These are described by partial differential equations which Elmer solves by the Finite Element Method (FEM).	Cornell *Supported by Derek Stewart*
HARES (High performance fortran Adaptive grid Real space Electronic Structure) computes electronic structure of atoms, molecules and solids with an adaptive grid in real space.	Harvard *Supported by Michael Stopa*
PATHINT: Path Integral simulation for semiconductor nanostructures, written by John Shumway at **Arizona State University**.	Harvard *Supported by Michael Stopa*
CPMD: The CPMD code is a parallelized plane wave/pseudopotential implementation of Density Functional Theory, particularly designed for ab-initio molecular dynamics.	Cornell *Supported by Derek Stewart*
UTQUANT is a quasi-static CV simulator for 1D silicon MOS structures.	Cornell-execution Download only- Texas

UT-MARLOWE is a distant descendant of MARLOWE, a neutron transport simulator developed at Oak Ridge national Laboratory by Mark Robinson in the 1970's. In 1989, MARLOWE was substantially modified by the TCAD group at The University of Texas at Austin, led by Prof. Al Tasch. The result was UT-MARLOWE 1.0, an ion-implant simulator capable of modeling the implantation of boron into crystalline silicon.	Download only-Texas
SDTRIMSP is a molecular dynamics code that is based on the popular TRIM code for analyzing ion scattering.	Download only-Texas
Quantum Espresso is a open source plane density functional code that takes advantage of ultra-soft pseudopotentials. It has the ability to calculate phonon dispersions, handle magnetic structures, and perform structural relaxations.	Cornell *Supported by Derek Stewart*
PARSEC solves density functional calculations using a real space approach and is ideal for modeling small clusters and finite nanowires.	Cornell *Supported by Derek Stewart*
LM Suite is a linear muffin tin orbital package that also users to model electronic transport in nanoscale structures through the use of a non-equilibrium Green's function approach.	Cornell *Supported by Derek Stewart*

5.6 Events

NNIN/C continues to hold events related to expanding its user base and broadening the profile of cyberinfrastructure generally. In the past year, a workshop focusing on the interface between geology and nanoscience was held at Cornell University.

3nd Annual CNF Fall Workshop – *Defining the Interface between Nanoscience and Geology*- In October 2007, the Cornell Nanoscale Facility hosted the 3nd annual Fall Modeling Workshop, *Defining the Interface between Nanoscience and Geology*. This two day workshop provided morning tutorials on several different approaches followed by afternoon hands-on sessions where participants were able to work directly with the codes. The workshop covered topics in nanoscale simulation such as molecular dynamics as applied to problems in, for example, bio-mineralization and crystal structures in condensed matter under high pressure. Many of the invited speakers were also key developers of these programs.

5.7 Coordination with other institutions

Sandia Center for Integrated Nanotechnologies (CINT) – During the summer of 2006 a collaborative effort was initiated between NNIN/C and Sandia National Laboratories (Department of Energy). Specifically, Dr. Normand Modine, of Sandia CINT, was awarded a grant through CINT to make a version of the code Socorro (see description above) available to the NNIN/C community. This grant proposal, written in collaboration with NNIN/C and Harvard University, provided for travel and software development funds. The installation of Socorro is complete and a wiki is being created on the Harvard University NNIN/C site for Socorro users. Access to the Socorro code is auspicious for NNIN/C for a number of reasons. Notably, variations in the results of electronic structure calculations emerged as a function of the basis of states employed for the calculation. While HARES employs a point basis and codes like Siesta employ an atomic orbital basis, Socorro is a plane wave code. Thus, the ability to compare a variety of calculational bases from a systematic viewpoint is now a major selling-point for NNIN/C

Purdue nanoHUB – The Network for Computational Nanotechnology at Purdue University hosts the Purdue nanoHUB which maintains a variety of user-oriented software packages. One of the strong points of the nanoHUB is the concentration that they have place on graphical user interfaces (GUIs) for making input and output of complex codes easier and more intuitive. Communication has continued and an exchange of web links has taken place in order to more fully exploit the complementary nature of nanoHUB and NNIN/C. Several NNIN personel, including the national director and the coordinator of NNIN computation, visited Purdue University in October of 2007 to further arrange cooperative efforts between the two projects. NNIN/C began a collaborative relationship where NNIN/C could take advantage of nanoHUB's GUI toolkit ('Rappture") and could, in turn, provide users of the nanoHUB with some of the research code resources that have been established at NNIN/C. To date, two of the codes from NNIN/C have been ported to nanoHUB (SETE and HARES) and additional work on these is envisioned in the coming year.

5.8 Conclusions and Outlook

During the preceding year NNIN/C:

- Substantially increased its user numbers both within NNIN sites and without.
- Held another major event: a unique, hands-on user workshop on the computational and nanoscience aspects of geology. Judging by user comments, the event was hugely successful.
- Increased its hardware resources by purchasing a new AMD Opteron cluster at Harvard University.
- Extended its code offerings and in particular recruited code from a variety of computational scientists including a unique collaboration with Sandia National Laboratories.
- Extended its publication records with acknowledged support from articles in Physical Review Letter, Science and Nature Physics.

In the coming year, NNIN/C plans to further increase its user base and its record of publications. Additionally, NNIN/C has begun establishing "wikis" for exchange of information on the various codes. Finally, the need for hardware is never adequately satisfied and NNIN/C will pursue avenues for independent funding from vendors of computational resources to further augment our base of facilities. In particular, we have begun exploring the use of graphical cards (developed by game software companies like Nvidia) for their promise in parallelization of complex scientific codes.

6.0 Societal and Ethical Issues in Nanotechnology

6.1 Introduction

The Societal and Ethical Issues (SEI) component of NNIN seeks to increase national capacity for exploring the social and ethical issues associated with nanotechnology. To accomplish this goal, the SEI component has developed an infrastructure for conducting research and disseminating information about SEI. That infrastructure is intended to serve both the NNIN itself and the broader community interested in nanotechnology. The NNIN SEI web portal is a critical part of this infrastructure, acting as a resource for current events and discussion and as an archive of historical information (http://sei.nnin.org).

The internal infrastructure to address this goal consists of SEI coordinators at each NNIN site, who help organize talks, panels, seminars, courses, or other activities involving SEI. They also facilitate the conduct of research on SEI at their sites. In particular, to seed the growth of the infrastructure, the NNIN's SEI component includes funding for research on issues in ethics, innovation, workforce development, and history of nanotechnology. The output of these activities is then distributed via the SEI website, workshops, presentations, and ultimately traditional peer-reviewed publications.

Prof. Doug Kysar and Dr. Ana Viseu, Cornell, are responsible for coordination of the SEI component of NNIN. Dr. Viseu left Cornell in December 2007 for a faculty position at York University in Toronto.

6.2 Network-wide activities

SEI web portal

The SEI web portal (http://sei.nnin.org/) underwent a comprehensive overhaul during 2006 under the leadership of Ana Viseu. The site now includes an introduction to societal and ethical implications of nanotechnology, an overview of NNIN-sponsored SEI research, an events calendar, and a large database of SEI-related materials, including publications, reports, video streams, and other resources. The SEI database includes tagged records which allow users to conduct flexible searches. The new site also offers visitors the possibility to subscribe to an email list with information on new resources and events.

SEI Training slides

We maintain that through our large user base and extensive training, NNIN directly impacts a significant fraction of the national nanotechnology workforce. Based on the preliminary findings of the study of our users done by Prof. Robert McGinn of Stanford (discussed below), we determined that we should take a more proactive role in introducing NNIN users to the Social and Ethical Dimensions of nanotechnology. Doug Kysar and Anna Viseu, working in concert with David Guston of the Center for Nanotechnology in Society at Arizona State University, developed a set SEI introductory slides for use as part of the training of all new users at all NNIN sites. This introduction is necessarily brief. Its purpose is not to indoctrinate anyone with a particular view, but rather to expose new NNIN users, many of them new graduate students to the concept that science, and in particular revolutionary science, does not occur in a vacuum but rather it is shaped by society and it in turns shapes society. The slides are this in the form of talking points based on historical examples to initiate discussion, either during the initial training or later and are supported by other reading material. These slides were tested at CNF and were distributed to NNIN sites in December 2007 and are being used as a part of the regular training process. They are available for download from the NNIN SEI portal.

Future of Nanotechnology Symposium Session

As part of NNIN's effort to increase visibility of social and ethical issues surrounding nanotechnology, Anna Viseu, NNIN SEI researcher, and Prof. Ron Kline, Cornell, organized a symposium focused on SEI issues in nanotechnology as part of CNF's 30th anniversary symposium, *The Future of Nanotechnology*, held at Cornell in June.

The keynote address was Constituting the NanoScale: Lessons from the 20th Century by Prof. Sheila Jasanoff, Harvard. Additional invited talks featured David Guston, Arizona State, Juergen Altmann , Dortmund University, Rosalyn Berne, University of Virginia and Douglas Kysar, Cornell University Law School. The session concluded with an open panel discussion.

6.3 SEI research

Four of the NNIN sites have specific (NNIN funded) resources allocated to SEI activities, including research into the social and ethical dimensions of nanotechnology. The NNIN research effort in SEI spans some broad areas, including

- Ethical issues in nanotechnology as viewed by nanotechnology researchers (McGinn, Stanford)
- Technology transfer, intellectual property, and commercialization of nanotechnology, (Thursby, Georgia Tech)
- Public perceptions of nanotechnology (Brainard, U.Washington)
- Workforce development issues related to nanotechnology (Brainard, U. Washington)
- Nanotechnology and society—ecology, risk, and environmental law(Kysar, Cornell)

Results and activities of these researchers are described below.

Ethics and Nanotechnology: Views of Nanotechnology Researchers

Prof. Robert McGinn, Stanford

In 2005 Prof Robert McGinn of Stanford undertook a large scale survey of nanotechnology (NT) researchers' views about ethics in relation to their work, with the NNIN user base as the sample population. With over 1000 responses this is the largest such study of of working nanotechnologists—their own interest and perceived knowledge of SEI issues, their own perceptions of risk, their perceptions of others' perception of risk, their personal response to various potential ethical issues related to nanotechnology and science in general, their perception of the response of their colleagues, and their overall perception of the important of examining social and ethical issues. This extensive data set has been analyzed over the last year. Prof. McGinn has begun to discuss the major findings in public forums including presentations at the 2007 NNIN Annual meeting at the University of Michigan, and at various venues at Stanford, Berkeley, and UCSB. The first paper analyzing these results was submitted to the referred journal NANOETHICS in November 2007.

Utilizing the NNIN questionnaire on ethics and nanotechnology as a basis, a 2.5 hour curricular module on ethics and nanotechnology was developed and inserted into a course at Stanford during spring 2007 seminar(STS 115/E131 Ethical Issues in Engineering), taken by 32 undergraduate engineering students at Stanford.

Technology Transfer and the Commercialization of Nanotechnology

Marie Thursby, Georgia Tech

With the revolutionary potential of nanotechnology, the means by which technology is commercialized has significant societal implications. The overall theme of work at Georgia Tech

is “How does industry capitalize on nanotechnology and how does this relate to universities and NNIN?”

Prof. Thursby has examined the ability of large companies to adapt to revolutionary scientific advances such as nanotechnology today (and biotechnology in the 1980s). The research results (**“The Nanotech vs. Biotech Revolutions: Sources of Productivity in Incumbent Research,” (with Frank Rothaermel)** ***Research Policy*****, Vol. 36, July 2007, 832-849**) hypothesize that the ability to capitalize on such scientific advances depends initially on the ability to directly tap into tacit knowledge of scientists and engineers responsible for the breakthrough inventions, but also their access to physical capital such as the resources available through networks such as the NNIN. These hypotheses were empirically tested on two longitudinal samples over the 21-year time period between 1980 and 2000: 80 incumbent pharmaceutical firms generating 15,607 biotechnology patents, and 249 firms across a diverse set of industries that were granted a total of 3,236 nanotechnology patents. The results have two major implications for NNIN. First, it found broad support for the view that in nanotechnology access to physical capital is more important than tapping into external human capital through firm mergers and acquisition. Second there are key differences in biotechnology and nanotechnology patent productivity: in particular, in biotechnology the ability to assimilate tacit knowledge of key scientists appears to have been much more important than in nanotechnology. This suggests an important issue for future research: that is, given nanobiotechnology as an emerging sector, we need to understand how access to physical capital and tacit knowledge interact for firms in this sector.

Within the past year, Prof. Thursby has initiated a project (with a PhD student) which modifies Fleming’s theory of research as a recombinant process, to predict the productivity of firms in terms of producing patents in nanotechnology as a function of their success in searching results patent classes in which they have no prior experience, searching public science, as well as forming alliances with other firms. This work is ongoing and involves the empirical analysis of 81 incumbent firms operating in the semiconductor industry from 1990-2002.

In a case study for the Harvard Business School, Prof. Thursby has examined the roles of industrial partnerships in nanotechnology. (HP Nanotech: Partnership with CNSI,” Harvard Business Case N9-606-045 and Teaching Note N-5-607-105 (with Lee Fleming and James Quinn), March 2007) . This case explores the reasons that industrial companies form strategic partnerships with universities. This is an important case in illustrating for networks such as the NNIN, or university initiatives in general, some of the critical issues in university-industry collaborations in nanotechnology. The case is based on the UCLA-Hewlett Packard negotiations for the California Nanotechnology Center and highlights the value of such partnerships, both to universities and industry of such partnerships, but also the pitfalls of managing such relationships.

The results of various aspects of this research have been presented in talks at the Joint Wharton Heritage Chemical Foundation Conference on Social Studies in Nanotechnology, the National Nanotechnology Manufacturing Center, and Emory-Georgia Tech Center for Cancer Nanotechnology Excellence (CCNE) Commercialization and Entrepreneurship Workshop.

Social and Ethical Issues in Nanotechnology

Prof. Susan Brainard, U.Washington

The SEI effort at the university of Washington is housed within the Center for Workforce Development (CWD).

Learning about Nanotechnology and the Social and Ethical Issues of Nanotechnology (SEIN)
The CWD has created an annotated bibliography, a nano overview for laypersons, a SEIN teachers guide for middle school teachers, a SEIN student guide for high school class activities on SEIN, and a Powerpoint presentation others can use to teach about SEIN. Pending NNIN review, these materials will be available on the NNIN website.

Public Health and Nanotechnology Perceptions
A research project entitled "Perceived Risks and Hazards of Nanotechnology Development – Comparisons among Faculty at the University of Washington Affiliated with Nanotechnology / Nanoscience and Environmental Health Science" was completed and submitted as a master's thesis in public health in 2006 and presented at the 2007 Society of Toxicology meetings. The results from this study are posted on the NNIN SEI portal in the form of an Executive Summary, and further information on the findings is available from CWD.

Identifying and Analyzing the Discourse(s) of Nanotechnology and Nanoscience
The research project entitled "Identifying and Analyzing the discourse(s) of nanotechnology and nanoscience" is the basis for a doctoral dissertation in communication. Data collection and analysis has been completed. The findings from this study are expected to be available by June 2008. In 2007, this research was invited for professional presentation to students and colleagues at Carroll College (Helena, MT), Bloomsburg University (Bloomsburg, PA) and Pennsylvania State University (Berks Campus). Additionally, two journal articles based on this research are in the process of revision for resubmission to "Discourse & Society" and invited submission to "Public Understanding of Science."

Nanotechnology and the Emerging Workforce
1) The Center for Workforce Development (CWD) has partnered with the Center for Nanotechnology (CNT) at the University of Washington to develop a system to track graduate student progress through the new, interdisciplinary program in Nanotechnology and to create the Nanotechnology Graduate Student Mentoring Program. The tracking process includes questions regarding career plans and impact of their nanotechnology Ph.D. program, among other issues.

2) A diversity awareness seminar was developed and piloted in March 2007 at UW. The goal of this workshop is to give scientists and engineers working in nanotechnology the knowledge to be able to work effectively across disciplinary fields. The workshop will be given to graduate students, faculty and staff at the University of Washington, and can also be given at other institutions.

3) Lastly, a proposal to NSF EESE solicitation was funded. The project involves the creation of a centralized resource for Ethics in Nanotechnology teaching materials, as well as the creation of nano-ethics teaching materials in areas where none exist.

Nanotechnology and Society

Ana Viseu and Doug Kysar, Cornell

The effort at Cornell has focused on risk assessments and understanding of regulations and regulatory mechanisms, and development of approaches for the nanotechnology area. Quite a bit of current debate regarding public health understanding related to nano is with reference to nanomaterials and the possibilities of environmental issues. These questions have been explored and form part of a large group of public discussion set and framed in a broader societal framework. Publications and presentations related to this subject are listed below:

Publications:

- *It Might Have Been: Risk, Precaution, and Opportunity Costs*, 22 J. Land Use & Envtl. L. 1 (2007)
- *Discounting On Stilts*, 74 U. Chi. L. Rev. 119 (2007, Symposium Issue: Intergenerational Equity and Intergenerational Discounting)

Presentations:

- Conference Commentator, Harnessing the Power of Information for the Next Generation of Environmental Law, University of Texas-Austin School of Law, Austin, Texas, February 1-2, 2008
- *The Point of Precaution: Economics and the Forgetting of Environmental Law*, University of British Columbia Faculty of Law, Vancouver, British Columbia, January 28, 2008
- *The Point of Precaution: Economics and the Forgetting of Environmental Law*, University of California-Davis School of Law, Davis, California, January 17, 2008
- *The Point of Precaution: Economics and the Forgetting of Environmental Law*, University of Southern California Gould School of Law, Los Angeles, California, November 15, 2007
- *Strategic Perspectives on Managing Emergent Nanotechnologies*, Center for Nanotechnology in Society, Arizona State University, Tempe, Arizona, October 26, 2007
- *Regulating from Nowhere: Environmental Law and the Search for Objectivity*, University of California-Los Angeles School of Law, Los Angeles, California, October 15, 2007
- *The Point of Precaution: Economics and the Forgetting of Environmental Law*, Loyola Law School, Los Angeles, California, October 11, 2007
- *Ecologic: Complexity, Cognition, and the Regulation of Nascent Technologies*, Cornell Nanoscale Science & Technology Facility 30th Anniversary Conference, Cornell University, Ithaca, New York, June 14, 2007
- *It Might Have Been: Risk, Precaution, and Opportunity Costs*, Syracuse University College of Law, Syracuse, New York, April 23, 2007
- *It Might Have Been: Risk, Precaution, and Opportunity Costs*, Illinois Program in Law and Economics Workshop, University of Illinois College of Law, Champaign, Illinois, April 5, 2007
- *It Might Have Been: Risk, Precaution, and Opportunity Costs*, Behavioral Law and Economics Workshop, University of Minnesota Law School, Minneapolis, Minnesota, April 4, 2007

7.0 Network Management

Network Management and Network-Level Activities

As a large group of university based laboratories in a very diverse technical area encompassing nearly all the areas of science and engineering serving a user community spanning academia, industry and national laboratories; and a multifaceted outreach mission, a cohesive, responsive and stream-lined management is essential for the NNIN to achieve its network goals and for the standards for operation and support of users to be maintained. Management is responsible for coordination of intra-network activities and for various levels of reporting to NSF, NNI, and others. The management structure of NNIN also has to take into account the large number of network university sites, the individuality of universities and their environment and yet has to be flexible, responsive and adaptive to the evolving environment of nanotechnology research. Our management structure and procedures follow the format outlined in the NNIN proposal.

Figure 26: Network Management Structure

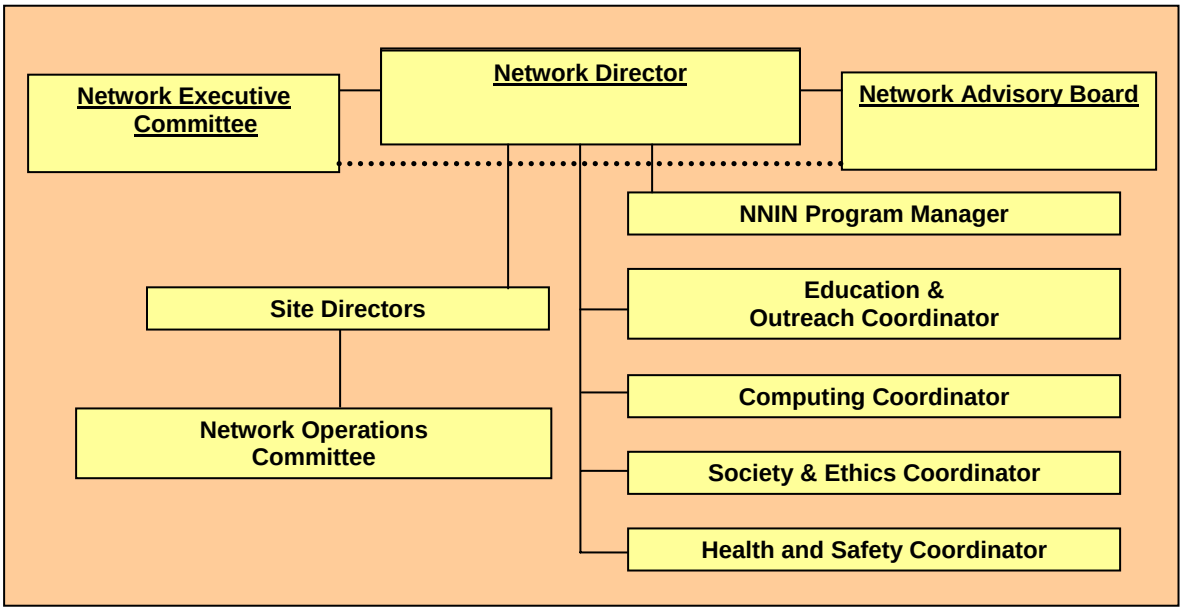


Figure 26 shows the broad outline of the organizational structure. Prof. Sandip Tiwari, Cornell University, the NNIN Network Director, is the point of contact with NSF, and is responsible for implementing the network policies and program. Dr. Lynn Rathbun, Cornell University, serves as the NNIN Program Manager coordinating the daily activities and communication with network sites.

Four Network Coordinators are responsible for coordinating the broad outreach activities areas across the network.

- Education & Outreach (Dr. Nancy Healy, Georgia Tech),
- Society & Ethics in Nanotechnology (Prof. Douglas Kyser, Cornell),
- Scientific Computation (Dr. Mike Stopa, Harvard),
- Environment, Health and Safety (Dr. Mary Tang, Stanford).

For the purpose of implementation of the program and policies, the Network Director and the Program Manager interact directly and regularly with the site directors and the coordinators for thrust activities.

The Site Directors are responsible for the operation of individual sites. A complete list of Site Directors is provided in Appendix. The network management hosts a conference call with the Site Directors as a group at least once every two months.

The Network Executive Committee (NEC), chaired by the Network Director, sets the vision, policies, operating procedures, evolution, and manages the allocation of the NNIN resources. NEC has 3 permanent members — the Network Director and the site directors at Cornell and Stanford, 3 members elected from the other sites (currently Howard, University of California at Santa Barbara and Texas), and the Coordinators of special thrust areas of the network. The elected and permanent members vote on the decisions with the network director voting only in the event of a tied vote. The NEC meets monthly by conference call, or more often, if necessary.

The NEC receives independent advice from the Network Advisory Board (NAB), an independent body of leaders of the disciplines and communities that the network serves. The NNIN advisory board represents eminent scientists, engineers, and administrators. The advisory board members are a cross-section representative of the nanotechnology user areas and are individuals with stature, experience and independence that can help the network evolve through critical advice and guidance of programs, activities, vision and future directions.

The Network Advisory Board has the following members:

- **Dr. Samuel Bader**; Assoc. Div. Director, Materials Science Division, Argonne Natl. Lab
- **Dr. William Brinkman**; Senior Physicist, Princeton & Retired VP, Research, Bell Labs
- **Prof. Harold Kroto**; Department of Chemistry, Florida State University
- **Dr. Carl Kukkonen**; CEO, ViaSpace Technologies
- **Prof. George Langford**; Dean of Natural Sciences and Mathematics, University of Massachussets
- **Dr. Jim McGroddy**; Retired Senior VP, Research, IBM
- **Prof. Hans Mooij**; Chairman, Kavli Institute of Nanoscience, Delft Univ. of Technology
- **Prof. Paul Peercy**; Dean of Engineering, U. Wisconsin
- **Dr. Kurt Petersen**; CEO & Chairman, SiTime
- **Dr. Tom Theis**; Director of Physical Sciences, IBM Research
- **Prof. Karen Wooley**; Professor of Chemistry, Washington University, St. Louis

The Network Operations Committee (NOC) consists of the Laboratory Managers/Associate Directors/ or equivalent personnel that have day-to-day laboratory responsibilities. The day-to-day inter-site coordination, user-focused activities, technology exchange and all other tasks that

require detailed implementation and exchanges between sites are activities that are the focus of NOC. This group is also responsible for implementing NNIN user support procedures at each site. They also share best practices and process offerings between sites. They communicate primarily by a private email discussion. The Network Operations Committee also collects lab use information that the network collects as part of its metrics for assuring responsiveness to the user needs and for evaluation.

The Coordinators for Education & Outreach, Society & Ethics, Computing, and Health and Environment thrusts implement the goals of their thrusts through regular interactions with the respective committees consisting of representatives from each of the sites.

NNIN typically holds two major meetings every year. One is a half-yearly meeting held at the National Science Foundation for discussions with the NSF program officers from the different divisions that support NNIN. This meeting is a mid-year summary of activities, focus, development of ideas for new initiatives, and mid-course correction. The main annual meeting consists of a review of the network by an independent NSF panel and is usually conducted simultaneously with a meeting of the NNIN Advisory Board. The NNIN Annual Review was conducted May 9-11 at University of Michigan, Ann Arbor. NNIN also meets and regularly solicits input from the advisory board as needed.

Following each of these two main meetings of NNIN, where the functioning of the network occupies central attention, there is individual feedback provided to the sites both verbally and following the annual meeting, in writing. These articulate the commitments, expectations, and any perceived areas requiring special attention at each of the sites as a summary from the discussions and deliberations. These exchanges are critical to delivering on the commitments and the promises made by the network and form an important element, together with the analysis of the quantitative and qualitative review of the performance in determining changes in site funding and future participation.

NNIN, as a large distributed organization, requires significant coordination of the execution of the tasks well beyond the overlying management functions of establishing policies, mechanisms, and outlines of the implementation of these policies. NNIN has developed special web-based applications to facilitate communication, advertising of events, participant feedback on events organized, evaluation of the tasks, and other documented information. These range from educational activities such as workshops to collecting data that is reported to NSF. Much as how Fastlane automates and structures many NSF communications functions, these tools automate and organize some of the information flow between NNIN sites and management, and among NNIN sites. These tools are all accessed by private (site specific) login at the footer of any nnin.org page. Three of these

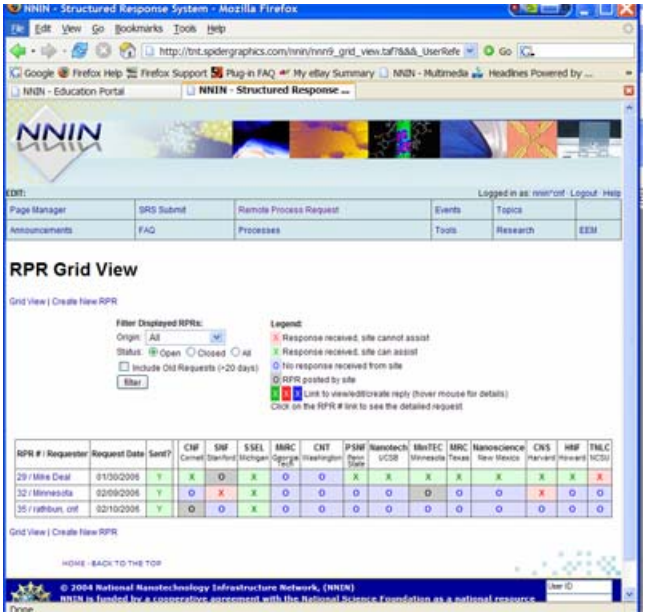


Figure 27: Site screen for entering or responding to Remote Process Request

tools are:

SRS-The Structured Response System: The Structured Response System is a query and response tool for communication from NNIN management to the sites. Example of information collected through SRS include data on users, input for reports and proposals, etc.—responses that must be both correct and timely. SRS requests information with deadlines using templates, issues reminders, and logs and collates information received.

RPR-The Remote Process Request System: The RPR is similar to SRS in that it creates structure for certain communications—in this case, communication between sites regarding remote process assistance (Figure 27). Any site can issue a request to other sites, emails are sent to each site and sites that can help, i.e. have the appropriate technology, can respond through the system. All communication is logged and structured and the request originator can see at a glance the status of responses; he/she will also get email synopsis of all responses. While this all could be done by email, the system assures that a consistent, complete set of information is included in each request and that the requests can be easily managed and reviewed.

Sample contamination is a critical issue whenever samples travel between sites—what contamination did it have when it went to the 2nd site, and what did it have when it returned to the original site. Misunderstandings in the level of cleanliness and in any cleanings that may be instituted at either site can be devastating. NNIN staff determined what information is necessary to assure system and sample integrity during this process, and this protocol has been designed into the RPR system. RPR asks for and records all previous processes as well as substrate information so that the each site can make an honest determination of compatibility.

EEM-The Education Event Manager: NNIN conducts a large number of educational activities, Some of these are major events such as workshops and camps. Others are minor events such as tours and small demonstrations. The major events need to be advertised adequately and the response of the community evaluated to assess impact and effectiveness. In particular, the assessments are helpful in determining the activities whose development and effectiveness is at a state that suggests network-wide adoption versus those that are ineffective and should be discontinued. EEM helps us adopt the successful practices across network wide, helps us expand the reach of major activities through the NNIN website and newsletter based advertising and to promote interaction and synergy between sites when appropriate. They also need to be able to extract summary event information at any time–number of participants, number of events, event types, etc.

Broader Promotion and Coordination Activities

Supporting and assuring awareness of NNIN capabilities to existing nanotechnology community and the expansion of nanotechnology into new fields is a critical part of the NNIN mission. Exhibiting at research conferences is one way in which NNIN reaches to these communities. NNIN exhibits and makes presentations at a significant number of conferences. During 2006 this included more than 8 major exhibition events and 6 presentations at professional society meetings. Typically, two or three NNIN staff representing different sites help staff the NNIN booth, talking to users and potential users about capabilities within NNIN and at their site. Staffing assignments rotate among the sites depending on interests, technology, and location. In addition, specific NNIN sites participate in regional nanotechnology events. NNIN's

presentations at professional meetings are usually made by the network director. Site and the network directors also make regular presentations at small company collectives and economic development groups and to international visitors.

Among the materials employed for reinforcing and disseminating information are introductory color brochures describing the network, the network sites, and network activities and site brochures and newsletters that highlight recent site-specific accomplishments, equipment and resources available, and upcoming events.

We also collect the publication lists, and highlights resulting from NNIN support and disseminate it to reinforce the breadth of research possible with NNIN support. In addition to being a tool for assessment of the network and site impact, these documents – publications and summary highlights of research (both included as an appendix in this report) provide a tool that an educated potential user can use to understand the advanced research and development that is possible through use of network resources.

NNIN's Education and Outreach activities are also featured regularly at meetings, e.g. at the National Science Teachers Association. At many of these events, NNIN has an exhibition booth which features materials and resources developed for teachers. Our focus was on introducing the NNIN to science teachers and providing them with information, resources, and activities suitable for the K-12 classroom.

The NNIN director and Education Coordinator also work closely with other nanotechnology centers and networks (e.g., the recently started manufacturing network, NSEC center network, the DOE centers, international centers, and Nanoscale Informal Science Education Network - NISE), in coordinating activities with research and development, educational and broad societal impact. An example of coordination is the initiation of a second year program for NNIN REU participants that will place exceptional undergraduate students at NIST laboratories and Sandia Laboratories and at National Institute of Materials Science in Japan, to work with exceptional professional scientists in their laboratories.

Information exchange within the staff of the network that goes beyond the electronic and occasional encounters at NNIN-sponsored major events or its presence at professional meetings is extremely important for detailed technical and working exchange. NNIN holds meetings of the Network Operations Committee and Lab Managers, and of technical staff in specialized areas with the primary focus of helping users s in an effective way and for technology exchange. Staff technology forums organized for these purposes have included dry etching, electron-beam lithography and soft lithography.

Network and Site Funding

NNIN is funded by a primary cooperative agreement between NSF and Cornell University at the level of $14M annually. The NNIN sites participate as sub-awardees from Cornell University.

A tenet of NNIN is that funding within the network can and will be adjusted during the award period based on performance and needs of the network in response to the changing user environment. Site award levels were essentially fixed for years 1-3. For year 4, significant changes in funding level of several sites were implemented. The revised funding levels are reflected in Table 20. The "odd" amounts ($18,750 or $12,500) in most site budgets reflect extra allocations, debiting the central management/ national-oriented activities account and crediting the site budgets, for support of 2 or 3 REU students. Two or three REU students were separately

funded by an NNIN REU award, making five supported students per site. This was done to assure that each site had a minimum of 5 REU students with support from outside the site budget. As this is a network directed program, supplemental funds were allocated from the central account to each site to cover the baseline participant expenses.

Funding for year 5 will remain at the same level.

Table 20 NNIN Annual Funding by Site

Site	**Year 4 (base +supplements) (and Year 5 funding)**
Cornell	$2,512,500
Stanford	$2,518,750
Georgia Tech	$1,418,750
Michigan	$1,218,750
Penn State	$768,750
Washington	$668,750
UCSB	$943,740
Minnesota	$893,750
Texas	$668,750
Harvard	$768,750
New Mexico	$518,750
Howard	$518,750
NCSU	$0
NNIN Management and National Activities (NNIN office at Cornell)	$581,250
Total	**$14,000,000**

8.0 Network Performance

During the formation of the network, in order to address the broad scope and to provide the most advanced technical capabilities within limited financial means, sites were chosen and assigned specific specializations based on internal research strengths. All sites have responsibilities towards education and outreach activities, with major efforts at Howard University, University of New Mexico, Georgia Institute of Technology, and University of Washington towards under-represented communities. Earlier in this report, in the mission and approach section, we provided a summary view of these responsibilities as viewed from focus areas. Institutionally, these site responsibilities are as follows:

- ***Cornell University**:* The Cornell Nanoscale Science and Technology Facility, CNF, along with the facility at Stanford, has the task of providing broad capabilities across biology, chemistry, MEMS, characterization, electronics, materials, and optics, with special focus on complex integration. Leadership of the network SEI activity (Prof. Douglas Kysar) resides at Cornell, and Cornell also has responsibility towards nanoscale scientific computation support. Management of the network also resides at Cornell.

- ***Stanford University:*** The Stanford Nanofabrication Facility is broadly responsible for user support across the entire range of nanotechnology, including capabilities in biology, chemistry, MEMS, characterization, electronics, materials, and optics, and complex integration. Stanford is also responsible for providing computation and modeling support and to participate in scholarship activity in social and ethical investigations. The network's health and safety efforts are coordinated from Stanford with Dr. Mary Tang as the network coordinator for these activities.
- ***Georgia Tech:*** Georgia Tech is responsible for leadership in the Biology and Life Sciences efforts for research and applications of nanotechnology. Georgia Tech also provides expertise in electronics, MEMS, and optics, and participates in SEI activities. In addition, the network's efforts in education and outreach are coordinated from Georgia Tech with Dr. Nancy Healy leading the effort.
- ***University of Michigan:*** The Michigan Nanofabrication Facility provides technical leadership within the network in integrated systems with particular focus on integration of MEMS, microfluidics in order to create systems for biological sensing and other applications. Michigan also contributes to computation effort of the network.
- ***University of Washington:*** NNIN services at the University of Washington are provided through the Nanotech User Facility. U. of Washington has specific responsibility for serving the biology, medicine, and life sciences communities in their needs for nanotechnology, participates in the SEI activities and leadership responsibilities for outreach activities.
- ***Penn State:*** Penn State has specific NNIN leadership in the area of chemical nanotechnology with a particular focus on molecular-scale science, engineering and technology support.
- ***UCSB:*** The laboratory at UCSB has network leadership responsibilities towards support of electronic materials and physics applications of nanotechnology, and to provide outreach support towards under-represented community in the local community.
- ***University of Texas:*** The University of Texas has responsibilities to support chemistry and chemical nanotechnology. U. Texas also has responsibilities for tool development for nanotechnology and through related activities support of manufacturing research.
- ***University of Minnesota:*** The Minnesota NNIN Node (MINTEC) consists of the capabilities of three laboratories: the characterization facility, and the particle technology lab and the fabrication facility, and is thus a bit different from the other nodes of the network. Through the former two laboratories, the Minnesota site provides NNIN leadership in remote access characterization and in particles and nanomaterials, particularly in regard to the health and safety concerns. Particles, characterization and nanoporous materials are the primary current areas of effort in NNIN towards the Geology community. Minnesota also has a traditional, clean-room based service laboratory similar to the other sites focused on the broader areas of science and engineering.
- ***University of New Mexico:*** Similar to Minnesota, Nanoscience at the University of New Mexico provides expertise in nanomaterials and materials characterization, again with strong interactions with the Geology community. U. of New Mexico also has a critical leadership responsibility in outreach to underrepresented community in the southwest area – the Native and Hispanic community.

- ***Harvard University:*** The Harvard node is located within the Harvard Center for Nanoscale Systems. Primary responsibilities for Harvard are leadership of the network in chemical nanotechnology, including synthesis and soft lithography, and the network leadership in computational effort in support of nanotechnology. The network computation activities are coordinated from Harvard and are led by Dr. Mike Stopa.
- ***Howard University:*** The facility at Howard supports a variety of specialized materials activities and has major educational and outreach responsibilities towards underrepresented community in the Washington DC area.
- ***Triangle National Lithography Center (NCSU/UNC):*** The Triangle Lithography Center is an affiliate member of NNIN with the objective of providing access to193 nm deep ultra-violet lithography. They receive no funding from the network for participation but agree to operate the DUV facility on an open basis, consistent with NNIN principles, and NNIN commits to redirect users who can gain from this resource to TNLC.

In most cases, a number of other nanotechnology resources and capabilities exist at each site, outside of the above defined scope, e.g. some level of characterization that is necessary for rapid execution of research and development objectives. Many of the universities also have additional resources useful for execution of nanoscale science, engineering and technology efforts, but which are outside the NNIN program. These resources can be and, in most cases, are made available to the user community through the NNIN program if their use can help with completing the task. Our goal is to provide service and help the user accomplish tasks with the highest level of technical support and rapidly. For example, a sophisticated characterization may be necessary in the middle of processing. That may be done locally or through U. of Minnesota and U. of New Mexico where the characterization responsibilities reside, which ever is most expedient. Sites are encouraged to make a broad range of technologies available on an open basis; in most cases, this includes entire clean room fabrication facilities. It is important, however, to recall the assigned site focus areas when evaluating site performance. This is our primary means to providing the best capabilities to the national community in those focus areas with limited financial resources, and to foster these disciplines through dedicated effort in these focus areas.

For NNIN to deliver the greatest possible value to the national user community and the nation, it is essential that the network be a dynamic organization that rewards performance and systematically adapts to changing circumstances and emerging opportunities. During formation of NNIN, we committed to making funding allocations yearly and based on productivity metrics and on the basis of leadership contributions in research service in areas of assigned responsibilities and the other NNIN thrust areas. A balanced evaluation requires understanding of responsiveness to user needs, the quantity and quality of output from the individual sites, and the changing requirements of new and rapidly developing fields. Sites are expected to allocate resources in accordance with the assigned focus areas and are held specifically accountable for success in those areas. We distinguish research and development usage, i.e. research usage, from educational usage that is in support of our broader outcome objectives. Research usage is in support of a specific research task, supported by research funds whose end result are publications for academic users, or new technology and commercialization-oriented development for the industrial users, and new knowledge for both. Educational and other broader area usage has as its goals training or knowledge dissemination. Technical workshops that we conduct, e.g., result in educational usage. On the other hand, an external user, who comes to our facilities, gets trained and uses our resources to accomplish their own technical tasks, is a research user. Evaluating

performance in this context is a complex task since it must balance between the nature, character, and the requirements of the activity and its appropriate evaluation.

Research user support and educational user support require different resources. Similarly, within research user support activity, different tasks may require different level of time and intensity of commitment from staff as well as of the level of complexity of instrumentation. Thus, data needs to be looked at in a variety of ways in order to assess the performance. In addition to quantitative measures, a qualitative evaluation of the enabled research also sets a different context of performance evaluation. Impact of the activity is also critical, and hence quality and quantity of research contribution enabled by site activities, particularly in the area of site focus, is an important consideration in performance evaluation. *NNIN focuses on collecting information that helps with forming a balanced and relatively complete picture of the network operation.* For research quality, this includes collection of highlights of research and development, related publications and presentations, as well as quantitative measures that look at research and educational user service.

A list of publications resulting from network efforts during a one year period is attached to this report together with research nuggets.

The different components of the NNIN mission - research-user services, computation and web-based services, education and outreach, and the societal and ethical thrust - each requires separate measures to evaluate productivity, quality of contributions, and user satisfaction.

NNIN sites also vary considerably in size and scope of effort related to NNIN. Consequently, the level of funding and the resultant expectations vary accordingly with the following guidelines:

- The range and volume of service that each site can, now and in the near future, provide to outside research users in specific technical areas assigned to it;
- The infrastructure needs of the technical focus areas that are supported by each site;
- The infrastructure needs for the educational efforts and educational user activities — activities that are different in character than research support activities;
- The level of responsibilities and range of activities that each site undertakes with regard to the NNIN education and outreach thrust, the computing and web-infrastructure thrust, and the societal and ethical issues thrust.

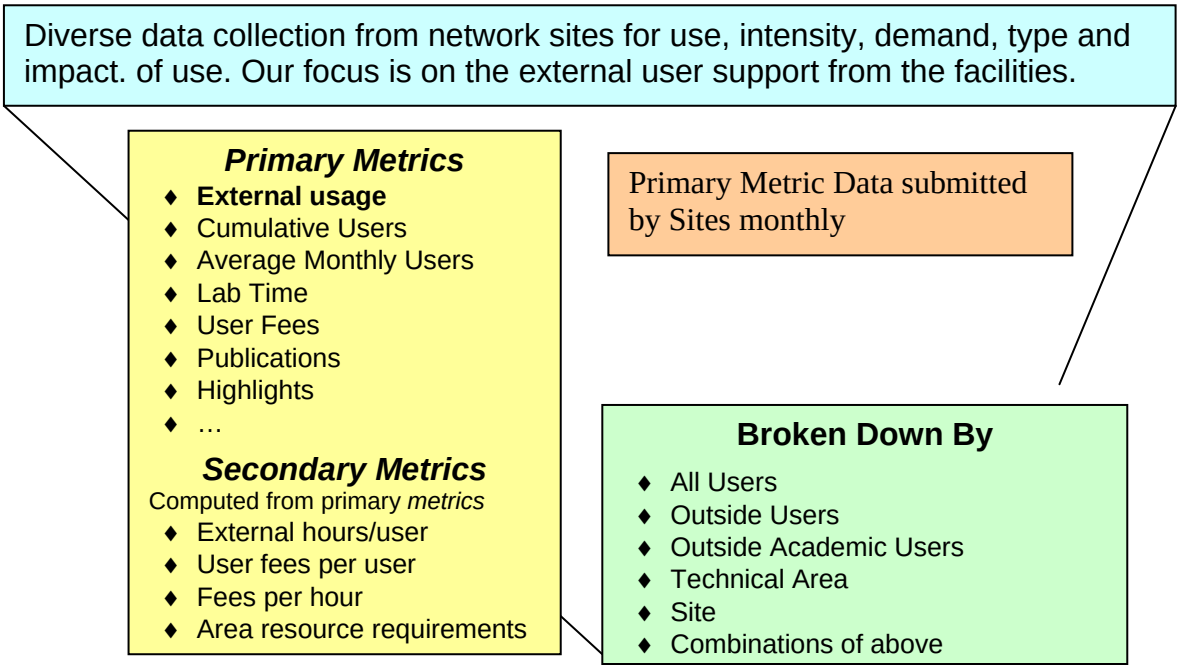
In the following, we summarize the performance of the network and the sites.

Network Quantitative Performance

A variety of metrics can be used to measure and characterize network performance. Figure 28 shows some of the major elements of the information collection. Since each user and each site is different, none of the metrics tells a complete story in itself. In particular, aspects of the quality of the research or the quality of the customer service are not captured well by any of the quantitative metrics. It is also acknowledged that the scope and type of use varies significantly from site to site, and that some types of users/fields have significantly different use profiles (e.g. a simple characterization or thin film deposition user vs. a user doing complex process integration for a MEMS or electronic device).

The information summarized here is for research lab usage. These are related to the projects where a users is trained and performs independent research, uses the variety instruments in the laboratory, and is the primary focus of the network research support activity. This data there does not include any educational "user", people who attended workshops, and other significant activities, or local students taking using any resources for class-room learning, etc.
These statistics also do not include Computation Users; although a significant number and requiring close work with our Computation Domain Experts, and doing in theory what we also do in experiments, they are evaluated separately as this is a distinctly different use available only at two sites currently.

Figure 28: Network information collection



No single "best" indicator

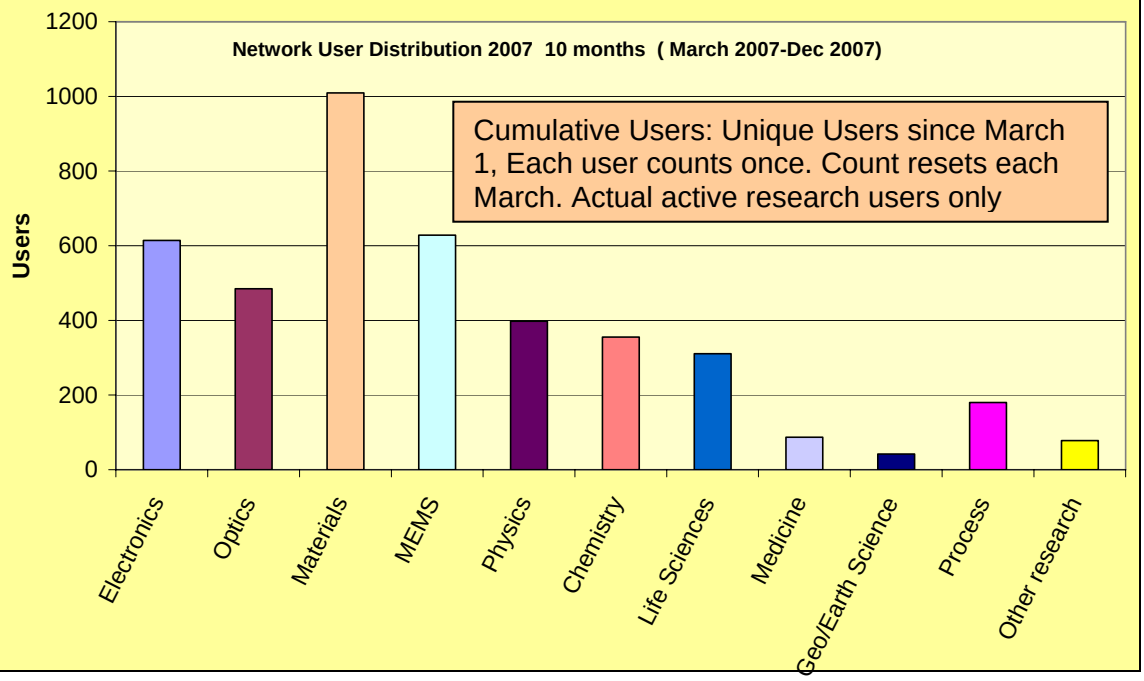
Primary usage data is submitted monthly by each site to NNIN management. All graphs are subject to the accuracy of the data supplied by the sites.

Unless otherwise noted, all data is for the 10 month period March 2007-Dec 2007.

Program Breadth

NNIN's mission in support of experimental nanotechnology covers a broad range of technical areas, from complex fabricated structures such as MEMS, biosciences, optics and electronics, to synthesized molecular scale structures. Figure 29 shows the distribution of users by field (10 months, cumulative users) across the network.

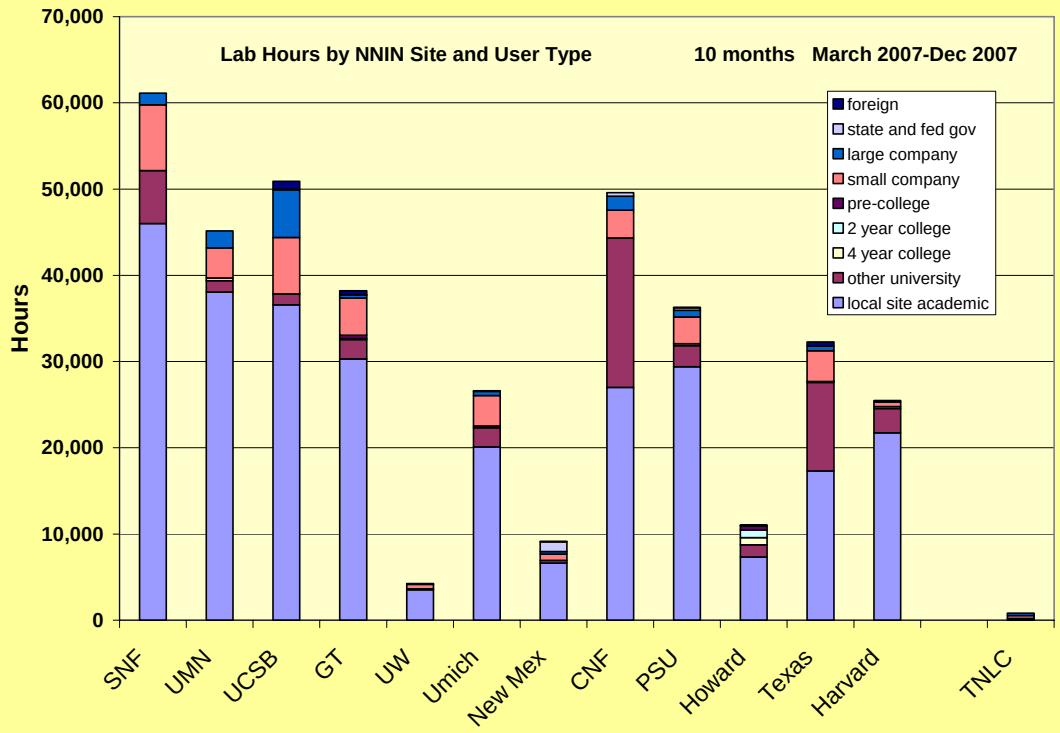
Figure 29: Network User Distribution by Technical Area.



Lab Use

Laboratory hours are counted by one of two means at NNIN sites; **either direct use equipment time, or clean room time**. The former does not include lab use for non-charged equipment or other general lab time but does count multiple simultaneous equipment use. The latter counts just time in the lab, which could be used for a single piece of equipment, or multiples or none. Thus, while there is correlation between the two measures, they are different in between sites. We accept this variation in counting methods as part of the uncertainty. However, laboratory hours are an important way to track intensity of laboratory activity at each site and across the network.

Figure 30: User Lab Hours by NNIN Site.

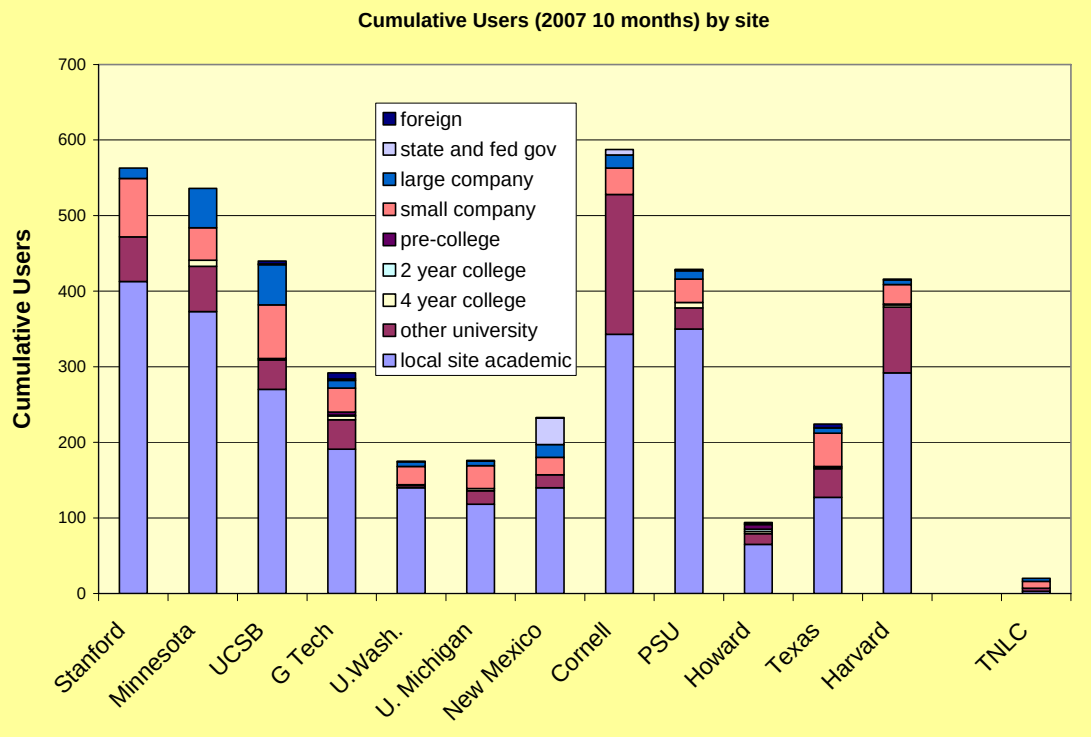


The chart in Figure 30 represents total lab hours during the 10 month period (March 2007-Dec 2007). Size of each NNIN facility varies significantly and each includes different amounts of "associated" facilities. Nonetheless, they reveal information about the size and scope of each laboratory's activities. The activity at all laboratories is dominated by local usage. The local users are a vital foundation of the facilities. The local users develop the processes, provide quite often the initial impetus for new technology development, and provide the rigor and reproducibility that becomes the knowledge and training foundation for the external user.

Cumulative Annual Users

***Cumulative Annual Users* is the primary user counting metric employed by NNIN**. This is each unique user counted once during the time period, using March as the starting time for every yearly cycle. This number monotonically increases during the year, reaching the maximum at 12 months when the counter is reset for the next year. This measures the number of different people that the site has served; a user who visits once counts the same as one who visits may times over the year, with a 4 hour threshold for usage. Figure 31 shows the distribution of users across the network by site, with types of users. This figure can also be contrasted with the hours (either laboratory time or equipment time). Cornell reflects a large and good balance between internal and external users, with Stanford, U. Minnesota, UCSB, Harvard, and Georgia Tech showing a significant external usage. Also recall that at U. of Minnesota, there are three laboratories that are part of NNIN, two of whom – particles and characterization – have as their focus remote usage. There is considerable variation in the number of users and in their distribution between sites, and this should be considered together with the technical focus responsibility area at the specific site. In this metric, each user counts the same regardless of whether he/she uses the facility 4 hours per year or 400 hours per year. To gain a fuller picture of the effectiveness of each site one has to look at other metrics as a supplement to this.

Figure 31: Cumulative Users at each site. (March-Dec)



As discussed in the introduction, NNIN's effort is organized around the theme of serving the external user – a focus we believe leads to a variety of benefits in quality, efficiency, and local community and external community effects that are essential to bringing the maximum benefits to progress in nanotechnology from an infrastructure. External users are the most important component of the NNIN effort, together with the focus on external users in assigned areas of technical responsibility within the network. Figure 32 show the distribution of outside users only,

i.e. local site users removed for clarity. Nearly all sites continue to make progress towards the objectives. Four major sites of the network, Cornell, Stanford, UCSB, and Minnesota have 150 or more outside users each in the 10 month period, with both academic and industrial users benefiting from the network.

Figure 32: NNIN Outside Users by Site.

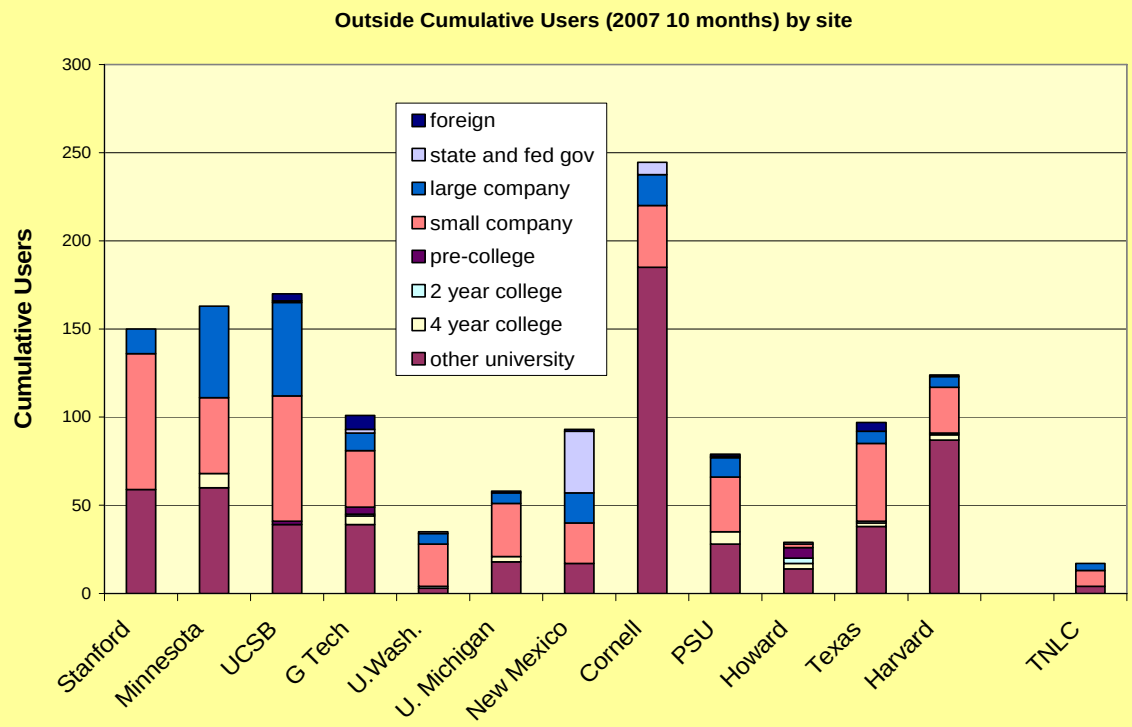
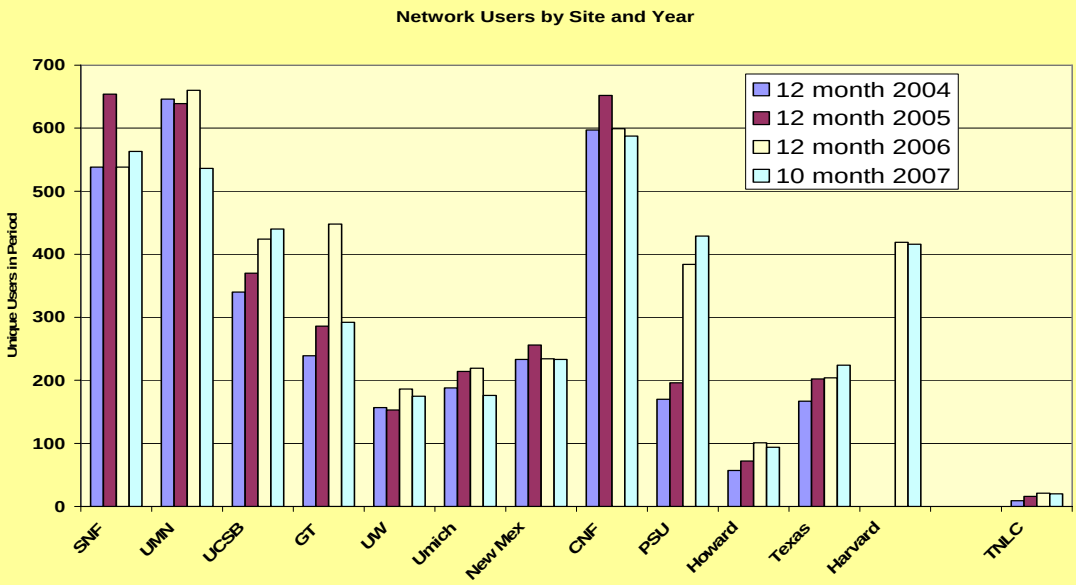


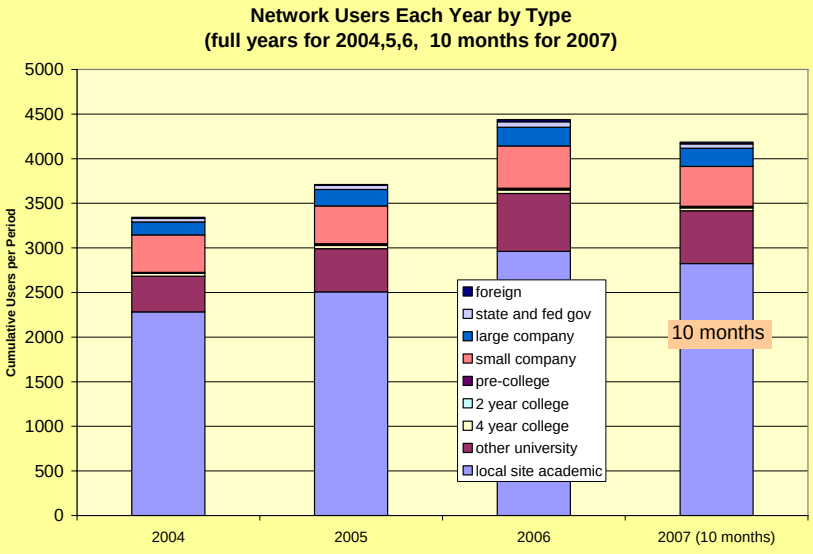
Figure 33: NNIN users by site in a three year comparison.



Accurate numbers of 2004,2005 cumulative users at Harvard are not available at this time.

Since the network started in 2004, it is important to also view the progress in network usage. The associated chart shows the trends in usage of the network at the sites (Figure 33). While comparisons of the 10 month period to prior 12 month periods is problematic, most site continue to expand usage.

Figure 34: Network wide research usage



When an adjustment is made for the shorter reporting period of 2007 ,Figure 34 shows a general increase in network usage across all institution types, summed across the network (2007 data for 10 months March 2007-Dec 2007),.

User Fees

Lab use fees supplement the NNIN funding at all sites. Fees are charged on a per user or per hour basis with the exact structure varying by site. The user fee rates at each site are set at local discretion according to federal and university regulations for cost centers. Some of the NNIN site programs are connected through existing, sometimes larger facilities and programs. As such, no attempt has been made to standardize fees across the network which must remain consistent with local university requirements. NNIN only demands that external academic users receive the same rate as local academic users, and that the NSF funds be organized to support open academic usage. Thus, industrial users pay the full cost of usage, while the academic users benefit from lower costs that the NSF support makes possible. Academic fees cover the incremental costs of operation while the industrial users are charged at higher rates to reflect full cost recovery and reflecting effort that does not compete with commercial sources.

User fees (Figure 35) provide a mechanism for allocating costs to different activities. The NNIN mission is to make these facilities available openly to the national user community. NNIN funds largely pay for the staff and training infrastructure required to support this outside user effort and not for operation of existing facilities. The level of expense recovery obviously varies with the size of the user base; examination of total fee recovery yields little new information. One of the tenets of NNIN and a necessary condition for forming the critical mass of users is that use must be affordable, particularly for academic users. An examination of average user cost (Figure 37, 38) across the network reveals that this in the case.

There can be several explanations for low fee recovery from outside users, among them: 1) low number of outside users, and 2) low average level of use by outside users.

Figure 35: User fee recovery in 2007.

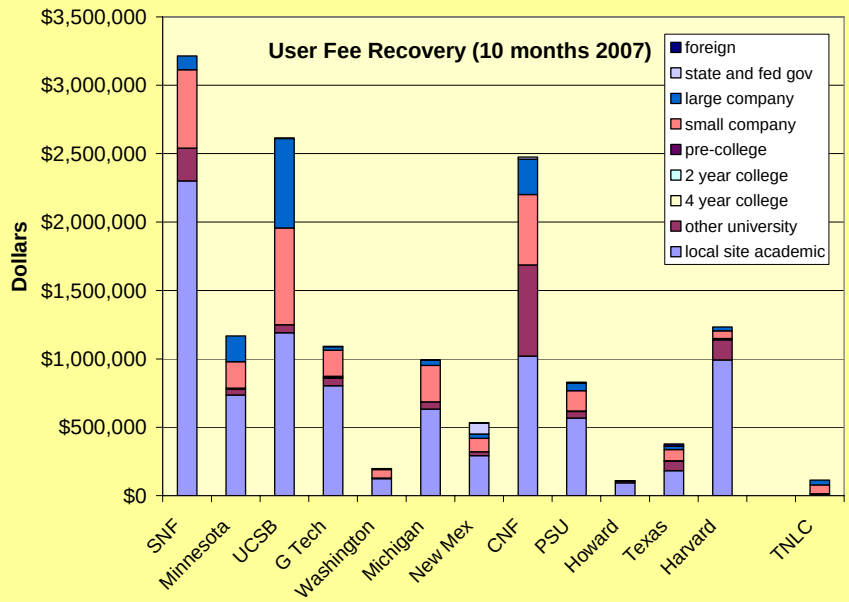
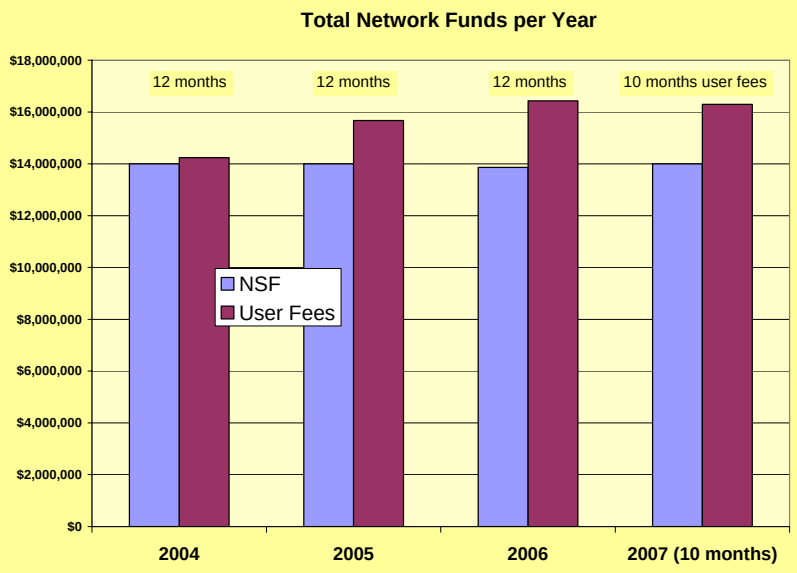


Figure 36 shows the overall high leverage of the NSF investment. Each dollar of the NSF cooperative agreement is more than matched by user fees. Both user fees and the NSF support are critical to operation of NNIN.

Figure 36: Two of network's major sources of funding: NSF and user fees.



One of the requirements of a successful user facility/network is that it be affordable. This is particularly the case for academic users whose work is paid by various government grants. Because of the economies of scale and the critical mass of users, NNIN is able to keep academic use charges low. Figure 37 compares the local academic (NNIN institution) and outside academic average user fees per user over the 10 month period (fees/# of users). By NNIN mandate, local users and outside users pay the same rates for use. While there is some variation between sites, the most striking part is that the average users paid just over $3000 during the 10 month reporting period. This is an average; many heavy users paid significantly more, and many users paid significantly less. Similarly, average fees per hour (Figure 28)are clustered fairly tightly around $30 per hour, a quite reasonable fee for access to high technology equipment.

Figure 37: Average academic user fees.

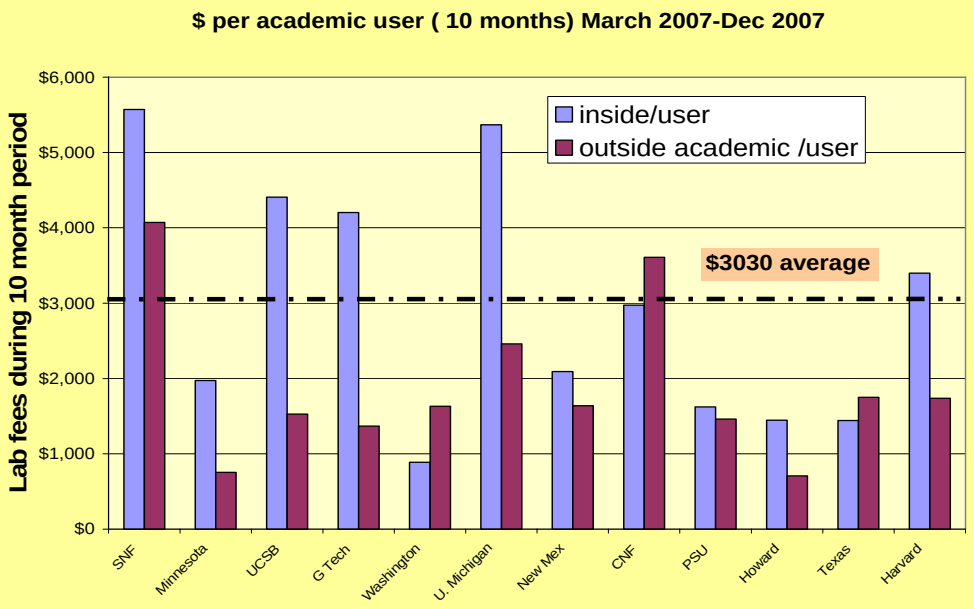
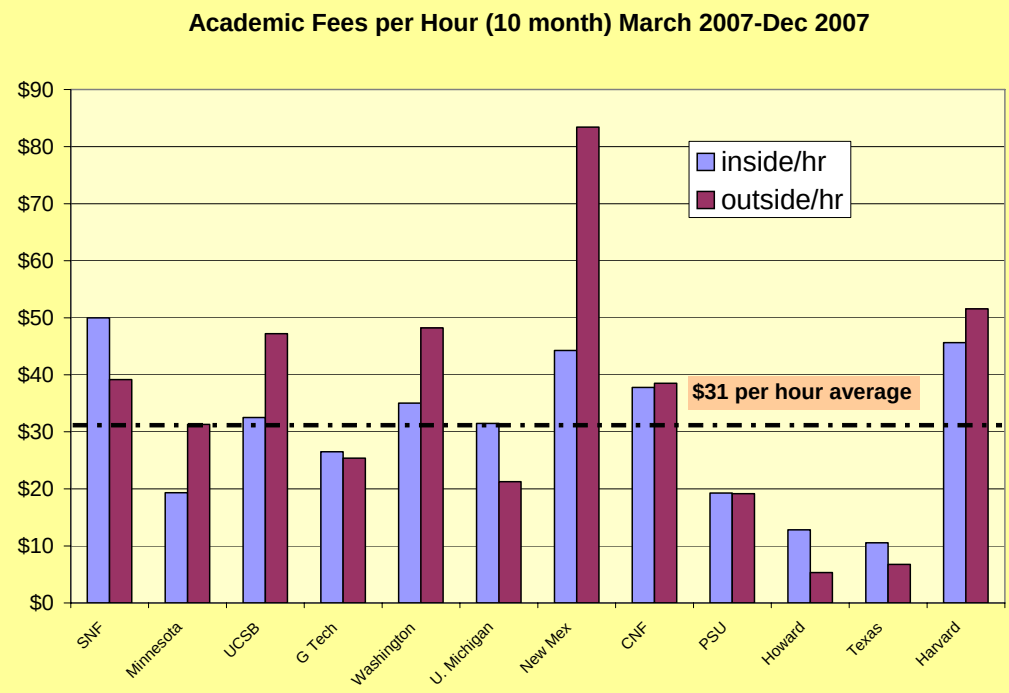


Figure 38: Academic fees per hour in NNIN facilities.

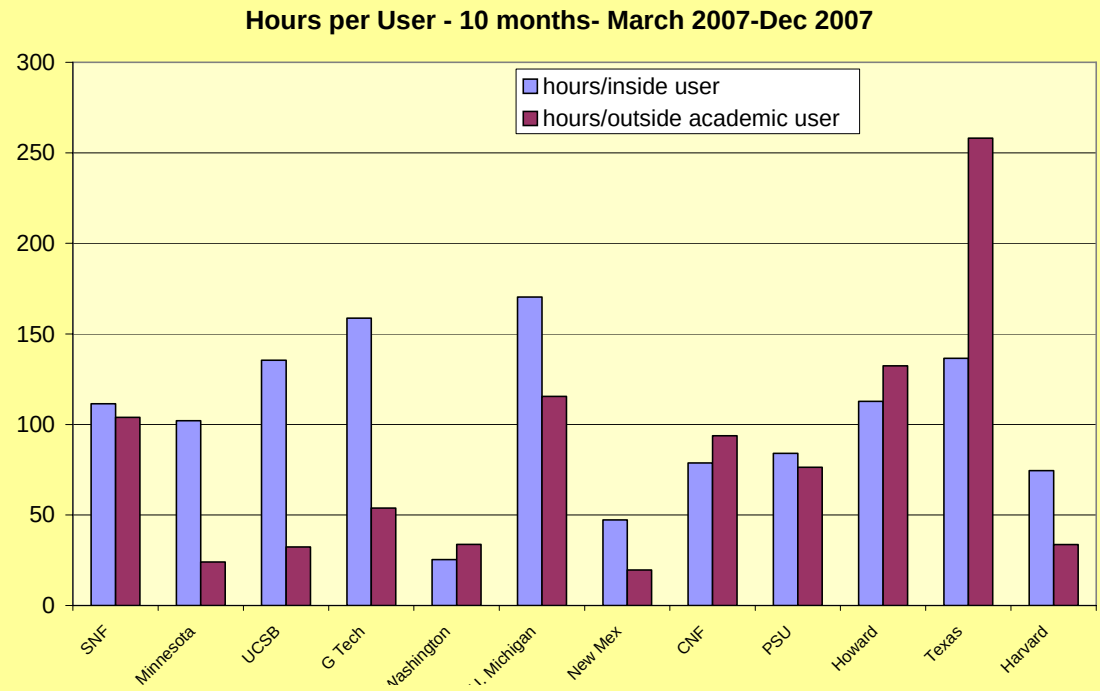


The point of these plots is not any individual variation, either between sites, or between local and outside users at a given site; there is far too much variation in complexity of projects and the available equipment sets to draw those conclusions (although actually most use falls in the $20-40 per hour range, a quite tight and reasonable result). One should thus not conclude that one site's fees are too high or too low from this data. And there are certainly individual users who are at both 4x the average and 1/4 the average, i.e. there is a broad distribution. It does show, however, that access to NNIN facilities for an "average" user is quite affordable. The full out average over all sites for all academic users is $3030 during a full year, quite within the budget of most research grants. In contrast, the average cost for a non academic user (company, foreign, government) is $7650 (not shown), again with a broad distribution both within sites and across sites, but extremely manageable for the complex resources that the NNIN sites provide.

For outside users we do not believe that the relative costs of NNIN facilities are a major factor in selection of a facility. Technical capabilities of the sites, technical alignment with the users requirements, and geographical considerations are significantly more important considerations.

Hours per user

Figure 39: Laboratory hours per user (local and external).



Hours per user is a particularly enlightening metric as it in some sense shows intensity of use. A site can more easily sustain a large number of users doing small processes than a similar number of users doing complex processing. Hours per user (per 10 months) (Figure 39) is an average secondary metric, gathered by dividing lab hours in a particular category by the cumulative annual users in that category. Average usages of 100's of hours per user would indicate a facility with more complex processing and a concomitant large impact upon the facility and its resources. Average usages of <25 hours indicate a group of users who place a significantly smaller burden on the facility. That use may still in fact be critical to a given project but it requires fewer resources to support on an incremental basis. Results across the network, for both internal and external users, are shown in Figure 39. It is obvious that there is considerable difference between sites in the intensity of use by an "average" user. Note, in some cases, this derived metric is the ratio of two small numbers and thus the metric is less enlightening for sites with a small number of users. In most cases, intensity of use by internal users is higher than external users reflecting the higher availability for routine and unplanned use.

New Users

Each facility is constantly accepting new users. This is not only necessary for growth but even to maintain steady state as users complete their projects and move on regularly. The number of new users is thus an excellent metric for measuring the demand for NNIN resources. Here (Figure 40) we show the number of new users trained in FY2007 by site. Note that at some sites (e.g. Stanford, Cornell, Harvard, and Minnesota) new users(inside + outside average almost 5 per week.

In addition, there needs to be a balance between new users and total users. Figure 41 shows the ratio of new users to total users in FY2006 at each site. A ratio too low could indicate a stagnant facility with little growth or replenishment. A high ratio hand could indicate a rapidly growing facility. On the other hand, a ratio too high could also indicate an excessive turnover often associated with short term low impact projects.

Figure 40: Training load for new users (internal and external).

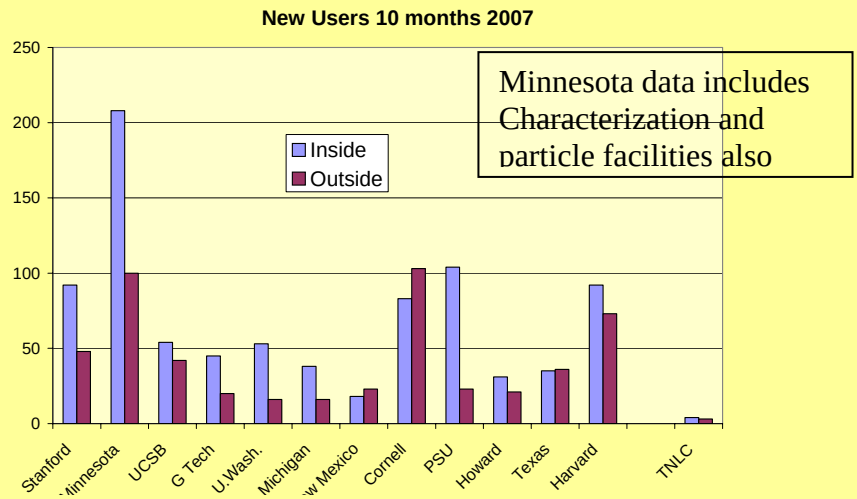
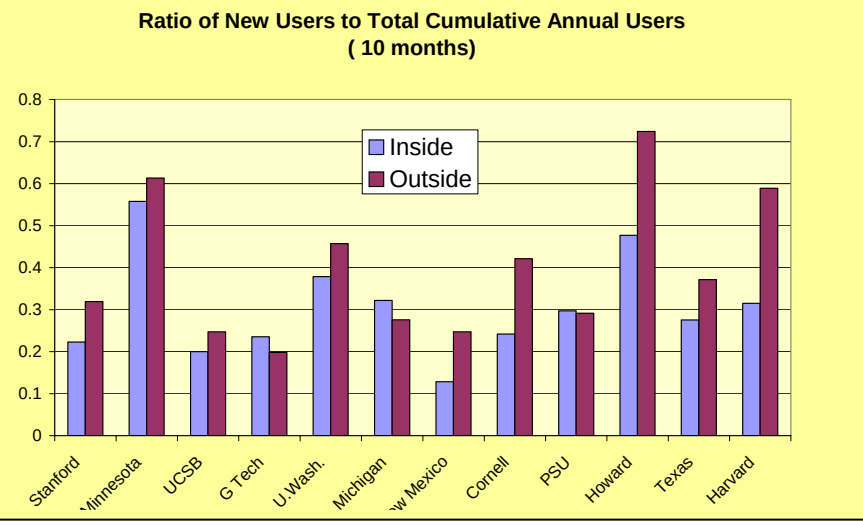


Figure 41: Sustained usage and new usage of sites.



8.2 NNIN Performance; Qualitative Self-Assessment

Qualitative assessments, by their nature, require a broader perspective and an understanding that the discussion is not one with mathematical clarity or one that can go beyond a number of factors that become "quality of life" issue. In the discussion that follows we summarize a number of qualitative attributes reflective of the impact of NNIN on external users who are the drivers of the focus of NNIN.

Our discussion here is to summarize some of the strengths that come through when we look at the impact that the collection of sites are bringing both in the form of quantitative impact as also in the form of intellectual output as seen through publications and highlights.

There is broad demand for NNIN resources and thisis reflected in the geographic and technical distribution of projects and users. The research usage within NNIN encompasses at least one institution from each or the 48 continental states. While there is some geographical concentration around NNIN sites, examination of the lists of institutions for each site shows considerable geographic diversity. Users often do not go to the closest NNIN site for a variety of technical and personal reasons. Generally they go to the site which can best serve their particular needs. The range of sites offered by NNIN, the range of technologies at each site, and the relatively low cost of transportation assure that the network resources are available to users from every state and locale.

In addition, user projects cover the entire range of nanotechnology, reflecting the broad interest n nanotechnology across the technical spectrum. Among these, geology/earth sciences is the smallest, but still with greater than 50 different users in the network,and is growing somewhat. The areas of materials, MEMS, electronics have the larges number of users, but are followed closely by physics, chemistry, and the life sciences. This of course varies widely by site; for example, at Cornell the broadly defined group of life sciences projects is largest. This reflects both the interest of the local academic community as well as the legacy of a history of accomplishments in this area. The largest external usage, the focus of our efforts, in terms of number of users occurs at Cornell, followed by UCSB, Minnesota, Stanford, and Harvard. The Minnesota site consists of three different laboratories— fabrication, characterization, and particle technology— thus reflecting a different character than most sites. Even within these sites, however, there is a significant variation between academic and industrial users, largely related to geography and history. Stanford, Minnesota, and UCSB have a relatively larger industrial user base, whereas Cornell has been able to attract significantly more outside academic users. Many of the new sites that joined the network four years ago have made excellent progress and contributions. In terms of hours of laboratory/equipment usage, Cornell has the largest usage by outside users, followed by Stanford, UCSB, and Texas. Clearly, depending on how one looks at "usage" one gets different answers about the size and effectiveness of each site. The level of user, the type of usage, and the funding level and size of each facility all have to be factored into any analysis of lab usage.

Evaluating the impact of research made by NSF funds to NNIN is subject to a number of subjective features. Over the years, we have looked at the publications and presentations from the external (and internal) users, publications in high impact journals, publications where the

work was cited with high publicity, publications where the submission was invited or was featured on the cover page of a journal, etc., as a way of evaluating the reception of the quality of the work by the community at large. Nanotechnology, as an area of major current interest, occupies the attention of most of the community and this is reflected in many of these measures. In a recent year nearly 15% of the Applied Physics Letters covers reflect research work conducted in NNIN. These are submitted publications that have been chosen as a feature by the editors of the journal. Materials Research Society, similarly, has chosen work of NNIN researchers as items of focus in a similar percentage of the publications, by invitation, in its MRS Bulletin. A number of publications, in the highly promoted journals – Nature, Science and Proceedings of National Academy of Science – have been from NNIN authors. The publication list and the highlights at the end of this report show a very significant output by both internal and external users. Bringing nanotechnology to the benefit of society through commercialization is another area where the network has made major contributions although this is more difficult to quantify.

Similar achievements also exist for impact from the educational and broader impact effort from the network. The NNIN Education Program has been particularly active with over 175 group events with over 14000 trackable participants. In addition web based efforts such as *Nanooze.org* have a broad effect. There is considerable interest in nanotechnology at all age levels; NNIN providing materials and activities to stimulate and cultivate that interest.

The funds supporting NNIN make possible research of 4400+ research users, 250+ small companies, trains nearly 1600 new research users each year (>1300 in most recent 10 months), and results in more than 1200 PhD awards each year. The rate of new users is particularly impressive and reflects a growing and continuing interest in nanotechnology and NNIN's resources. The funds provided by National Science Foundation make possible in excess of 30 to 1 leverage in the research and development that advances the knowledge and commercial frontiers in the broad areas affected by progress in nanotechnology.

By any measure, this is a very major impact of the nation's resources invested in science and technology.

9.0 Summary

NNIN is nearing the end of its 4th year of operation. This report covers the 10 month period from March 1, 2007 to Dec. 31, 2007. NNIN has implemented methodologies for user support at all sites and has a large and growing user base. Over 5000 new users have been accommodated into NNIN sites during this period, and NNIN continues to serve over 4000 unique users each year. The research accomplishments of these users are extensive and well documented. NNIN has demonstrated an effective model for support of users in a high technology environment, with large leverage of government funds. In addition, NNIN has established an impressive array of local and nationwide educational activities and SEI based activities.

Appendices

The appendices contains the following information

1. Site contact information
2. Site reports and site summaries as received.
3. Publications list for one year (July 2006-June 2007) collected in July, 2007 and listed as (a) internal user publications, (b) internal user conference presentations, (c) external user publications and (d) external user conference presentations
4. Research highlights collected in October 2007 covering the period Oct. 2006-Sep. 2007.

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