Annual Report of the National Nanotechnology Infrastructure Network

March 1, 2006 through Feb. 28, 2007

Cooperative Agreement: ECS-0335765

ABRIDGED

Participating Institutions*:* Cornell University, Georgia Institute of Technology, Harvard University, Howard University, North Carolina State University (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
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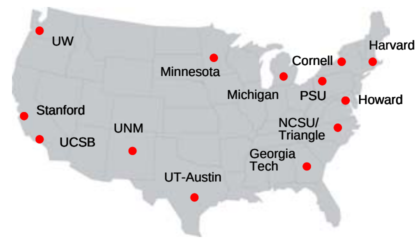
Figure 1: Member institutions of NNIN.



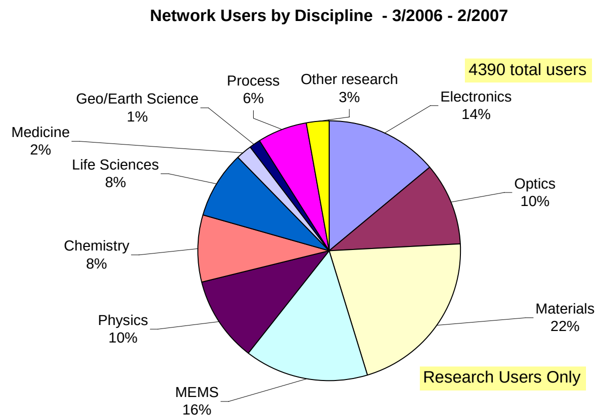
The National Nanotechnology Infrastructure Network (NNIN) provides access to infrastructure within open shared facilities to enable the national science and engineering community to pursue research, education and technology development within all the many disciplines that can benefit from nanotechnology. We are a partnership of 13 university-based laboratories, each of whom while serving broader needs, provides leadership in specific technical focus areas so that the advanced techniques, instruments, and knowledge can be efficiently utilized. 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.

Science, Engineering and Technology Support: The network's current technology scope and activities are summarized in Fig. 1. We make continuous efforts through workshops, advertising, and presence at professional society conferences to assess needs of new directions developing through the worldwide nanotechnology activities, and to actively develop infrastructure and technical support for these new directions. Supporting hands-on nanoscale research so that graduate researchers, industrial and national laboratory professionals, as well as smaller institutions can build and explore materials, structures, devices, and systems using a combination of bottom-up and self-assembly techniques and top-down fabrication techniques is our central mission. The user support for these tasks is accomplished through rapid technical interchange via user-support staff, arranging the visit to the appropriate facility, and a rapid initiation to the experimental work through training and staff-researcher interactions. NNIN's staff includes PhD level experts that facilitate cross-disciplinary propagation of know-how and NNIN provides remote support for many processes and for characterization where a visit may not be necessary. The key to success in this effort is openness and equal access to all, commitment to service, low costs, and rapid interchange. The network usage is growing in double digits, and success with serving the diverse user community is encapsulated in Fig. 3 which shows the breadth of our user community. ~200 new research users per month are being

Figure 2: NNIN is organized as an open resource available to all focused through its user-centric culture on activities that lead to rapid reduction of nanotechnology related ideas to practice. The staff train the users to use the large instrument set and provide the technology and processing support.

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 and hosting site visits, and we organize 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.

Figure 3: Discipline breakdown of unique research users of the network (3/2-2/28/07). The research usage of the network is growing at double digit rate with a similar distribution of interest in new users.



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 outreach activity for education and social and ethical discussion. 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. Increasingly, characterization is also an important part of the research since observation of properties and structures at the nanoscale is non-trivial. Thus, various forms of microscopy (cryo-tem, tem, stem, etc.) and preparation of samples, such as through focused-ion beam techniques, are available through the network, alongside traditional and non-traditional synthesis and fabrication tools for integrated processing. We continue to increase our effort in support of technical usage through remote means. This support activity ranges from critical electron-beam lithography and processing of nanoscale features, providing membrane structures used in a variety of nanoscale experiments, to integrated processing of more complex device and systems. In order to assure that the network remains dynamic in its support and capabilities and makes judicious use of resources, the network sites have assigned technical focus areas for leadership. These areas correspond to the areas of exceptional strength of the local research and allow us to selectively apply precious financial resources towards maintaining the most advanced capabilities for national community. Cornell and Stanford provide extensive support across disciplines as well as for complex integration projects. For biology and life-sciences, Georgia Tech and U. Washington; for chemistry at nanoscale, Penn-State, Harvard and Texas; for Geosciences, New Mexico and Minnesota; for integrated systems, Michigan; for tool development and manufacturing research support, Texas;

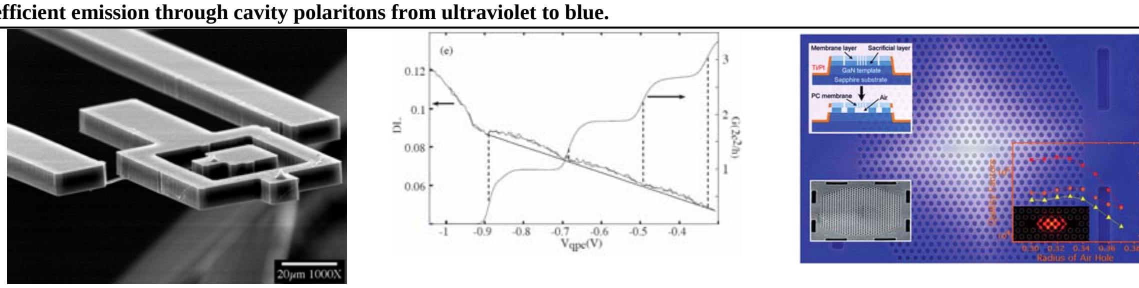
for remote use and characterization, Minnesota and New Mexico provide the focus technical area leadership.

Education, Development and Outreach: Education and outreach at the local and national scale is a very key component of the network activities. These activities encompass the needs of public and of the education community. We organize local and national workshops that tie technical areas to research and to practicing 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 more practical lectures related to mentoring (art of scientific presentation or writing of scientific papers), as also instructional material related to social and ethical considerations. The network also conducts a very successful REU program and a program for teachers. During 2006, 64 interns from institutions across the United States and representing 32 fields of study participated in the program. Sites also have activities focused on local needs, ranging from attracting underrepresented high school students through rewarding experiences, and support for local teaching community – high school, community college and other small colleges. We are also active in workforce development through hands-on practical training. In time, we will have courses and an open text-book available on the web. The workshops conducted by the network during the past year included hands-on three-and-a-half day lectures coupled to fabrication, computation and modeling, movement of ideas and technologies from research to manufacturing, and workshops for small institutions for an immersive laboratory experience. The network has also extensive international cooperation that take the form of joint workshops as well as web-based Nanotechnology International Cooperative for knowledge and experience interchange. Reports of such activities are available on the web. ~700 attendees participated in our workshops during the first six months this year.

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 as the nanotechnology area evolves for future studies. These activities are centered at Cornell, Stanford, Washington and Georgia Tech. Discussions and seminars from these activities are available as multi-media presentation from the NNIN web-site.

Example Research: Several examples of research from NNIN are available on the web-site. To provide a breadth of the activities made possible, a few examples are provided in Fig. 4.

Figure 4: Projects conducted in NNIN are very diverse. In the three examples here, the first is a highly compliant torsion probe using in scanning probe microscopy of soft materials in solutions (Sachs et al.), the second is a measurement of the screening from electrons near point contacts (Goldhaber-Gordon et al.), and the third is an example of a high Q photonic bandgap cavity in InGaN for efficient emission through cavity polaritons from ultraviolet to blue.



Summary: NNIN, in its third year of operation, is now reaching out to nearly ~4400 research users nation-wide, ~250 small companies, has trained ~1600 new users during 2006 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 unified in their commitment and practices in supporting research and development activities in the diverse directions of nanotechnology nation-wide. We complement this research support with broad outreach activities locally and nationally. The network focuses its infrastructure resources so that the national user community, a large fraction of which is from outside the home institutions, can benefit through expeditious, affordable, and knowledgeable hands-on use of difficult to access instruments, processes, integration, and technical know-how in interdisciplinary and disciplinary research. The infrastructure provides for the coordinated integrated implementation of large numbers of top-down processing steps together with the complex tasks of synthesis and assembly at the molecular scale to make structures, devices, and systems feasible. The network also supports specialized techniques for characterization at the atomic scale, and supports advanced and robust modeling and simulation tools in support of nanotechnology research. The network 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.

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. 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 nature and scope of research performed within the NNIN facilities is determined by the users and the results of the research belong to the users.

During the year 2006, the network supported the research objectives of 4380 users from academia, industry and the national research laboratories. More than 250 mall companies employed the network resources to reduce their ideas to practice. In educational activities, more than 1600 participants gained their initial hands-on experience with tools and techniques of nanotechnology.

The network began operation on Mar. 1, 2004. This is the report of the third year of operation of NNIN — March 1, 2006 – Feb 28, 2007.

2.2 Mission and Approach

NNIN’s mission is to enable rapid advancements in science, engineering and technology at the nanoscale by efficient and affordable access to nanotechnology infrastructure and through a broader set of activities with educational and societal emphasis.

Our approach to accomplishing this goal is a cultural commitment of openness that focuses on external users, of technical excellence that focuses on bringing key instrumentation and knowledge through sites that builds on a sites’ research strengths, of effective and leveraged use of scarce resources through careful checks and balances, and of a synergistic set of local and national activities that take advantage of our educational and social interests and strengths.

Accomplishing the technology support requires that we place the highest priority to the needs of external users. This develops openness and practices that enable a broad swath of research of the highest quality, and creates effective and efficient means for large groups of users to leverage the scarce resources that the network provides. Accommodating large numbers of new users arriving weekly and training them to operate safely and creatively in a shared-facility environment is a critical step of this culture. This makes possible delivery of complex technology such as e-beam lithography and multi-step integrated processing procedures at the same time as new developments such as new synthesis and functionalization techniques. It thus broadens the reach of knowledge of new nanoscale approaches across disciplinary boundaries and leverages the synergies of a network for the mutual benefit of all users. This is a continuing improvement process that builds on experience, expansion of areas and emergence of new directions.

Each of the network sites is committed to the vision of open facilities, outstanding service to the external user, comprehensive training and staff support, support of interdisciplinary and emerging areas research, and openness to new materials, techniques, and applications.

The operating principles we have all committed to and beholden to are

- 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

As a networked community of university-based facilities that take advantage of the unique research and knowledge strengths of the local community, and by providing an open environment that makes these resources equally accessible to academic, government and industrial users, we provide a low-barrier and low-cost approach for research, education, and technology development to flourish within all of the many disciplines that can benefit from nanotechnology. Through openly accessible facilities distributed across the country we provide a network that welcomes researchers from established and emerging disciplines with a strong emphasis on accommodating new materials, techniques, and processes.

Qualified technical staff is provided by each of the NNIN sites to serve as a resource for our direct users and to support the broader scientific community through workshops, short courses and web-based instruction. Each site is responsible for providing the staff resources sufficient to enable comprehensive training and support for external research projects. Currently, NNIN trains approximately 1800 new users per year, with a total of over 4300 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 responsible 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.

NNIN also serves user community remotely for specialized techniques that are reproducible. These range from fabrication to characterization and have in many cases remote visualization capabilities. This is a rapidly growing area for the network. These capabilities coupled with a strong web presence allow NNIN to serve a vast community of researchers beyond the geographic reach of the network. Remote-access projects are treated the same as projects that involve hands-on use of NNIN facilities by external users.

The entire breadth of nanotechnology can not be covered by one facility or by a set of identical facilities. We obtain efficiencies in the use of the scarce financial resources by connecting the individual sites' research strengths to providing network technical leadership in those assigned areas. This provides a path for new developments, knowledge and ideas to become nationally available in a timely manner. NNIN sites are all different and have 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. Similarly, responsibilities for education and SEI activities are distributed across the network.

The network consists of 12 funded sites and one 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. 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:

- **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.
- **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 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 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.

Figure 5: Technical area responsibilities of NNIN sites**.**

	Bio- and Life Sciences	Bio- and Integrated Systems	Chemistry and Molecular Scale Technology	Electronics, Optics, MEMS	Materials and Physical Sciences	Computation	Geosciences	Manufacturing Research Support and Tool Development	Remote Usage and Characterization	Education	Society & Ethics
Cornell	■	■	■	◆	■	◆	■	■	■	◆	◆
Stanford	■	■	■	◆	■	◆	■	■	■	◆	◆
Georgia Tech	◆	■		■		■				◆	■
Washington	◆			■						◆	■
Michigan	■	◆		■		■			■	■	
U.Texas Austin			◆	■				◆		■	
Minnesota				■			◆	■	◆	■	
Penn State			◆	■	■					■	
UCSB				■	◆					■	
Howard				■	■					◆	
New Mexico				■			◆		◆	◆	
Harvard			◆	■	■	◆		■		■	
NCSU				■							

■ Assigned Activities

◆ Special Focus-Network Leadership

- **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 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.

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

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, other participatory activities, and feedback from the advisory board to keep 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.

Network activities are also directed towards encouraging underrepresented groups in the scientific disciplines and in making successful models available on the web through our infrastructure. Our outreach and educational activities are both national in scope (children's magazine, training and technical resources, etc.) and are also focused on local needs. With participating universities located strategically in areas with large under-represented communities, e.g., Howard in Washington DC, U. New Mexico in Albuquerque in South West, Georgia Tech in Atlanta, and UCSB in Santa Barbara, we have also in place strong directed programs for local outreach. As these programs continue to develop, the successful efforts become models for development of nation-wide efforts.

The vision of a nanotechnology future is also critically dependent upon human resources. **Education, human development, and outreach** 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, is served through hands-on and web-based tools which provide national and local reach.

Most of the NNIN funds are used in support of the staff wit a small (~10%) directed towards capital equipment. 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 research support 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 Practices for User and Technology Support

This section summarizes the practices of NNIN to enable research and development support activities together with the mechanisms.

The facilities of NNIN are resource facilities, i.e. the primary mission of NNIN and NNIN 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. The NNIN facilities thus do not have a particular research thrust or a portfolio of research thrusts. 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 sites there are resident research programs 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 centers” 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 as research collaboration. Our users come for a short period of time (days, weeks, months depending on the task; there is also a sub-group of users who are resident at sites year round as employees of external institutions) 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 user can use the facility quite independently, having learned the instruments, or can take 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 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 a research project of itself, and it 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.

In addition to normal support staff, NNIN has a small set of "Technical Liaisons" or "Domain Experts." These are senior staff members, typically Ph.D.s, who are scientists and experts in nanotechnology applications to 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 higher 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.

NNIN User Access

The access process can be brief spanning as little as a week or two. 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 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 a sponsored research contract, merely a purchase of services. 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 always less than a month. New users are accepted into the NNIN facilities at least monthly—weekly at some sites. Some of the larger NNIN sites can accommodate 10 new users each week, and through special efforts, more than that during the summer period. *Over 1600 new research users were trained and entered NNIN facilities in 2006 (12 months, Mar-Feb).*

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 toolset, i.e. the structural requirements and 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 staffs are 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, …) 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 include 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 etc. that the user is trained for.

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 only 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. 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 user process 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.

Technology Access

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 several hundred million dollars and most of it predates the formation of NNIN.

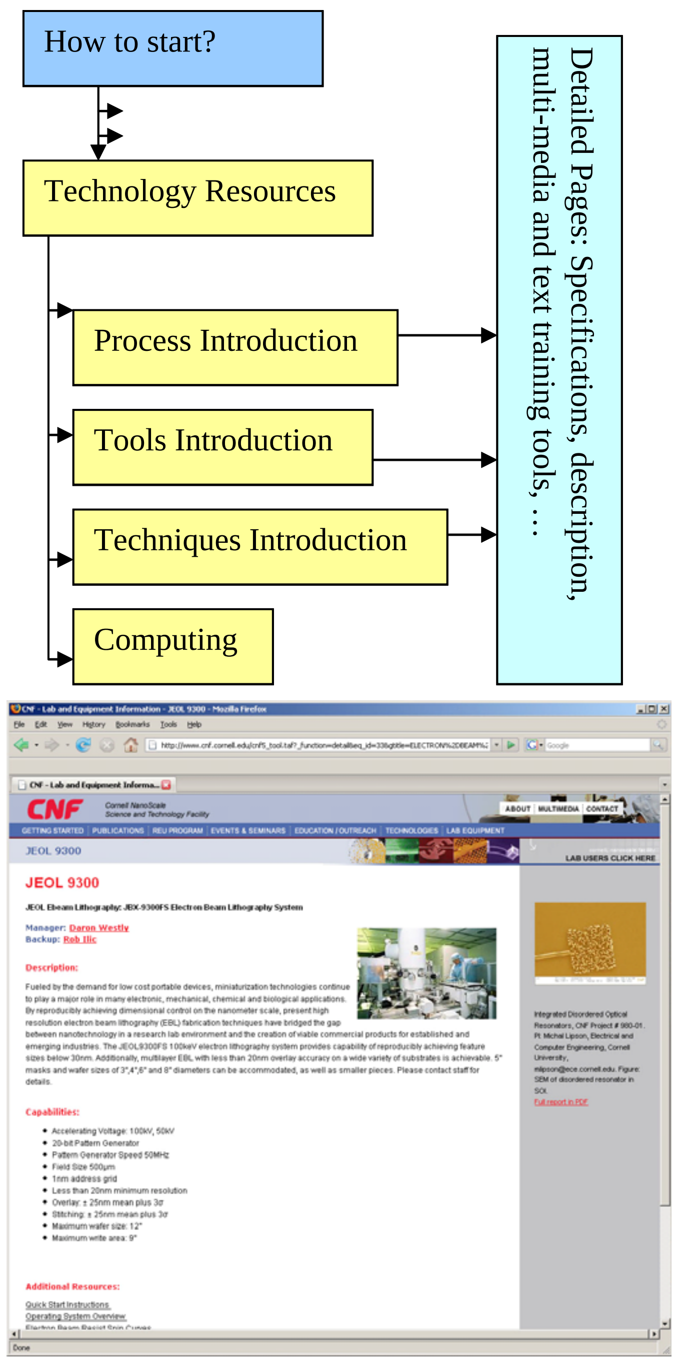
Our tying of research strengths of a university with the technology leadership and contribution, and the technical diversity achieved across a larger group of university, allows us to partially overcome limitations that arise from limits on capital equipment budget (lest than 10% of NNIN's overall budget). Most capital equipment is obtained from other sources: university, other research centers, local faculty grants, equipment competitions such as Major Research Instrumentation (MRI), and donations.

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.

Fig. 6 shows the path from NNIN website outlining the various approaches to accessing information related to the different technologies available from NNIN and summarizes a small subset of the major resources that are available from NNIN.

Fig. 7 is a short summary of the breadth of technical capabilities available from the network.

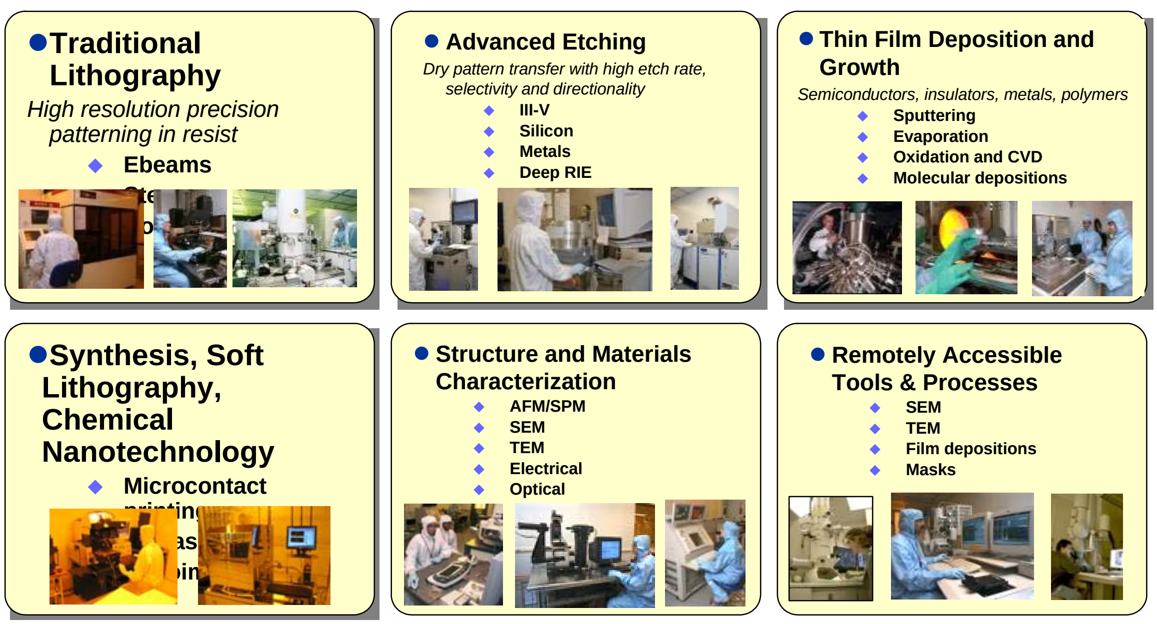
Figure 6: Technology information access from the website.



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 or 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.

A major portion of NNIN support goes to staff as the major NNIN tasks are staff intensive; 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 Liaison (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

Figure 7: A short summary of the major technology capabilities available from NNIN**.**



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.

Having a large diverse state-of-the-art equipment set is critical to a successful user facility. But a facility can only afford to support a large set of equipment if it has a large set of users, i.e. a critical mass. Complex integration tasks also bring very interdisciplinary knowledge-intensive demands. The critical mass of users enables a large equipment and knowledge base, and is in turn necessary to attract the critical mass of users. NNIN, through its networked operation, makes this easier to achieve and in turn influences the research of a large community of users, where this technology knowledge becomes widely available with lower barriers.

In most cases, a number of other nanotechnology resources and capabilities also exist at each site, outside of the NNIN-defined scope. 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 accomplish tasks with highest level of technical support and rapidly. If a specific sophisticated characterization is necessary in the middle of processing, and the resource is available on campus, we put effort in helping the user take advantage of those capabilities. Alternatively, this may be accomplished by movement of samples to other sites within NNIN where these resources are available, usually remotely. This coordination leverages resources to help accomplish tasks. Sites are encouraged to make a broad range of technologies available openly; 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 best capabilities to the national community in those focus areas by focused use of limited financial resources, and to foster these disciplines through dedicated effort in these focus areas. Sites are expected to allocate resources in accordance with the assigned focus areas and are held specifically accountable for success in those areas, separately from research or educational user numbers in broader areas, or quality of technical accomplishments made possible, or other derived data metrics.

Remote Access

NNIN staff also executes projects remotely for users. These are for the most part limited to straight forward process sequences with a few steps where a unique reproducible capability exists in NNIN, or where it is more efficient to have a step or sets of steps to be conducted by a staff member without loss of intellectual property control or the time necessary in visiting, or in characterization where visualization and project execution can be easily achieved remotely. Low stress membranes, electron-beam lithography exposures, multi-wavelength multi-angle optical characterization, transmission electron microscopy, etc. are all examples where remote projects can be conducted without the necessity for a site visit. Many universities have been developing nanotechnology centers, yet no university can have the complete suite of necessary resources. For researchers at many of these universities, as well as industry, this remote access mechanism is a very efficient mechanism. During the 2006 year, more than 100 projects took advantage of this remote mechanism.

2.3 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.

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.

Examples of talks at professional groups' meetings during this past year include SPIE: Society of PhotoInstrumentation Engineers, International Nanotechnology Conference on Communications and Cooperation, Materials Research Society, SEMI Forum, etc. We have two booths that can be used in exhibiting at conferences together with supporting posters and literature. During 2006, NNIN was present at American Physical Society March Meeting; American Chemical Society Spring Meeting; Biophysical Society; Materials Research Society (Fall and Spring); Electron, Ion Photon Beams and Nanostructures; Society of PhotoInstrumentation Engineers-Microlithography; American Vacuum Society; National Science Teachers Association; and NSTI Nanotechnology Conference. 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.

Workshops that are held at individual sites allows 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 their 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 2006, significant hands-on training workshops were conducted at Cornell University, Harvard University and Georgia Institute of Technology in addition to day long events.

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, we are now encountering resource-limitations. The effort however, has provided a very powerful mechanism for the theory 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 once-a-month 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 (Figure 8) emphasizes 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:

Figure 8: NNIN Web Site

- 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

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, *Nanooze* – NNIN's children magazine) 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.

Figure 9: NNIN Education Portal

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 9). 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 will be the repository of all the training materials, lesson plans, and activities developed by NNIN sites. 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.

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 by Cornell in collaboration Prof. Carl Batt and Main Street Science. This magazine is also featured at http://www.nano.gov, the NNI web site. The target group for Nanooze is grades 3-8 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, and interviews with scientists and engineers. The original articles address interesting topics in nanotechnology, often taken from current events. Interactive science learning games are under development. An Editorial Board of teachers and a testing group of children advise the developers on matters of content. *Nanooze* is now also available in Spanish.

The NNIN SEI portal (located at sei.nnin.org) is the central face for SEI efforts within NNIN. (Figure 10). 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.

Figure 10 : NNIN SEI portal

4.0 Education and Human Resources

4.1 Objectives and Program

The NNIN Education and Outreach program continues to grow in both number of individuals reached and the number of activities offered. To set the framework of our activities, it is important to provide an understanding of our goals and objectives. Broadly, NNIN has as its goals a wide variety of educational outreach that spans the spectrum of K-gray, i.e. school aged children through adult professionals. Education and outreach components of the NNIN include network-wide programs to address needs at the national scale and more specific efforts for communities that are local to network sites. 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 10,000 individuals during the past twelve months.

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

NNIN Education Program Goals
• 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 and guidance counselors about the discipline of experimental sciences, provide additional teaching tools, and enhance their enthusiasm for having students pursue careers in science; • 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 have an impact at the national or local scale. These objectives include:

NNIN Education Program Objectives
Using Nanotechnology as a multidisciplinary vehicle, the NNIN education program will: • Develop and distribute activities to encourage K-12 students to enter science and engineering fields; • Develop resources to inform the public about nanotechnology; • Develop activities and information for undergraduates regarding careers in nanoscience; • Develop tools and resources for undergraduates and graduate students that focus on teaching and learning and research; • Design programs to ensure the inclusion of underrepresented groups; • Develop programs for technical workforce development; and • Develop programs and resources for K-12 teachers and guidance counselors.

To attain each of the NNIN's education objectives, a variety of innovative activities have been defined and developed at the individual site level and at the network level. The network coordination for these activities occurs at Georgia Institute of Technology with certain sites responsible for specific components of our education programs. In addition, the NNIN 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 challenges of any large-scale activity center on coordination and communication. The coordination of the NNIN education efforts is undertaken by the education coordinator who is located at Georgia Tech. The site coordinators meet twice a year at one of the NNIN sites for a minimum of two days. In addition, regular communication occurs through e-mails and tele-conferences. The education and outreach program has reached a point where sharing of ideas, approaches, and materials is a regular practice among the sites. During the past year, the coordinators met at the University of Texas during the NSF's NNIN Annual Review (February 2006) and again at the University of California Santa Barbara (January 2007).

An additional challenge is keeping accurate records of our activities and resources. Because of the wide variety of activities across the sites, it is important to know the types of activities, the duration, and the impact in terms of numbers served, etc, both at individual sites and across the network. The NNIN education coordinator and program manager worked with our web service provider to develop the **Education Events Manager (EEM)** , an online tracking system for entering and tracking educational activities. All NNIN education activities/events are to be logged in the system as they happen. This allows NNIN management to review events in real time, to comment, and to suggest synergies within the network, as well as to assemble reports on content, audience, and participant demographics. This tracking system for education efforts was implemented in early 2006 and is used by each site to provide quantitative data on our efforts. This system also forms a base upon which more extensive assessment protocols can be built. **Timely entry of events in the EEM by the sites is mandatory.**

4.2 What is an NNIN Educational Activity

We are educational institutions and thus essentially everything we do is in some sense an educational activity. For the purposes of tracking, planning, and evaluating the scope and impact of the NNIN Educational Program, it thus becomes imperative to first define which activities will be considered NNIN Educational Activities. This requires, at a minimum, that we separate, 1) education activities from activities that are primarily research in nature (i.e. conference presentations and equipment training), 2) normal university education activities (university course support) from education enabled by NNIN, and 3) education activities due to our NNIN centers from the education activities of other funded centers at each campus. This distinction can not always be done cleanly; nonetheless, we have established the following metrics which we use to distinguish reportable NNIN Education Activities from other education activities.

Reportable NNIN Education Activities must:

- Address one or more of the NNIN Education Objectives and Goals
- Have significant NNIN (site) contribution to the activity (planning, execution, staff and funds)
- Be advertised and promoted as NNIN events, including listing major events on NNIN web

site

- Take advantage of network synergy where possible (NNIN activity modules, curriculum, etc)
- Not be in support of local university courses
- Not be primarily research support or for existing NNIN Research Users
- Not be primarily for the recruitment of research users
- Be reported in real time on EEM

More specifically, equipment demos, vendor presentations, equipment training, general seminars, and research visitors are not part of the NNIN Education Program. That is not to say that these other activities are not valuable for other purposes, only that they are not part of the NNIN Education Program. Only reportable NNIN Education Events are included in this education report. **Sites were similarly instructed to only include such events in their site reports**. With these guidelines we can focus our NNIN efforts and can assure that we are reporting and tracking events which are significantly attributable to the NNIN program. And with a common definition, we can reasonably compare level of activity, effort, and results across sites. Even within these guidelines, there are many hundreds of NNIN educational events each year.

4.3 Scope of Effort and Impact: National and Local

NNIN has both local and national (i.e. site specific and network wide) educational programs. Each site has a significant history and a set of local expertise in educational activities. These efforts were incorporated into NNIN as the network was formed, taking advantage of the uniqueness of each site. Some of these activities have been sufficiently strong or had sufficient broad support that they have been expanded to national (network wide) activities taking advantage of synergy between sites and the increased visibility possible with a network program. Some site activities will grow to national activities; others will remain as successful specialized site activities. Similarly, educational activities can have either localized or broader national impact or range. The quad chart in Figure 11 shows the categories of current NNIN education activities.

Figure 11: NNIN educational activites.

	Site Specific Activities	**Network wide Activities**
Local Scope	**Local Activities – Site Specific (I)**	**Network Activities w/ Local Scope (III)**
	Facility tours Community days Open house Seminars/Public lectures	User support and training Diversity K-12 education Summer camps, after school/ weekend programs, on and off site programs
National Scope	**Site Activities w/ National Scope (II)**	**Network Activities w/ National Scope (IV)**
	Workshops Technical Training	National Conferences & Meetings Research Experience for Undergraduates

Teacher Training	RET
Research Experience for Teachers (initial)	NNIN Web site
Curriculum Development (initial)	User support
K-12 Instructional materials	Diversity
	Open Textbook
	Nanooze

As activities develop they may move from one category to another. In particular, successful activities within quadrant III (site activities with National Scope) are prime candidates for new Network wide programs (quadrant IV). In this way we can take advantage of network strengths when appropriate, but let site specific activities flourish with the local environment. We have had good success in propagation of good site activities to the network scale. This will be an ongoing process.

4.4 NNIN REU and RET Programs

The NNIN **Research Experience for Undergraduates** (REU) and the NNIN **Research Experience for Teachers** (RET) serve both education and research functions. Both are successful implementations of network wide educational activities which, while implemented locally, take advantage of network synergies to create a superior program. Both the REU and the RET network programs built upon successful local site programs.

REU Program

The NNIN has developed, operated, and managed a highly successful Research Experience for Undergraduates (REU) Program in nanotechnology since its inception,with 65-81 students in recent years. Prior to 2006, the former NNUN sites had separate funding from NSF for 48 students in this program. NNIN had no NSF REU program funding in 2006. We consider REU one of our premier programs and committed to self fund the program in 2006 out of site funds. Sixty four students participated in summer 2006.

Our program consists of a 10 week intensive research experience at one of the NNIN laboratories. To assure a quality experience, projects are carefully chosen and closely monitored. NNIN's expertise in training users quickly and efficiently is put to good use in the REU program. With proper planning, good mentoring, and proper supervision, students are able to learn about both the research experience and nanotechnology and complete a quality research project in ten weeks.

Our REU program is large. To assure that the students identify with their peers both at the site and across the network, a critical part of the program, at least 5 students are required at each site. To make it truly a network program all sites should participate. A critical mass of 5 or more at 12 sites dictates a large program, too large in fact to be easily funded within constraints of the NSF REU program. NNIN was successful in 2006 in obtaining funds from an NSF REU proposal (Tiwari and Healy) submitted for the NNIN program. Unfortunately, due to funding limitations at NSF, we received approximately 1/3 of our requested funds for the next three years or approximately $540,000. This may be as large as can be expected out of the NSF REU program. This will support approximately 25 students each year.

To assure a critical mass, for 2007 each site is committed to hosting a minimum of five interns each summer. NNIN as agreed to support three students from the Management Funds. Several sites have supplemental industrial or other funding. The distribution of students and funding sources for 2007 is shown in Figure 12. NNIN is committed to continuing our successful REU program and in finding innovative ways to fund it.

Figure 12: REU Funding Breakdown for 2007

	NSF REU	Management Funds	Site Funds	Industrial funds	totals
Cornell	3		3	5	11
Stanford	2	1		5	8
Georgia Tech	2		3		5
Michigan	2	1		3	6
Penn State	2		3		5
Washington	2		3		5
Santa Barbara	2	1	2		5
Texas	2		3		5
Minnesota	2		3		5
New Mexico	2		3		5
Harvard	2		3		5
Howard	2		3		5
				total	**70**

Our program is advertised nationally and all participants are selected from a common applicant pool. Our program draws top quality participants resulting in 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 (do not award a Ph.D.). Our program remains a popular choice among students with 354 applications received in 2006. 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 and 53% of the 2006 participants had not participated in a prior summer research experience. Figure 13 the demographic make-up of applicants, participants, and their type of home institution for 2005 and 2006. Prior years show similar results. Women and minorities are well represented in the applicant pool but **more importantly** at an even higher level of participation.

Figure 13: Demographics

NNIN REU Program Demographics

	Applicants		Applicant Pool (%)		Participants		Application Success Rate		Participation (%)	
Year	'05	'06	'05	'06	'05	'06	'05	'06	'05	'06
Overall	500	354			81	64	16%	18%		
Gender										
Women	148	97	30%	27%	33	28	22%	29%	41%	44%
Men	352	257	70%	73%	48	36	14%	14%	59%	56%
Race/Ethnicity										
Minorities	74	68	15%	19%	19	15	26%	22%	23%	23%
Non-Minorities	426	259	85%	73%	62	45	15%	17%	77%	77%
Institution Type										
Ph.D. Level	343	231	69%	65%	49	39	14%	17%	60%	61%
Master's Level	82	71	16%	20%	28	12	21%	17%	21%	19%

Bacc. Level	63	40	13%	12%	13	11	21%	28%	16%	17%
Assoc. Level	12	12	2%	3%	1	2	8%	17%	2%	3%

**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.

To provide to participants with a sense of being part of a larger network, Stanford organized and hosted a seminar that was webcast to all the REUs at the NNIN sites. Prof. Hongjie Dai of the chemistry department spoke about "Nanofabrication, Nanotubes, and Nanowires." Students from the other sites emailed in questions that Prof. Dai addressed.

The NNIN REU program culminates with the NNIN REU Convocation which is a "mini" scientific conference of all the NNIN REU participants. The 2006 convocation was held August 9-12 at Cornell University. At the convocation, each student presents his/her research results to fellow NNIN REU participants and to staff and faculty who also attend. 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 to view the convocation as well as any other interested viewers. All students write a research report which we publish in the *NNIN REU Research Accomplishment*s. These are also available online at http:// www.nnin.org/nnin_2006reu.html.

Each year we contract with an external evaluator to assess the impact of the REU convocation and provide feedback on the overall program. Dr. Matthew Sullivan, Physics Professor at Ithaca College served as the evaluator of the 2006 convocation. Prof. Sullivan attended student presentations and conducted interviews with the interns. From these, he concluded that the program meets or exceeded its goals. He states, "The NNIN REU program is a highly ambitious program that runs smoothly despite its size. The program attracts a diverse body of students and provides the students an unparalleled educational and experiential opportunity. The students are well supported by the NNIN REU program and by their individual sites." The report also noted that the preparation for the convocation helped students in developing "many writing and presentation skills necessary for the modern scientist."

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. For example, Katrina Murphy (Georgia Tech REU) was an invited speaker at a Gordon Conference on *Electronic Processes in Organic Materials* held at Mt. Holyoke College July 2006. Kaylie Young (U. of Washington REU) presented her research at the ACS Northeast Regional meeting (October 2006) in a session titled: *Nanostructured Materials: Fundamentals and Applications.* Four of our participants published their research in the *Journal of Young Investigators* (an undergraduate, peer-reviewed science journal): Michael Adams (Harvard REU), Juliet Lawrence (Howard REU), David Toyli (UCSB REU, and Kaylie Young (U. of Washington REU). Niall Mangan (Michigan REU) is a co-author on a paper to be submitted, with her summer research group, to the *Journal of Applied Physics*. These attest to the high quality of the research done in the NNIN REU program and the quality career experience that the students receive.

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 research, support by faculty and graduate student mentors, and technical training and support (among others). Below is a table highlighting several questions from our annual survey of 2006 participants (61 respondents; scale of 1-5 with 5 being the highest rating):

NNIN REU Program Survey Questions	**Average Score**
Did the program offer you a substantial independent research project with a strong intellectual focus?	4.5
Did the program provide you with experience that allowed you to see the breadth of nanotechnology applications?	4.2
Were you able to plan, execute, and complete a research project using the necessary equipment and facilities?	4.3
Did you receive sufficient scientific interactions with a faculty member or senior staff at your site?	3.9
Did the program assist you in learning to use advanced equipment and processes in nanotechnology?	4.2
Did the program assist you in making future educational and career choices?	4.2
How likely is it that when you return to you home campus that you will share your experience with fellow students and faculty?	4.6
Do you consider participation in this program as a positive experience? Would you do it again?	4.5
How do you rate the overall quality of the program?	4.5

Measuring the impact of our program on career choices is challenging because it plays out over the course of 10 years after the REU experience. Because of its size and long history, the NNIN/NNUN program has had the opportunity to generate statistically meaningful, long-term outcome data on its participants. We have initiated an investigation of the career paths and impact of our program on the approximately 250 participants in the first six years of the program (1997-2002) (Figure 14). To date we have contacted 90 of the 250 with the results shown in the table. Eighty-nine percent of the respondents indicated that the program significantly or very significantly influenced their career path. We are continuing this longitudinal study which is a time-intensive task in locating past participants. However, we believe that such efforts will provide information specifically on the impact of our program and REU programs in general.

"Thank you for this opportunity. I can say it was definitely life-changing for me as I now plan on pursuing a Ph.D. which is something I never considered before this experience." Stephanie Petrina, UCSB REU

"The experience was top notch and the program is very well done. I wish we could have had more time at the convocation. It was a great chance to meet people. It would be amazing to get everyone together again in 5 years or so. I had the best summer I can remember in some time, and one of the most educational." David M Schluneker, Georgia Tech REU

"Thanks to everyone from NNIN, specially people from Cornell. Hopefully I would get an opportunity to work with all these wonderful people in graduate school at Cornell." Ravneet Bajwa, Cornell REU

Our REU has always produced high quality students who are enthusiastic about nanotechnology. Although many wish to be able return for a second summer, we have been unable to accommodate this, preferring to reach a new group of students each year. To take advantage of this pool of talent and meet this demand, NNIN has recently submitted a proposal to NSF international directorate to expand our REU program to collaboration with international researchers. The proposed project would support five select REU participants from the prior year's program to participate in a second year experience at the National Institute of Materials

Science in Japan. We believe that this would provide our participants an understanding of the global nature of science as well as afford them a second summer experience in nanotechnology. Along this same vein, we are negotiating arrangements with several National Labs to use our REU program as a feeder program for internships at their laboratories.

RET Program

Building upon its successful REU program and upon smaller RET programs at individual sites, NNIN established a network RET program in 2006 funded by a separate NSF grant. Five sites are included in this program led by Georgia Tech with participation from Harvard, Howard, Penn State, and UCSB. In 2006, the first summer of this joint program, nineteen teachers conducted research with faculty mentors and developed instructional units for their classroom. During the school year, each site supports the teachers in their classroom to help introduce nanotechnology into their courses. The program will culminate at the National Science Teachers Association (NSTA) annual meeting which will be held at St. Louis March 28 to April 1. At the meeting, RETs from each site will present their experience and instructional unit in a session on the NNIN RET program. All of the sites will also meet for a half-day session where materials will be shared and critiqued and teachers will interact with their fellow NNIN RETs. 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. One teacher has twice presented nanotechnology lessons to pre-service teachers enrolled in a science education class at Mercer University. Three of the teachers recently presented at the Georgia State Teachers Association. Two of Harvard's participants presented posters at the Museum of Science, Boston's Nanotech Symposium for Teachers 2006. Each participant has been developing units for their classrooms and these will be field tested and then placed on the NNIN education portal (http://www.education.nnin.org).

Figure 14: NNIN's longitudinal REU program study.

NNIN REU Longitudinal Study
(5-10 years after REU experience)
Approximately 80 out of 250 participants surveyed

Degree/career	**1997-2001**
Ph.D. (completed or in progress)	44%
Terminal Master's	32%
Terminal B.S.	10%
J.D.	5%
M.D.	7%
Science Career	92%

In a related but separate program, the University of Washington uses NNIN funds to provide a one week summer program for teachers. This year they combined forces with a newly funded MRSEC at UW, the Genetically Engineered Materials Science and Engineering Center (GEMSEC) and engaged 13 middle and high school teacher participants in a week-long immersion in nanoscale research. Teachers participate in a Bio-Nano workshop which focuses on bionanotechnology and molecular biomimetics. Classroom modules were developed - using a unit developed during the 2005 NNIN-RET as a guide – around four themes: AFM, proteins, self-assembly, and microscopy. Some of these units have been reviewed and field tested and are on the NNIN education portal.

Similarly Stanford University separately supported one teacher who was part of the Industry Initiatives in Science and Math Education (IISME) eight week program for teachers. A total of 18 teachers took part in this program with all of them spending a day at SNF to learn about nanotechnology. The participant has developed a unit for physical science titled *Excelling in Data Analysis*. The University of Minnesota supported RETs who were part of a larger RET program within the Department of Electrical and Computing Engineering. The participants were trained on several techniques in the Nanofabrication Center and learned to use the SEM and AFM microscopes in the Characterization Facility.

4.5 Development of Materials for Training and Education

NNIN sites have developed a number of nanoscience related modules and activities for use in both formal and informal learning environments. Sharing these modules and activites between sites is part of the synergy engendered by a network program. We have now moved to the level where we can assemble and share a number of locally created modules and units, and can collaborate on testing, improving, and implementing them in a network context . At the January 2007 education coordinators meeting, we had a day-long “share-a-thon” where each site presented units they have developed and used with school groups and teacher training. 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 which meet the National Science Education Standards (NSES).

We are aware that the current science curriculum is very crowded and teachers do not want to add anything new to their teaching. 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, among others. These activities are also used by NNIN sites in support of their own education programs. Sites are encouraged and expected to share units, modules, and activities with other NNIN sites. The Penn State Nanoproducts kits, for example have been used by several other NNIN sites for day camp activities. Some sites have even expanded upon them by adding more products and background information. The NNIN web site is the primary vehicle for disseminating these activities to the larger audience. Development of new modules and activities continues while existing modules are being distributed, refined, tested, and evaluated.

Our RET program has been a significant source for the development of materials suitable for students in middle and high school. Many of the units developed by our 2006 RETs are in the final stages of refinement which will then allow them to be field tested in other classrooms. A subgroup of sites (UCSB, UW, and GT) has formed the NNIN Education Activities Development Committee (EADC) which is focused 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 several of the NNIN sites. These materials will be correlated to NSES and 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 have just developed a field testing evaluation instrument based on one used by our colleagues at Cornell’s Center for Nanoscale Systems’ Institute for Physics Teachers. Below (Figure 15) is the timeline for the EADC:

Figure 15

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, continued the development of two high school curriculum modules that address nanoscale science and national standards. This year the team has developed two different two to three week modules: one to be used in a physical science course and one to be used in a chemistry course. The development team has developed PowerPoint class materials, teaching guides, problem sets, assessment tools, and videos (http://www.mcrel.org/nanoleap). The units are being pilot tested this school year by 16 master teachers who have been participating in the design process. The project is recruiting teachers for fall 2007 and spring 2008 field testing and NNIN sites are actively assisting in this recruitment.

As part of the NanoLeap program, Stanford is investigating and developing the use of NNIN remote access tools and capabilities, originally developed for NNIN's remote lab members, for classroom instruction and outreach. 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. Minnesota and Georgia Tech are working with Stanford to develop and test two remote access demos/activities. The Physical Science remote access activity (SNF and Minnesota) explores the use of atomic force microscopes and the concepts of scale, the nanoworld, imaging techniques, and adhesion. Stanford and Georgia Tech remote activity focuses on cleanrooms, nanofabrication and contamination, and what researchers in nanotechnology do.

The University of Minnesota, under the direction of Dr. Steve Campbell, is the lead site for the NNIN Open Textbook. This web-based textbook for nanotechnology will be used at upper undergraduate and beginning graduate student level courses. The lead writing assignments for the chapters have been finalized and approximately 35% of the textbook is complete. Other sites support the development of each of the chapters in addition to the lead site.

Penn State and the University of Minnesota continue to offer their nationally recognized community college programs in nanotechnology. Steve Fonash, of Penn State, presented a webcast seminar for Northwestern's National Center for Learning and Teaching Nanoscale Science and Engineering (NCLT) 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 continues its collaboration with North Seattle Community College to develop a similar associate's degree program in nanotechnology. The two institutions collaborated on two successful NSF proposals to develop courses: an NSF ATE planning grant and a NUE for creating undergraduate nanoscale laboratories.

Cornell continued to offer its three day hands-on workshop for students from Clarkson University. The workshop is a one-week laboratory course for 10-12 students at the graduate level during which the students fabricate fully functioning silicon nitride cantilevers. It complements a class on nanotechnology taught during the spring semester at Clarkson University. The content of the course is tailored specifically to the fabrication of cantilever devices, a project chosen because it requires the application of all aspects of traditional nanofabrication techniques. Additionally, the performance of the cantilever devices can be measured upon the return of the students to their home institution. Of the 22 students who have participated in this workshop, 19 reported that the workshop will have an impact on the choice of their future career, 16 rated the workshop and the hands-on laboratory sessions as extremely valuable (5 on a scale of 1-5), and the remaining 6 students rated the workshop as valuable to them (4 on a scale of 1-5).These ratings reflect the fact that by conducting the workshop, CNF provided an experience to these students that would not have been possible at their own institution due to the lack of cleanroom facilities. Although the course was first implemented with Clarkson University, it can be a supplement to nanofabrication courses taught at any university that lacks access to cleanroom facilities.

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.

The University of New Mexico has created a new Nanoscience and Microsystems (NSMS) Curriculum to prepare a highly trained nanotechnology workforce. Under an NSF-funded EESE award, *Nationwide Nanotechnology Ethics Education Development,* a course from the curriculum (Societal and Ethical Implications of Nanotechnology) is being adopted and adapted at five NNIN sites: Georgia Tech, Penn State, Michigan, Washington, and Howard. This course addresses one of the recommendations deriving from Robert McGinn’s (Stanford) NNIN survey of ethics at NNIN facilities for the need of nanotechnology ethics curricular materials. Each site will adapt the course materials to fit the needs of their own campus programs.

4.6 Education and Workforce Workshops

Several sites are active in providing and developing 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. Penn State offers two types of three-day professional development workshops for secondary and post-secondary educators. Since the inception of the NNIN, 206 educators have attended these workshops. The *Hands-On Nanofabrication Workshop for Educators* 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 the class 10 clean rooms of the Penn State NNIN site. The second workshop is *Nanotechnology in the Secondary Classroom* where high school teachers create and test nanotechnology laboratory experiences and activities to utilize back in their home classrooms during the upcoming academic year.

UCSB is finalizing a program to provide a nanotechnology education course for teachers which will earn professional development credits. The course and agenda are completed, and UCSB is currently applying to the California Department of Education for approval of professional development credits. UCSB has also developed and offered a *Pre-service Teacher Workshop: Nanotechnology 101* to introduce pre-service science teachers to nanotechnology and its role in society. The first offering reached nine students.

The University of New Mexico is transitioning to a new education coordinator who brings strong experience in interacting with the K-12 community through the New Mexico EPSCoR program which is ending. UNM will adopt and adapt teacher programs which feature sixteen-hour workshops and five-hour seminars in nanoscience and materials science. In addition, UNM will support a Community Outreach Program that establishes a teacher-focused list-serve for interested individuals who can submit questions, curriculum ideas, resources, or any other pertinent information or request related to materials science and nanoscience that is shared with list-serve members. Materials developed in these programs, including a twenty-lesson booklet which is in the final stages of preparation, will be available to NNIN sites and also posted on the NNIN education portal.

The University of Michigan has developed a workshop that is offered to area teachers and school administrators entitled *An Introduction to Micro and Nanotechnology for Teachers*. The Triangle National Lithography Center (NCSU/UNC) hosts a summer week long workshop *Emerging Science and Technologies Short Course in Nanotechnology* for middle and high school teachers. This year's theme was "*Exploring Nanotechnology--How Small Can We Go?*" and included classroom discussions of nanotechnology, discussions of the ethical issues associated with nanotechnology and hands on lithography processing in the cleanroom. As noted above, the University of Washington provides a week-long workshop for its RETs called *BioNano 2006*. The NanoLeap project at Stanford also has provided workshops for the teachers who are assisting in the development of the curriculum units.

For the second year, Georgia Tech has provided a workshop for teachers participating in the Museum of Science's (along with the Nanoscale Informal Science Education Network) *Nanotech Symposium for Educators*. These workshops focus on hands-on activities for middle and high school science teachers. A similar workshop was also presented to teachers at the Georgia Science Teachers Association annual meeting.

4.7 Other K-12 Outreach

Numerous outreach activities have occurred which include K-12 field trips to facilities, visits to schools, summer camps, mentoring, 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.

Hands-on summer, weekend, or after-school camps/programs to engage students in nanotechnology have been 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 workshop with Mathematics, Engineering, Science Achievement (MESA) to provide six nanotechnology workshops at its annual campus-wide event which reached about 550 middle and high school students.
- Georgia Tech's *Nanotechnology Explorations* camp for high school students and *Explore Nanotechnology* for GT's Women in Education middle school girls camp
- Penn State's *NanoCamps* hosted 12 groups during summer 2006 and reached over 250 students and chaperones.
- U. of Washington's *Science for Success* for disadvantaged high school students
- U. of Michigan offer *Microelectronics and Nanotechnology Experiences* for middle and high school students

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 of our programs also include discussions on career and educational opportunities to encourage students to consider careers in science, technology, engineering and mathematics, (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.

4.8 Other Community Outreach

In Fall 2006 Howard University launched the NanoExpress, a mobile laboratory which presents the world of nanotechnology to the general public from K-Gray (Fig. 16) . The NanoExpress has 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. As of late February, The NanoExpress has had over 4000 visitors. Howard has already scheduled events that include training for district judges in Maryland, visits to elementary, middle, and senior high schools, national conferences, senior civilian civic clubs, Boy and Girl Scouts meetings, Lego Clubs, etc. and expects to reach 16,000 visitors by the end of summer 2007.

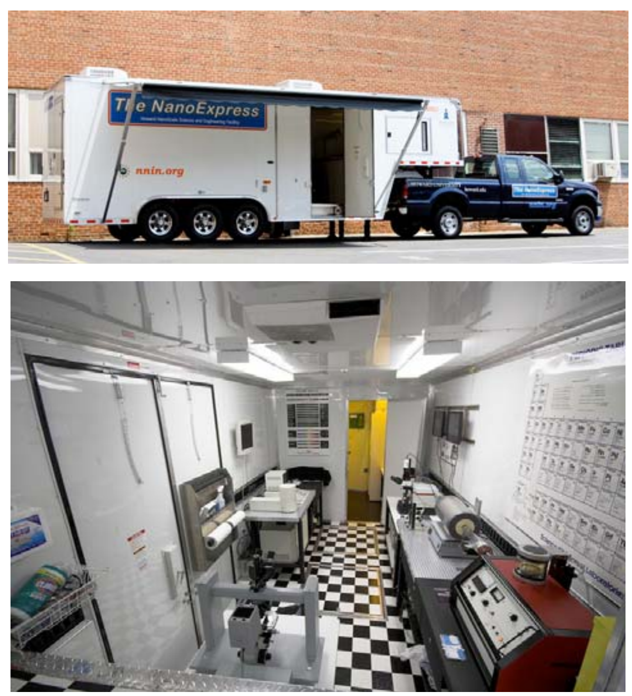


Fig. 16: Howard's Nan0express Van

The past Fall, many of the NNIN sites received requests for assistance from FIRST LEGO® League teams (FLL). The FIRST organization (For Inspiration and

Recognition in Science and Technology) was founded in 1989 by Dean Kamen, president of DEKA Research and Development Corporation, to inspire kids in the fields of science and technology. The organization develops yearly challenges involving robotics for children at the high school, middle school, and elementary age ranges (Figure 17). The theme for this year's challenge was nanotechnology. Teams needed to learn about nanotechnology as well as interview professionals in the field of nanotechnology. Cornell, Georgia Tech, UCSB, U. of Michigan, Stanford, U. of Minnesota provided outreach for FLL teams. Sites provided a variety of activities, facility tours, and time for the teams to talk to researchers. Nearly 1000 FLL team participants were reached through these efforts.

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 relating 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. As *Nanooze* was a featured resource for the *FIRST* LEGO League nanotechnology completion, special articles were developed to specifically address the areas featured in the competition. The interaction between Nanooze and FIRST LEGO generated a lot of interest in nanotechnology and traffic to Nanooze and the NNIN Education web site.

Fig 17: Junior FIRST Lego team at Cornell

Community and open house activities are also part of the efforts of the NNIN education and outreach programs. In addition to hosting such events as the FLL teams, sites provide outreach to the public in several other ways. The University of Washington has developed five roll out carts for use at the Pacific Science Center. U.W. and Stanford provide activities for campus community outreach programs such as community days and College of Engineering open house events. Georgia Tech hosted an open house for campus visitors during Homecoming Weekend.

NNIN has also reached out to professional organizations by developing symposia for national meetings. The NNIN co-chaired a three-day symposium on nano education at the Materials Research Society spring 2006 meeting. The other co-chair institutions were Arizona State University, University of Central Florida, Sandia National Laboratory, and the German Aerospace Center. The sessions featured over 40 national and international speakers involved in nano education, particularly at the undergraduate level. Sir Harry Kroto (NNIN Advisory Board Member) was the opening speaker who drew a very crowded audience. Electronic proceedings of the papers are available at http://www.mrs.org. NNIN also organized two sessions on workforce development issues at the Nano and Bio in Society meeting held in Chicago in August of 2006. At the NSTA, NNIN provided a breakfast workshop attended by approximately 40 teachers. A survey of the participants provided NNIN education coordinators with valuable information on the level of understanding teachers have about nanotechnology and the type of materials and training teachers need to place nanotechnology in their classrooms.

4.9 Technology Workshops

The NNIN is committed to workforce development training and research training 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. 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. 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.

Technology and Characterization at the Nanoscale is a workshop offered twice a year by Cornell. The content of the TCN 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. Georgia Tech offers a similar workshop each summer for three days titled *Technology, Fabrication, and Characterization* at the Nanoscale.

The University of Minnesota was very active in providing several workshops during the past year. Some of the topics addressed include small angle x-ray scattering, air and gas filtration, aerosol and particle measurement, ASME Nano boot camp, among others. The University of Michigan presented one day workshops on wafer bonding, advanced characterization, and reactive ion etching.

An NNIN Etch Forum was held March 23-24, 2006 at Cornell. Etch personnel from all NNIN sites were invited to participate in an active discussion of their sites' current etch capabilities, process issues, as well as future needs and requirements. In October 2006, the Cornell Nanoscale Facility hosted the 2nd annual Fall Modeling Workshop, *Building Nanostructures Bit by Bit*". This three day workshop provided morning tutorials on the different approaches followed by afternoon hands-on sessions where participants were able to work directly with codes. Harvard hosted *"Synergy between Experiment and Computation in Nanoscale Science"* (May 31 - June 3, 2006. The world's foremost experts in nanoscale computational science descended upon Harvard for the NNIN/C's *Synergy Conference* to initiate and enhance collaborative efforts between computational scientists and experimentalists working in the nanosciences, with a purpose to exhibit the software and hardware resources of NNIN/C to the computational nanoscience community. The event had 100 attendees from eleven countries.

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.

4.10 Diversity

A primary focus of NNIN education outreach is inclusion of underrepresented populations. This 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 REU section of this report demonstrate that women and minorities have a higher participation rate in our program in comparison to the applicant pool.

Our 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. This initial year we had 19 RETs 68% were male, 32% were female, and 32% were underrepresented. Figure 18 below indicates the student demographics for the RETs at Georgia Tech.

Figure 18

Georgia High School	White	Black	Hispanic	Other
Henry County	59%	34%	3%	3%
Stone Mountain	3%	89%	3%	5%
Starr’s Mill	87%	7%	2%	4%
Douglass	0%	99%	1%	
Duluth	49%	13%	14%	24%
So. Gwinnett	62%	28%	5%	5%

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). Listed below are some **examples (Figure 19)**:

Figure 19

Institution/Activity	Diversity Participation
UCSB Chip Camp	42% Hispanic 36% Female
MESA at UCSB	70% Hispanic 52% female
University of Washington SFS summer program	70% Black 15% Hispanic
University of Michigan Micro & Nano Electronics	42% Minority 68% Female
G. Tech NanoInfusion (Centennial Place)	100% Minority
Georgia Tech WIS TEC Camp	30% Minority 100% Female
Penn State Summer Camps	50% Minority 56% Female

The newly revised education program at the University of New Mexico will afford us the opportunity to reach Native American students as well as Hispanic students. UNM’s new program brings already established contacts with 43 of 89 public school districts in New Mexico including schools governed by the Eastern Navajo Agency, Southern Pueblo Agency, Bureau of Indian Affairs, the Navajo Nation, and Santa Fe Indian School (private school). This will allow them to reach a high percentage of teachers of Native American and Hispanic students. UCSB is also very active in providing outreach to Hispanic students. Their eight chip camps reached 66 students, of which 26 were Hispanic and 30 were female. Their Day in Nanoscience and Nanotechnology with MESA reached 555 students of which over 70% were Hispanic.

7.0 Social and Ethical Issues in Nanotechnology

7.1 Introduction

The goal of the Societal and Ethical Issues (SEI) component of NNIN is 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 Ana Viseu are responsible for coordination of the SEI component of NNIN. Kysar assumed the role in late 2006; previously, SEI coordination had been supervised by Prof.Bruce Lewenstein.

7.2 Network-wide activities

Annual meeting: Although no meeting was held among SEI site coordinators during 2006 due to a transition in the network coordinator position, the site coordinators plan to hold an annual meeting later in 2007. Sessions will be held for SEI site coordinators, during which participants will consider ways to strengthen the SEI infrastructure, including especially recommendations that arise out of NNIN's annual review process. Anticipated topics will include how to promote research and discussion regarding specifically ethical – as opposed to societal – implications, given a perceived imbalance by some outside reviewers of current NNIN SEI activities; how to better leverage the network for the development and dissemination of SEI materials; and which strategies, formats, and processes have succeeded at various sites in terms of promoting dialogue and reflection across the natural and social sciences divide.

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.

Collaboration with national and international SEI community: Robert McGinn (Stanford) has been contacted by the head of the Norwegian National Research Council's committee on social and ethical issues implications of new technologies regarding McGinn's NNIN ethics survey and its findings. The Norwegian Research Council is launching a 7 year effort studying ethical and social implications of new technologies, including nanotechnology.

7.3 SEI research

Four of the NNIN sites have specific resources allocated to SEI activities, including research. The research activities include:

Cornell: Lead researcher: Bruce Lewenstein.

- Nanotechnology and Public Communication. One thread of ongoing research concerns the public communication of science and technology, including media coverage and public opinion. Preliminary results show that public knowledge of nanotechnology is limited, but that public opinion is likely to be shaped as much by emotion as it is by knowledge, even if knowledge increases.
  - Gorss, J., & Lewenstein, B. V. (2006 (accepted)). The Salience of Small: Nanotechnology Coverage in the American Press, 1986-2004. Science Communication.
  - Lewenstein, B. V. (2006). What counts as a "social and ethical issue" in nanotechnology? In Nanotechnology Challenges: Implications for Philosophy, Ethics and Society. Schummer, J. & D. Baird (eds.).
- Regulation of Nascent Technologies. An additional line of research concerns legal and ethical aspects of competing policymaking paradigms for the regulation of nascent technologies. This research in particular examines the invocation of cost-benefit analysis and the precautionary principle within intergenerational policymaking contexts, evaluating certain under-explored moral and political assumptions that are latent within such invocations.
  - Kysar, D. A. (2006 (accepted)). It Might Have Been: Risk, Precaution, and Opportunity Costs. *Journal of Land Use & Environmental Law 22,* __-__ (also supported by NSF NIRT #0304483).
  - Kysar, D. A. (2006 (accepted)). Discounting…On Stilts. *University of Chicago Law Review 74,* __-__ (also supported by NSF NIRT #0304483).
- *Personal Nano: An Ethnography of the Institute for Soldier Technologies (ISN).* The goal of this project is to critically examine the ways in which ISN researchers incorporate notions of embodiment, personhood, information, and agency within their practices and knowledges. Such situated analysis will contribute to understanding not only of the policy instruments that facilitate research initiatives, but also of the sociocultural frameworks that researchers draw upon and construct within their practices, and how these affect the shape and functionality of the research's final 'products.' The ethnographic component of this project is scheduled for April-May of this year and will be conducted by Ana Viseu.
- *Bridging the Gap: Being a Social Scientist at a Nanofabrication Site.* This international collaboration led by Ana Viseu and Dr. Robert Doubleday (Cambridge University, UK) has as a goal the production of a number of articles exploring the ways in which the appointment of social scientists in large technical physical sciences projects are conceived and made to work in practice.

Georgia Tech: Lead researcher: Marie Thursby.

- Ongoing research on innovation and productivity of large firms in nanotechnology, with particular attention to intellectual property and comparisons with biotechnology. The latest paper published in this line of research compares two 21-year longitudinal samples of patenting practices among biotechnology and nanotechnology firms, finding that as technologies mature, firms' ability to exploit the technologies depends initially on access to tacit knowledge, but shifts over time to depend on more traditional research and development investments. In addition, the research indicates that access to physical capital, in the form of cutting edge equipment, is a more important predictor of patenting behavior for nano firms than biotech firms.

- Rothaermel, F. T., & Thursby, M. (2006 (accepted)). The Nanotech vs. the Biotech Revolution: Sources of Productivity in Incumbent Firm Research. Research Policy, Special Issue on "Emerging Nanotechnologies." Autio, E., B. Bozeman, & V Mangematin (eds.).

Stanford: Lead researcher: Robert McGinn.
Ethics and Nanotechnology: Mapping the Views of the NNIN Community. Robert McGinn continued work on his project examining ethical issues as perceived by NNIN users. Since the survey phase of the project ended in August, 2006, McGinn has been analyzing the data and presenting preliminary results at numerous venues (see Stanford site activities, below). Submission for publication is anticipated to occur in 2007. Key preliminary findings include:

- Ethics has considerable salience for most nanotechnology practitioners, as regards respondent belief in ethical issues related to nanotech, belief that it's important that such issues be considered, and personal interest in such issues.
- However, there is a large gap between nanotechnology researchers' modest prior exposure to and low level of familiarity with ethical issues, and the substantial degrees to which they view such issues as important and are willing to devote time to study same.
- Most nanotechnology researchers, even basic researchers, believe that they have ethical responsibilities to society, not just in the laboratory; in particular, responsibilities to try to anticipate ethical issues that may arise from future application of their research work and to alert appropriate authorities if they have good reason to believe that their work will be applied in society in ways that pose unreasonable risk to humans.
- NNIN labs differ in the dominant attitudes they exhibit toward individuals who jeopardize lab safety by violating lab safety rules. On the whole, some labs have "laissez faire cultures," others "safety cultures." While 43% of respondents believe that the dominant response in their labs to a shortcutter who violated lab safety rules would be attempts to persuade the individual to stop shortcutting, 24% believe that the dominant response would be that no action would be taken in response to such activity.
- Researchers agree overwhelmingly that top managers have a moral responsibility to actively promote a safety culture in their labs.
- Almost 60% of respondents believe that it is "necessary" to develop guidelines for the ethical practice of nanotechnology research.
- Researchers in NNIN labs, drawn from countries around the world, have different assumptions about what ethical responsibility in the lab requires of them. This poses a hitherto unrecognized safety risk. More concerted and explicit efforts at socializing newcomers are needed.
- Relatedly, most NNIN researchers believe quite strongly that study of ethical issues should become a standard part of the education of future engineers and scientists. This parallels the recommendation made to that effect by the UK's Royal Society of London and the Royal Academy of Engineering (2004).

University of Washington: Lead researcher: Suzanne Brainard.
Ongoing research on several projects:

- *Public Health and Nanotechnology Risk Perceptions*. This study surveyed 52 UW faculty associated with the Center for Nanotechnology or the Department of Occupational and Environmental Health Sciences. The study objectives were to measure and evaluate differences between nano researchers and environmental health scientists in behavior, knowledge, beliefs, and attitudes relating to nano-development. Variances in knowledge, communication, and attitudes including trust, regulation, and perceived benefits and risks were examined in order to better understand cross-disciplinary differences. The results of this study suggest that people with more knowledge of nanotechnology are more likely to think the benefits of nano-development will outweigh the risks, that there is a general lack of definition of nanotechnology among the field's own community, and that there is lack of trust in regulatory agencies to prevent hazards from nano-development.
    - Hughes, C. A., S. G. Gilbert, H. W. Meischke, & E. Litzler, Elizabeth. Perceived Risks and Hazards of Nanotechnology. Accepted for Society of Toxicology Meeting 2007
- *Identifying and Analyzing the Discourse(s) of Nanotechnology and Nanoscience*. The goal for this project is to help bridge gaps in understanding between disciplines. The study intends to: conduct an ethnography of communication that identifies the various discourses about SEI of nanotechnology, and in so doing, provide a taxonomy that enables researchers from different disciplinary backgrounds to engage with each other, as well as with the media and the public at large in meaningful discussion about nanotechnology and nanoscience. Fieldwork and data collection phases of the project will be finished shortly.
    - Bassett, D. "That's just a scientist's attitude": Analyzing the authoritative discourse of nanoscience. (Under journal review)
    - Bassett, D. & E. Litzler. Competing discourses of disruptive technologies: A case study. (Expected to Discourse & Society)
- *Interdisciplinary Communication*. The goal of this research will be to gain an understanding of how multi-disciplinary, cross-site communication works among the people associated with the NNIN grant at all involved institutions. In addition, a workshop will be developed utilizing research literature on diversity awareness and multi-cultural communication in order to help bridge differences in background, experience, and training. The workshop will be given to graduate students, faculty, and staff at the University of Washington, and can also be given at other institutions.
    - Bassett, D. & T. Dutton. A study of Fisher and Ury's negotiation model for intercultural interaction. (Expected submission to Negotiation Journal.)
- *Nanotechnology Workforce.* This project examines implications of nanotechnology for the workforce. In particular, a survey focusing on the nanotechnology personnel needs of companies and current demographics of the nanotechnology workforce at these same companies is in development. Also, some data on the future nanotechnology workforce has been collected from students in the University of Washington interdisciplinary nanotechnology Ph.D. program, and students who have taken nanotechnology courses. The goal of this project is to track nanotech students and document where they start their

careers. Preliminary results suggest that, although students feel that their nano education prepares them well for both academic and non-academic careers, most intend to work in private industry.

7.4 Other SEI site activities

In addition to research and general support, many of the NNIN sites contribute or host substantial teaching, guest-lecturing, public presentation, campus and community collaboration, and other activities. These include:

<u>Cornell University</u>

Courses

- A new seminar course concerning legal and ethical implications of emerging technologies is expected to be launched next year at Cornell Law School. The course will use regulatory and ethical issues relating to nanotechnology as a vehicle for exploring governance questions concerning emerging technologies more generally. SEI researchers will be invited to present work in progress to students and interested community members.

Presentations

- Along with a Cornell collaborator, Ana Viseu has organized a day of presentations on ethical and social issues of nanotechnology in conjunction with CNF's thirtieth anniversary forum. Speakers for this one-day series will include Sheila Jasanoff, Juergen Altmann, Rosalyn Berne, David Guston, and Priscilla Regan.
- Doug Kysar presented aspects of his ongoing research regarding competing policymaking paradigms for the regulation of nascent technologies at various locations, including: at Vanderbilt Law School's Roundtable on Consumption, Law and the Environment on October 20, 2006; at a University of Arizona Rogers College of Law faculty workshop on October 12, 2006; at the Conference on Intergenerational Discounting held at the University of Chicago Law School on April 21, 2006; as the 2006 Distinguished Lecture in Environmental Law at Florida State University College of Law on March 20, 2006; at a University of Pennsylvania Law School faculty workshop on March 13, 2006; at a Notre Dame Law School faculty workshop on March 3, 2006; and at the Georgetown University Law Center's Workshop on Governance on February 16, 2006.

Campus and community collaboration

- Doug Kysar presented workshops on risk regulation, with attention to SEI aspects of nanotechnology, to the Environmental Toxicology Seminar and the Bovay Colloquium Series on Engineering Ethics. He also guest lectured in Cornell's Engineering Ethics course concerning ethical issues related to risk assessment within the engineering profession.

<u>Georgia Institute of Technology</u>

Courses

- A Harvard Business case on issues in university industry collaboration in nanotechnology was developed and field tested at Harvard and Georgia Tech in Spring 2006. Teaching notes related to the case will be finalized and tested soon.

Presentations

- Marie Thursby participated in a number of presentations on issues in commercialization of nanotechnology, highlighting NNIN research on the role of tacit knowledge in the process including at a panel discussion in a public meeting of the Technology Association of Georgia, “Myth and Reality of Nanotechnology,” July 14, 2007.
- Robert Kirkman, Assistant Professor of Public Policy, led a session on societal and ethical implications of nanoscience for an NNIN workshop for the Center for Disease Control, April 4, 2006.

Courses

- Marie Thursby increased recruiting of PhD students working in nano labs to her TI:GER program, which brings together PhD, JD, and MBA students to learn about the challenges of commercializing new technologies.

<u>Harvard University</u>

Campus and community collaboration

- Ongoing collaboration with Museum of Science to include social and ethical issues in outreach activities.

<u>Stanford University</u>

Courses

- This spring, Robert McGinn will include a nanotechnology unit for “Ethical Issues in Engineering” (STS 115/E131), focusing on his NNIN ethics survey
- In summer 2008, McGinn plans to develop and disseminate (i) new curriculum materials based primarily on the results of his NNIN “Ethics and Nanotechnology” research project; and (ii) a series of case studies of actual incidents in nanotech research labs in which safety issues arose at least in part because of issues covered in the “Ethics and Nanotechnology” survey.

Presentations

- Robert McGinn made a number of presentations of his NNIN ethics survey and preliminary results, including: at a public citizen “Forum on Nanotechnology” at the Exploratorium Museum in San Francisco, on August 7, 2006; at the semi-annual meeting of NNIN at NSF, in Washington, D.C., on October 27, 2006; at a conference entitled “Social and Ethical Implications of NBIC Convergence” in Avignon, France, on December 17, 2006; and at the Center for Nanotechnology in Society at U.C. Santa Barbara, on January 11, 2007.

Campus and community collaboration

- Robert McGinn shared preliminary results from his research at numerous Stanford events, including: at an “all-hands” meeting of the Stanford Nanotechnology Fabrication Facility, on January 9, 2007; in a graduate electrical engineering course on January 29, 2007; at a “Lab Meeting” of the Work, Technology, and Organization Center on February 12, 2007; and at the Symbolic Systems Program Forum on February 15, 2007.

<u>University of Michigan</u>

Courses

- "Societal Impact of Microsystems," which is required for all students in MEng in Integrated MicroSystems and which explores possibilities for microsystems to address key challenges facing humanity over the next century.

University of New Mexico

Courses

- The University of New Mexico has created a new Nanoscience and Microsystems (NSMS) Curriculum to prepare a highly trained nanotechnology workforce. A unique core course in this curriculum, Societal and Ethical Implications of Nanotechnology, developed by Kirsty Mills and given for the first time in the Fall 2005 semester, is being disseminated throughout 5 NNIN sites (GT, Penn, Michigan, U. Washington, and Howard) under an NSF-funded EESE award, Nationwide Nanotechnology Ethics Education Development, (SES-0629278; PI Dr. Kirsty Mills). This speaks directly to one of the recommendations deriving from Robert McGinn's survey of ethics at nanotechnology facilities, for the need for availability of nanotechnology ethics curricular materials. The course prepares students for a rapidly evolving, multidisciplinary environment by developing their capacity for critical analysis and their awareness of the multiple issues they will meet as they work in nanotechnology, as well as inculcating the flexibility and insight necessary to take an ethically responsible position when faced with unprecedented circumstances.

University of Washington

Presentations

- Bassett, D. "Cultural Codes in Science: Analyzing the Discourse(s) of Nanoscience/Nanotech," Native American Students in Advanced Academia annual conference, UW, Spring 2006.
- Bassett, D. & E. Litzler. "Competing discourses of disruptive technologies: A case study," Society for the Social Studies of Science Conference, Vancouver, B.C. November 2006.
- Brainard, S.G. Panelist on "Social Science Engages Nanotechnology," 2006 American Association for the Advancement of Science Annual Meeting.
- Bassett, D. & T. Dutton. "A study of Fisher and Ury's negotiation model for intercultural interaction," National Communication Association 2006 Convention, San Antonio, TX (invited presentation for Intercultural Communication Division panel).

Campus and community collaboration

- Ongoing interactions with UW Nanoscience and Nanotechnology Student Association (NaNSA).
- Guest lecture, "Cultural Codes in Science: Analyzing the Discourse(s) of Nanoscience/Nanotech," for upper-division undergraduate communication class, UW, Spring 2006 (Bassett, D.).
- Taught 50-minute session on "Introduction to Social and Ethical Issues in Nanotechnology" to 10th grade participants in University of Washington and Center for Nanotechnology "Science for Success" Program, July 2006.

- Presented and led discussion of "Dialogue on Social and Ethical Issues in Nanotechnology," BioNano Teacher Workshop, University of Washington, July 2006.
- Developed a variety of online SEI resource materials, including an annotated bibliography, an SEI overview document, both teacher and student guides to Social and Ethical Issues in Nanoscience and Nanotechnology, and an introductory slide presentation.

8.0 Computation

8.1 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.

8.2 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 freely accessible to the nanoscience community. Thus far NNIN/C has not imposed user fees either for the hardware facilities nor for the use of codes nor for consultation related to those codes. The only fees that NNIN/C has charged the user community is in the form of registration fees for NNIN/C workshops and conferences. The hardware that is either currently installed or in the process of being 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.

8.3 Timeline

A timeline of NNIN/C activities, highlighting major events such as workshops and conferences, is displayed in Figure 12. The principal events which have occurred during the last year 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 user workshop *Building nanostructures bit by bit*, held at Cornell University from October 23-25, 2006. Additionally, NNIN/C participated in the workshop on cyberinfrastructure organized by the Division of Materials Research of NSF during the summer of 2006. Finally of note, a second workstation cluster is, as of this writing, being installed at Harvard University.

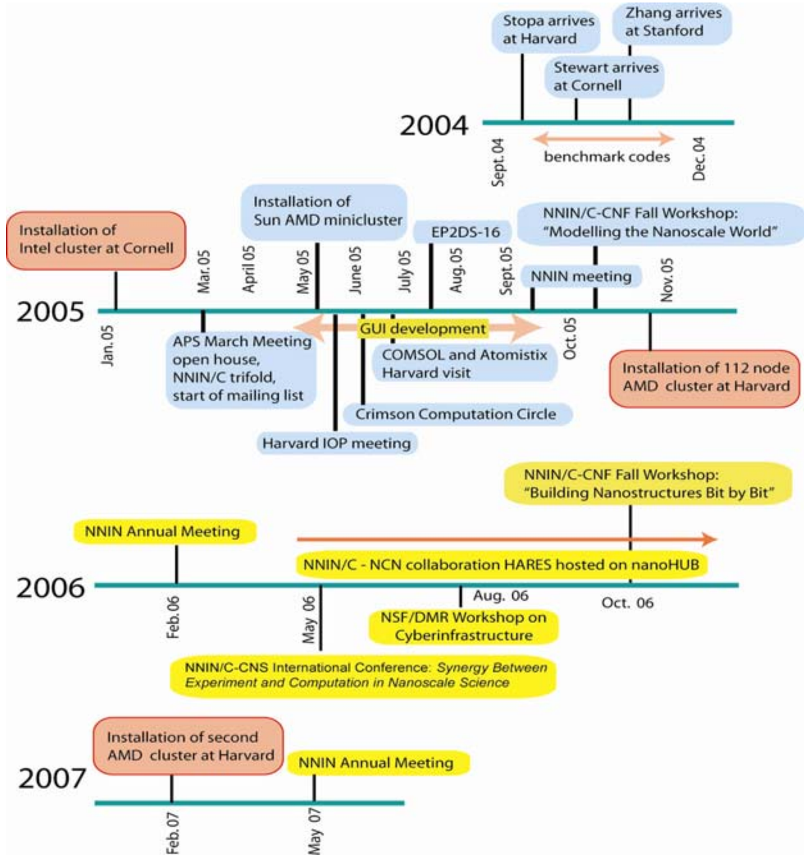


Figure 20: Timeline of NNIN/C from its inception in 2004.

8.4 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 AMD Opteron cluster: 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 64 Bit Opteron workstations are available through a donation by AMD Corporation.

8.5 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 (Fig. 21) :

Figure 21

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*
Fleur - This code is based on the all-electron full potential linear augmented plane wave approach. It can provide important check for plane wave calculations and also has special options for handling surfaces and 1d structures.	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	Cornell *Supported by Derek Stewart*

equations which Elmer solves by the Finite Element Method (FEM).	
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*

8.6 Events

NNIN/C continues to hold events related to expanding its user base and broadening the profile of cyberinfrastructure generally. In the past year, two major events, one at Harvard University and one at Cornell University, have been organized.

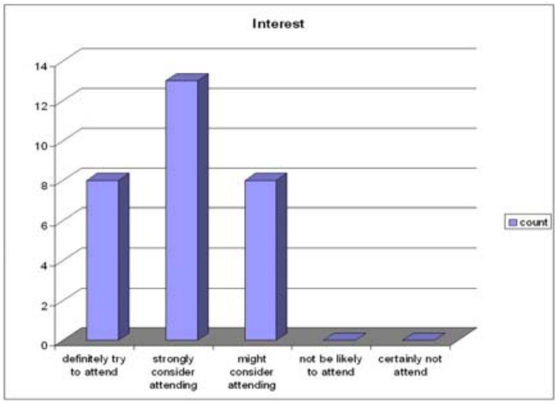


Figure 22: Post conference questionnaire: would you attend again next year?

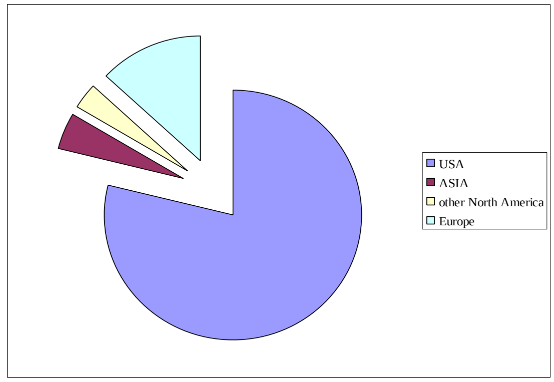


Figure 23: Distribution of Synergy participants by country.

Synergy Between Experiment and Computation in Nanoscale Science – May 31 – June 3, 2006, Harvard University. *Synergy* attracted over 100 participants (figure 23) from 12 countries and included such distinguished invited speakers as: George Whitesides (Harvard), John Joannopoulos (MIT), Sadasivan Shankar (Intel) and many more. The conference featured more than thirty submitted oral and twenty five poster presentations. From the conference poster:

> *In this workshop, we will discuss a varied assortment of nanoscale systems and phenomena with an emphasis on computation. The main theme of the conference, the synergy between experiment and computation, will be explored in focused presentations from experimentalists who will describe the impact of computation on their research and what their desiderata might be for future computation.*

Feedback from the participants was solicited and approximately one third responded to the conference poll. Among the questions polling general satisfaction was the one illustrated in figure 22. The proceedings from *Synergy* have been published in a special issue of *The Journal of Computer-Aided Materials Design,* which is available online (as of January 2007) and will be issued in print in April 2007.

2nd Annual CNF Fall Workshop – *Building Nanostructures Bit by Bit* -- In October 2006, the Cornell Nanoscale Facility hosted the 2nd annual Fall Modeling Workshop, *Building Nanostructures Bit by Bit*". This three 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 including real space and plane wave density functional approaches, molecular dynamics simulations, microfluidics, and nanophotonics. Many of the invited speakers were also key developers of these programs.

Twenty five people participated in the 2006 CNF Fall workshop. Participants attended from 9 states including Texas, Florida, Virginia, New York, Massachusetts, Kentucky, New Mexico, California, and Pennsylvania. Nanoscale research requires an interdisciplinary outlook for success and this fact was reflected in the wide range of attendee backgrounds. Fields represented included chemistry, physics, materials science, mechanical engineering, and space science. Of the participants that filled out evaluations, they *all* stated that the information they learned in the workshop would be useful in their education and career.

Many lectures and tutorial material from this workshop and the first workshop in 2005 are available online through the CNF website. The availability of this information has proven useful to the greater community of nanoscale researchers and in some cases has helped initiate discussions with prospective new users of the CNF and NNIN.

Comments from Bit by Bit Workshop at Cornell, Oct 2006:

> *"The workshop was great!"*
>
> *"Overall this was an excellent experience. I would recommend to many of my colleagues"*
>
> *"I've never been to anything like this. Very helpful and attentive to every attendees needs even when those needs were very varied. Good job."*

8.7 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. Beginning in the summer of 2006, 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.

8.8 Publications

Numerous articles have been published in the past year which have been based on work accomplished through NNIN/C. Some of the highlights of these works are:

1. Vidan et al., Multipeak Kondo effect in one- and two-electron quantum dots, Phys. Rev. Lett. 96, 156802 (2006).
2. S. Lüscher et al., Charge rearrangement and screening in a quantum point contact, accepted in Phys. Rev. Lett.
3. Amit Ghosal et al., Correlation-induced inhomogeneity in circular quantum dots, Nature Physics 2, 336 (2006).
4. Ji Feng et al., Structures and Potential Superconductivity in SiH4 at High Pressure: En Route to "Metallic Hydrogen, Phys. Rev. Lett. 96, 017006 (2006).
5. Gondarenko et al., Spontaneous Emergence of Periodic Patterns in a Biologically Inspired Simulation of Photonic Structures, Phys. Rev. Lett. 96, 143904 (2006).

6. M. Yamamoto et al., Negative Coulomb Drag in a One Dimensional Wire, Science 313, 204 (2006).

8.9 User statistics

Because the nature of computational use is significantly different than laboratory use, and because computation use is limited to a few sites, **NNIN/C computation users are not counted in the normal research statistics (# of users, # of hours, etc) quoted elsewhere in this report.**

The number of users of NNIN/C has grown significantly in the past year. Some of this growth appears to have come in anticipation of the *Synergy* conference. We present graphics for the growth in total user numbers of the two major sites, Harvard and Cornell, in figures 24 and 25.

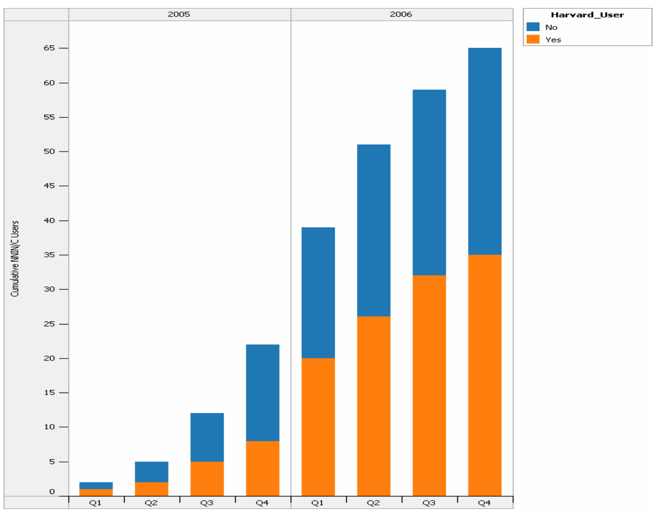


Figure 24 Harvard site NNIN/C user statistics.

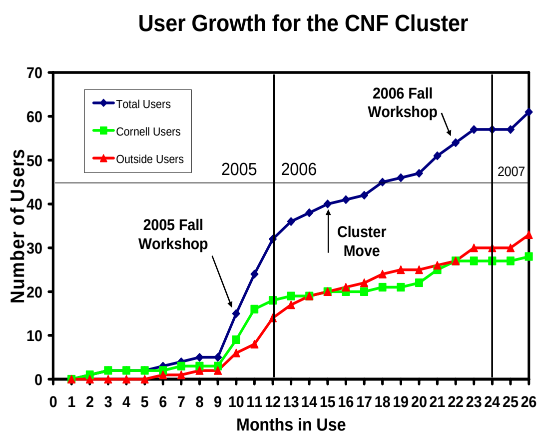


Figure 25: Cornell site NNIN/C user statistics.

Conclusions and Outlook

During the preceding year NNIN/C:

- Substantially increased its user numbers both within NNIN sites and without.
- Held two major events: a unique conference on computation and experiment in nanotechnology and a hands-on user workshop. Judging by user comments, both events were 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. This activity will continue in the future. 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.

9.0 Health and Safety

During the last review period, safety personnel across the NNIN sites defined EH&S issues specific to shared nano-facilities:

1. The convergence of different disciplines with different lab cultures;
2. Higher potential for incompatible processes or process interactions; and
3. The risks posed by introducing new nanomaterials into an environment where experimentation is the norm.

Although equal in terms of the safety concerns presented, the first two can be regarded as challenges of engineering and administrative controls, stemming from the nature open/shared use labs. The third, however, is specific to the inherent properties of nanomaterials and our researchers' study of them. For this year, following recommendations of last year's review panel, the safety personnel at NNIN sites plan to focus attention on the last concern, namely, how can we best manage the safe handling and disposal of nanostructured materials in the lab environment?

Each of the sites participates in a broad range of activities to learn more about nanosafety. For example, the TNLC has been working with and advising the EH&S professionals at their institution on issues of nanotechnology safety; SNF has hosted discussions and lab tours with groups such as the Northern California Chapter of the American Industrial Hygiene Association, the Semiconductor EH&S Association, and the nanotechnology group from Cal-OSHA; CNF sent several staff members to the Nanomaterials Safety Workshop last fall, which featured Andrew Maynard from NIOSH as a keynote speaker. All NNIN safety personnel are keenly aware of the rapid growth of interest and concern in nanotechnology safety and work to keep up with developments by engaging EH&S professionals. However, we are also uniformly disappointed in the dearth of recommended "best practices" for the actual handling of nanomaterials in a laboratory setting. Recognizing that industrial hygiene standards can follow only once the toxicology is understood which is years away, NNIN labs are still left with a problem of how to determine the best methods of managing nanomaterials in the lab today.

Currently, each of the NNIN labs has independently developed its own nanomaterials handling policy tailored for its particular user base and the technology/services supported. Recently, a survey was conducted across all NNIN labs to try to capture this information. The survey shows a broad range of engineering controls used to manage nanomaterials handling, but a surprising consistency in how they are administered at all sites. For example, at all sites, no special handling considerations are given to nanomaterials which are already either adhered to or integrated onto substrates as these are presumed to be safe. But at each lab in which there is extensive handling or processing of free nanomaterials, at least three different engineering or administrative controls were used (out of the seven listed, the most common were: a dedicated workbench for processing nanomaterials; registration procedure for new materials; specialized safety training for nanomaterials.) And in these labs, nanomaterials were treated in much the same way as hazardous chemicals.

Thus, recognizing that nanomaterials may pose unusual health risks, the various labs have implemented systematic methods for controlling where and how nanomaterials are handled.

What this exercise suggests is that in the absence of definitive toxicological data, safety officers in nanotech facilities do not need to become toxicologists or industrial hygienists to establish good lab policies.

So, for this coming year, the NNIN safety personnel will continue to engage EH&S professionals in discussions about nanotechnology safety and implications for laboratory research. Personnel will also continue to attend workshops, short courses and other forums on nanotechnology safety. And finally, the NNIN safety staff will develop a short, best-known-lab practices guide aimed at educating student researchers in a lab environment about nanomaterials safety.

10.0 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

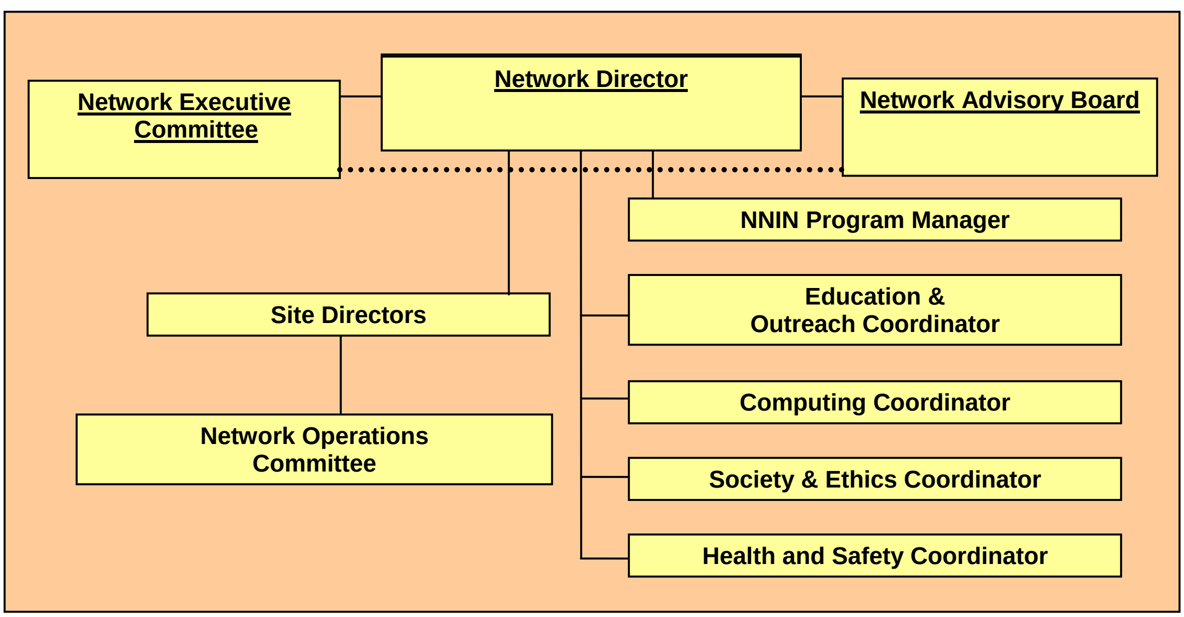


Figure 26 shows the broad outline of the organizational structure. Prof. Sandip Tiwari, Cornell University, the NNIN Network Director, is the point of contact with NSF, and is responsible for implementing the network policies and program. Dr. Lynn Rathbun, Cornell University, serves as the NNIN Program 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 Minnesota), 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 be a private email discussion list. 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.

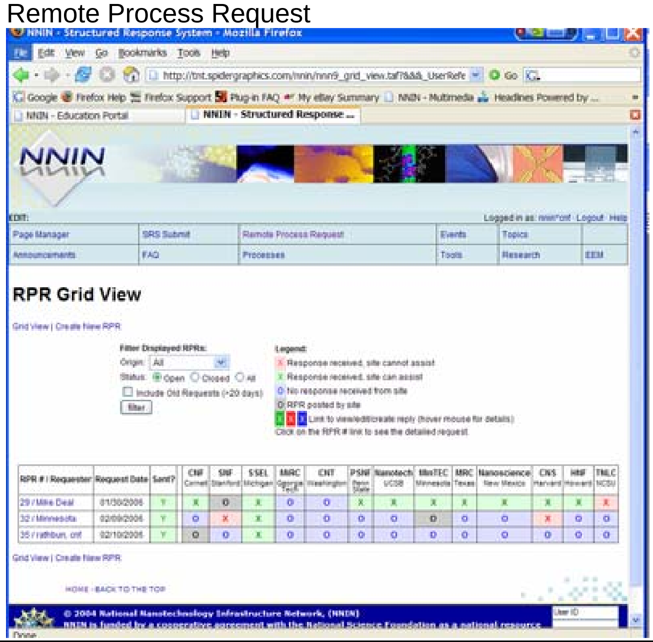
NNIN holds two major meetings every year. One is a half-yearly meeting held at National Science Foundation for discussions with the NSF program officers from the different divisions that support NNIN. This meeting is a mid-year summary of activities, focus, development of ideas for new initiatives, and mid-course correction. The review of the network, by an independent panel, is conducted yearly and this year it is slated for May 9-11 at University of Michigan, Ann Arbor. NNIN also meets and regularly solicits input from the advisory board as needed. These have guided equipment decisions, and have guided a number of key decisions every year. During 2007, following the completion of the annual report, a separate meeting is also being held with the Advisory Board to discuss the variety of issues that an organization such as ours faces. The Network Advisory Board also assembles and participates, with its input, at the annual review.

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 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.

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



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 (Fig. 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 if a proposal is successful at National Institute of Materials Science in Japan, to work with exceptional professional scientists in their laboratories.

At this point, many of the advanced countries around the world have developed nanotechnology centers or more commonly a nanotechnology network. As they are all operating with different histories and with different financial constraints, their organizational and technical approaches to this concept vary significantly but they all have a common goal—to leverage experience at multiple institutions to realize the scientific and economic potential of nanotechnology. All, however, recognize the experience and leadership of NNIN and seek to learn from our experience. At least one VIP delegation from each of the following countries has visited NNIN in the last 2 years: Denmark, Korea, India, Japan, Germany, Italy, Israel, Singapore, and Sweden, to name a few. Typically they visit both the management node at Cornell and one or more other NNIN sites. The questions all start out the same: "How do you handle users?" and "How do you allocate resources?" but then expand into more site specific questions. These meetings are very informative with much learned by each side. NNIN has established the International Nanotechnology Cooperative, an informal group, with membership by invitation that provies a web-based forum for exchange of information and experience with the international entities.

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.

During 2006, the network also made a self-assessment of its equipment needs. The information collected through this assessment is a continuing mechanism for coordinating the needs of the users, of the technical directions and the sites' interests.

11.0 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: 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: 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.

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 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.

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: 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 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 highest level of technical support and rapidly, e.g. a sophisticated characterization 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. 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 best capabilities to the national community in those focus areas by focused use of 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 research made possible 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.

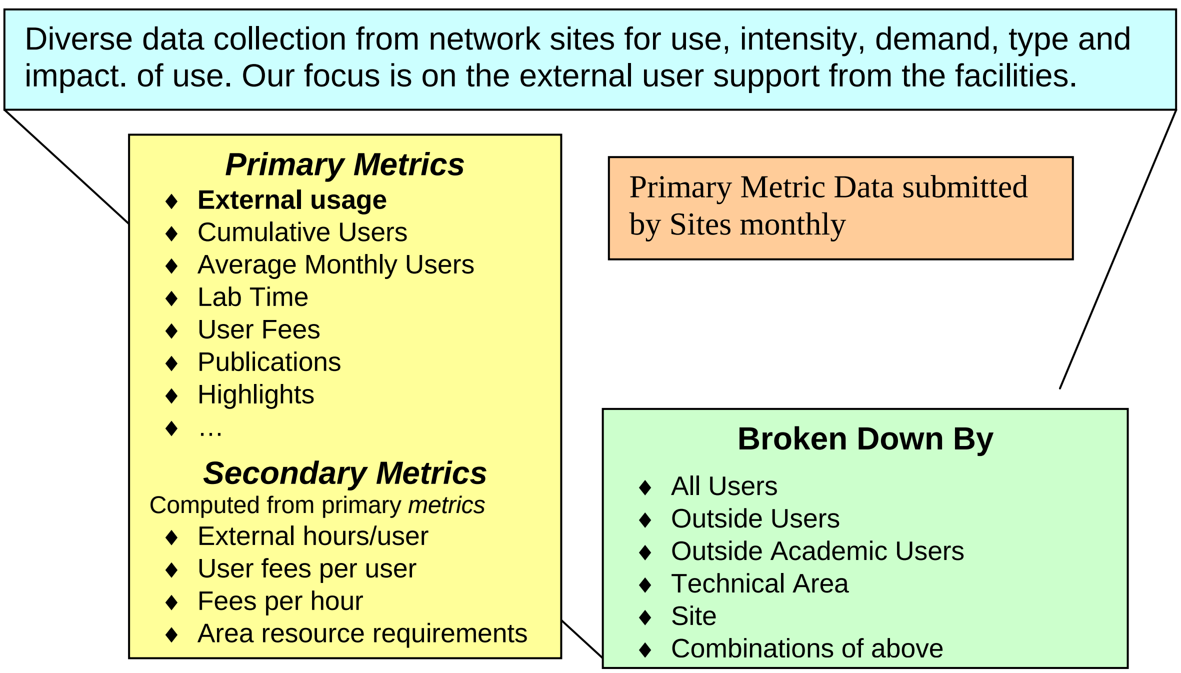
In the following, we summarize the performance of the network and the sites.

11.1 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

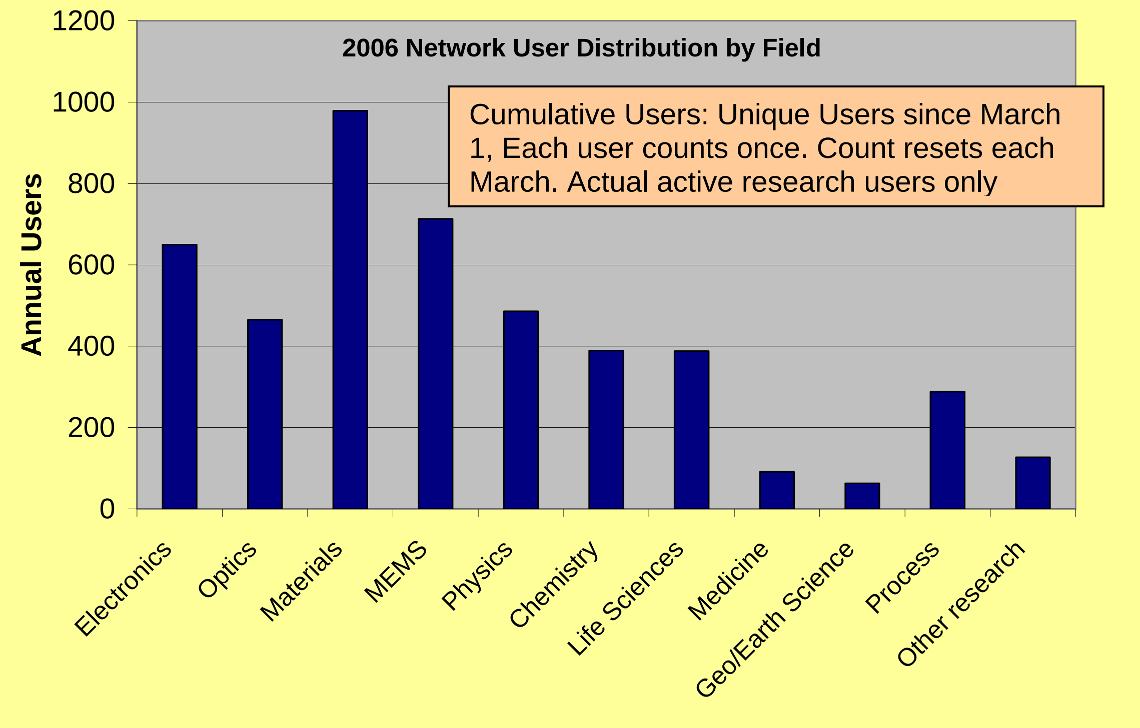
Primary usage data is submitted monthly by each site to NNIN management. **All graphs are subject to the accuracy of the data supplied by the sites.**

Unless otherwise noted, all data is for the 12 month period March 2006-Feb 2007.

11.1.1 Program Breadth

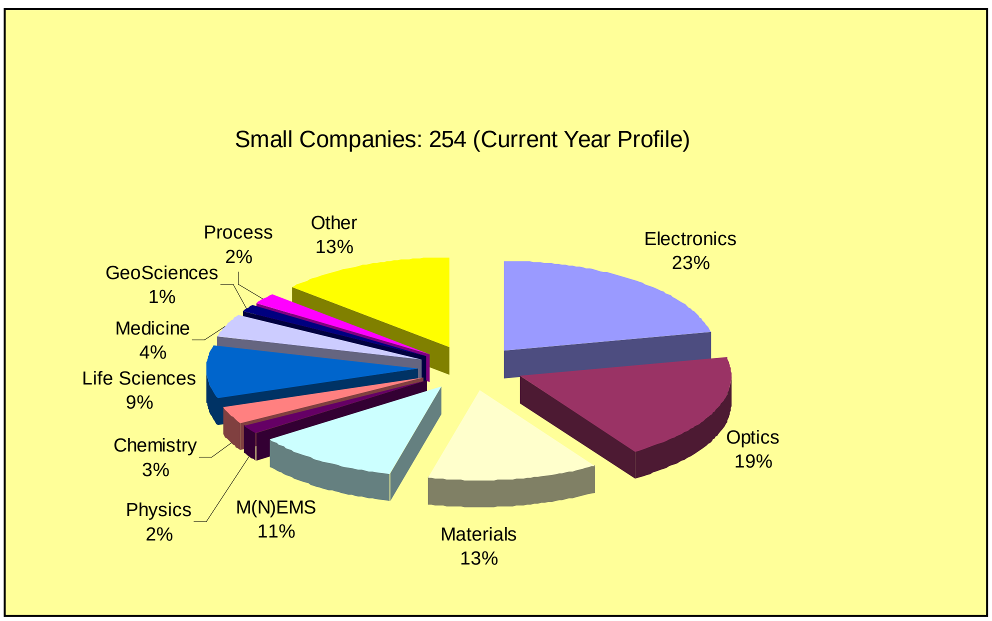
NNIN's mission in support of experimental nanotechnology covers a broad range of technical areas, from complex fabricated structures such as MEMS, biosciences, optics and electronics, to synthesized molecular scale structures. Fig. 29 shows the distribution of users by field (12 months, cumulative users) across the network. NNIN users come from a broad range of technical fields. Particularly interesting is the increasing use in GeoScience area, a new direction of effort within NNIN.

Figure 29: Network User Distribution by Technical Area.



Serving small company users is an important part of NNIN's mission. Fig 30 shows the broad field coverage in this important subset of users. This data is from 2005 and the information on small companies listed in the site reports shows a similar trend.

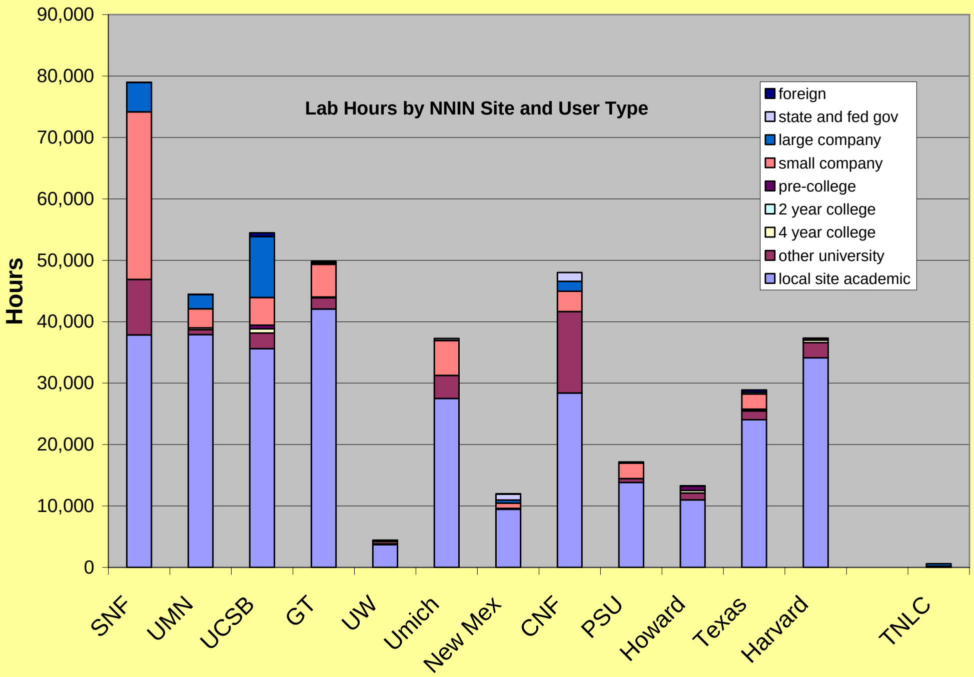
Fig. 30: Small company usage in NNIN.



11.1.2 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. Usually, the method of counting clean room time somewhat exceeds the direct equipment use time since users spend considerable time characterizing, planning and discussing experiments, a time that may be spent in the clean room but that is not usually reflected in equipment time. 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 31: User Lab Hours by NNIN Site.

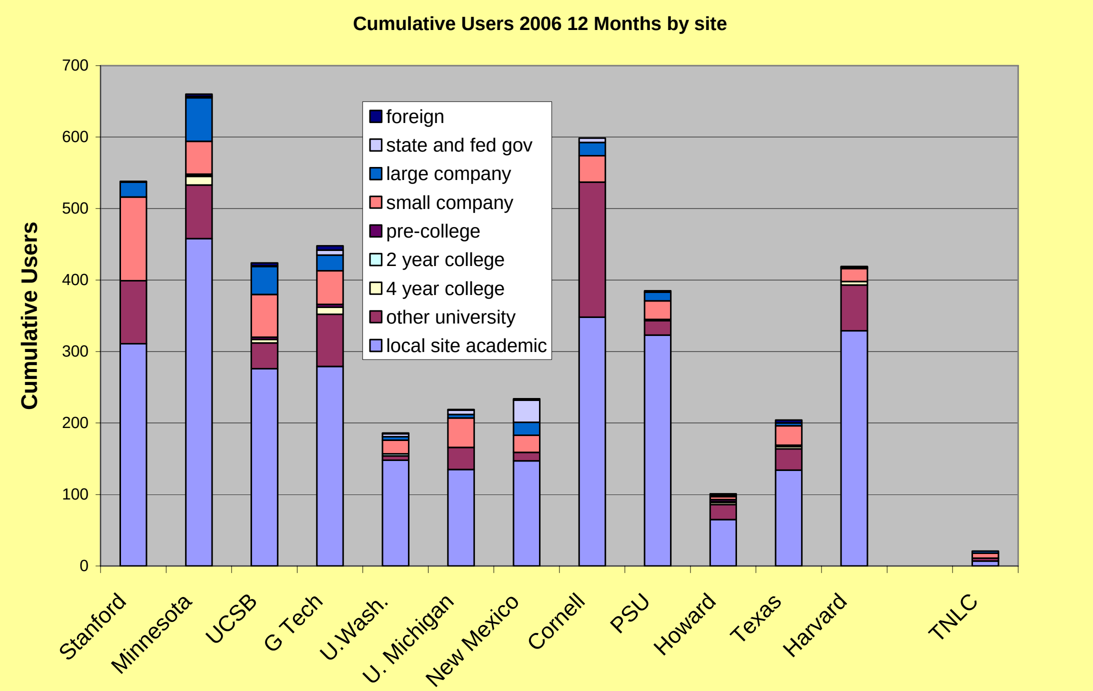


The chart in Figure 31 represents total lab hours during the 12 month period (March 2006-Feb 2007). Size of each NNIN facility varies significantly and each includes different amounts of "associated" facilities. Nonetheless, they reveal information about the size and scope of each laboratory's activities. 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. These statistics show that Stanford, UCSB and Cornell, three of the older members of the network, have a good balance between internal and external usage, with the former two stronger in industrial support and Cornell in external university support.

11.1.3 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 32 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 and Stanford, the two older NNIN sites, reflect a large and good balance between internal and external users, with U. Minnesota, UCSB, 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 we will have to look at other metrics as a supplement to this.

Figure 32: Cumulative Annual Users at each site.



As discussed in introduction, NNIN's effort is organized around the theme of serving the external user – a focus we believe leads to the 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 33 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. The three major sites of the network, Cornell, Stanford, and Minnesota have more than 200 outside users each in the 12 month period, with both academic and industrial users benefiting from the network.

Figure 33: NNIN Outside Users by Site.

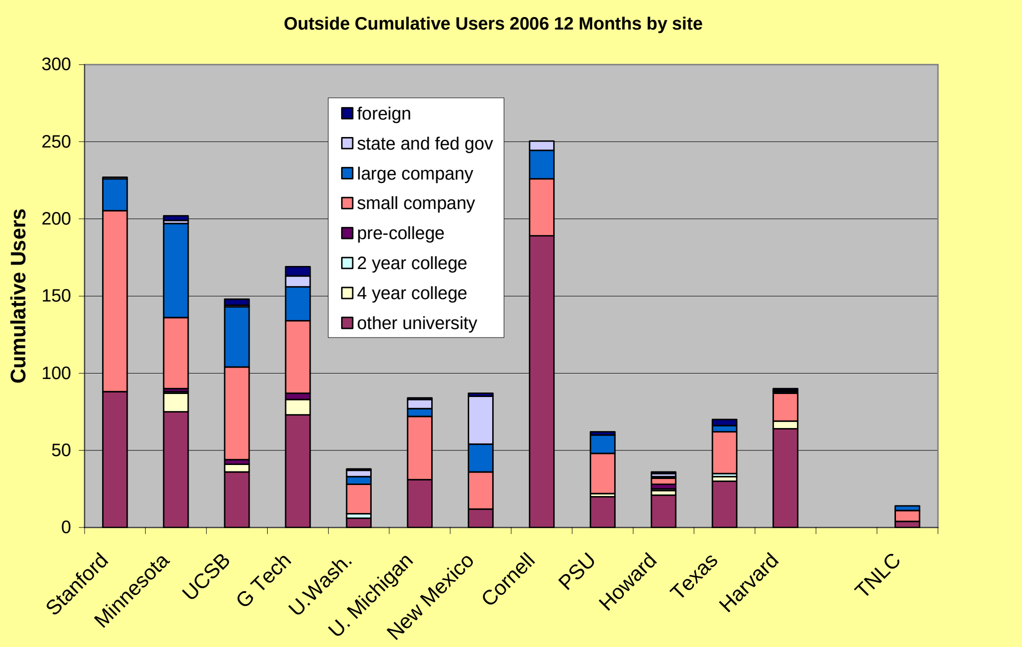
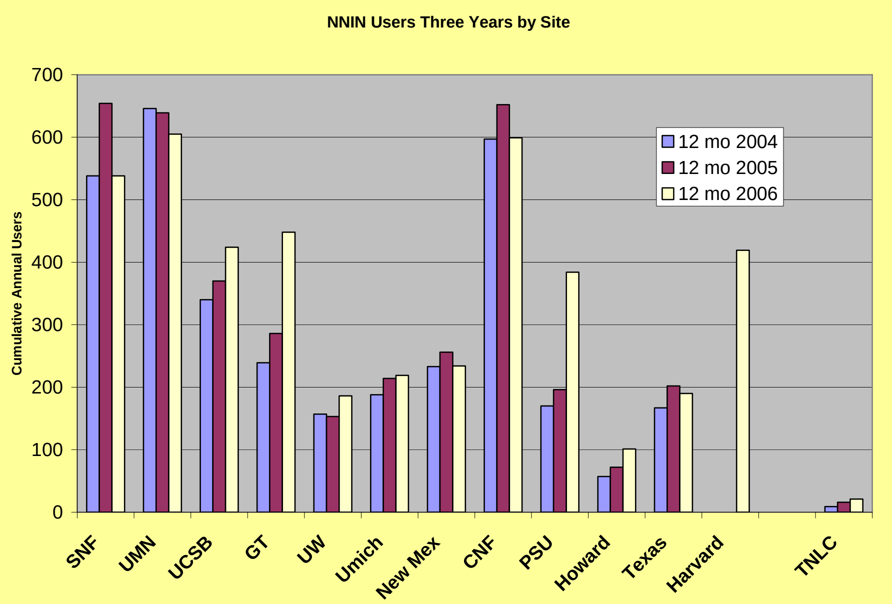


Figure 34: NNIN users by site in a three year comparison.



Accurate numbers of prior year 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 growth in usage of the network at sites (Fig. 34). Nearly all the sites continue to make progress in this objective as shown the two figures, as does the network.

Figure 35: Network wide research usage

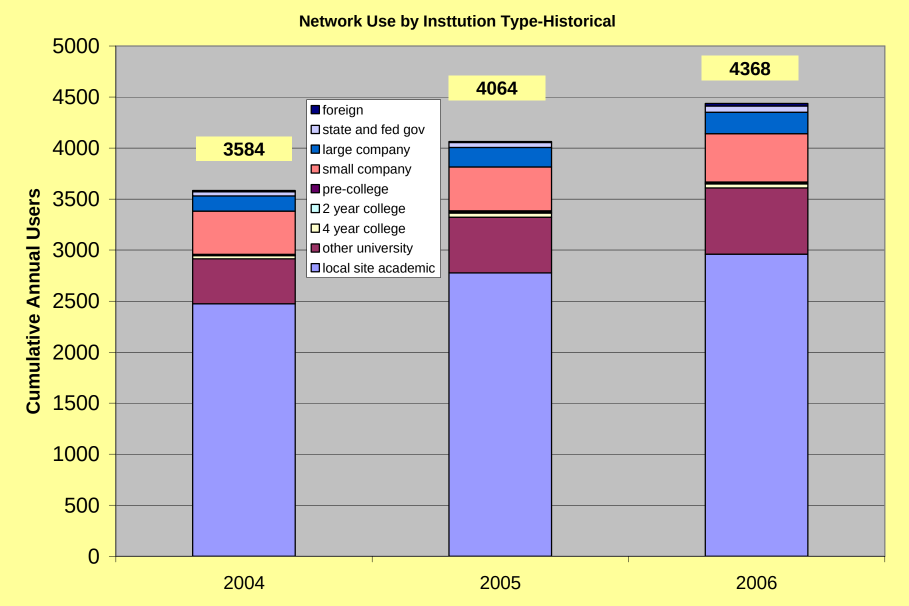


Fig. 35 shows a general increase in network usage across all institution types. Summed across the network and projected to a full year (March 2006-Feb 2007), NNIN usage projects to approximately 4400 research users, an increase of 7.5% year to year.

11.1.4 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 (Fig. 36) 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 (Fig. 38, 39) 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.

Fig. 36: User fee recovery in 2006.

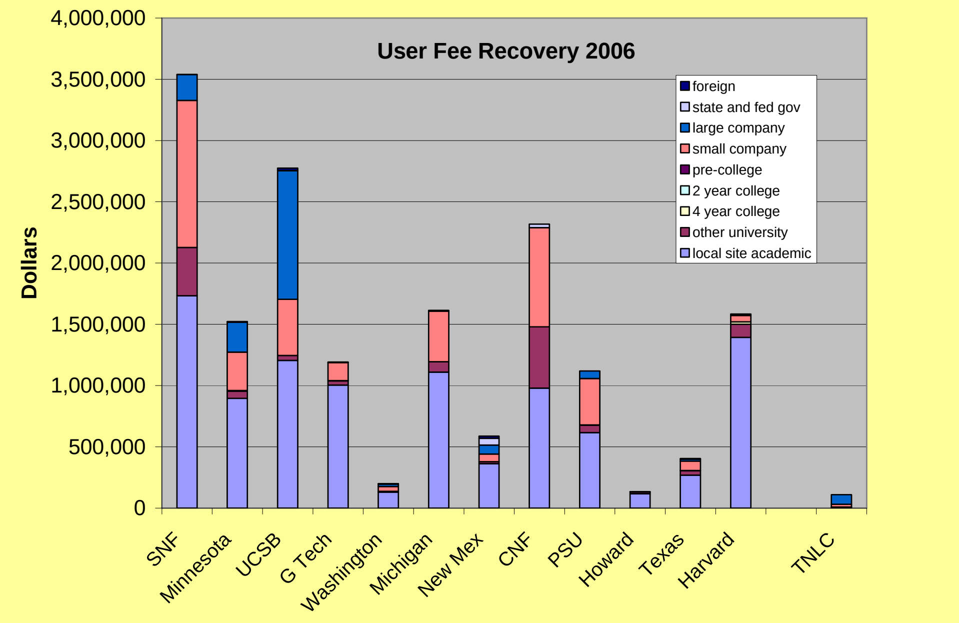
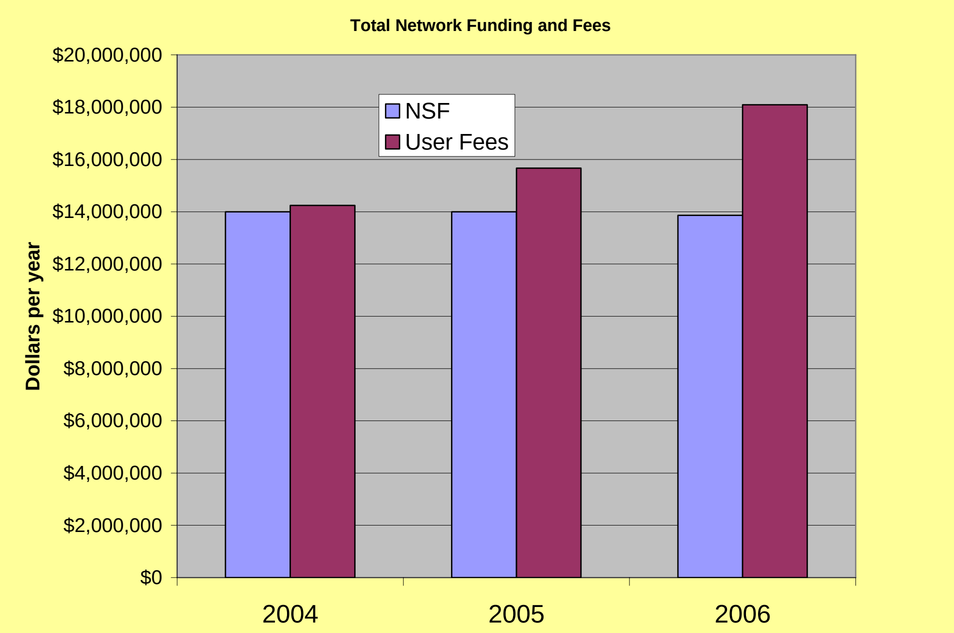


Figure 37 shows the overall high leverage of the NSF investment. Each dollar of the NSF cooperative agreement is more than matched by user fees. Both user fees and the NSF support

Figure 37: Total network user fees.



are critical to operation of NNIN.

Figure 38: Average academic user fees.

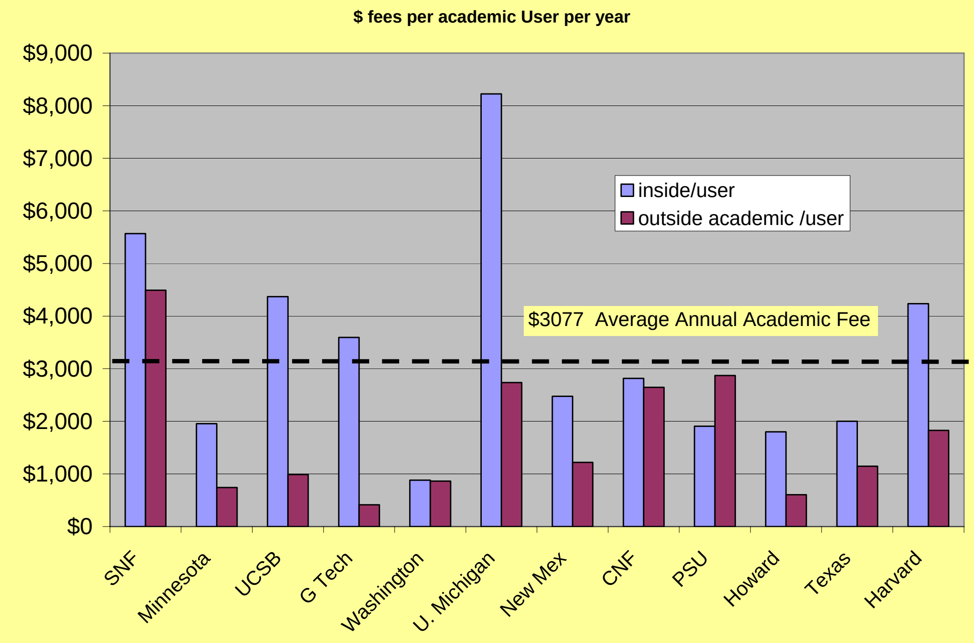
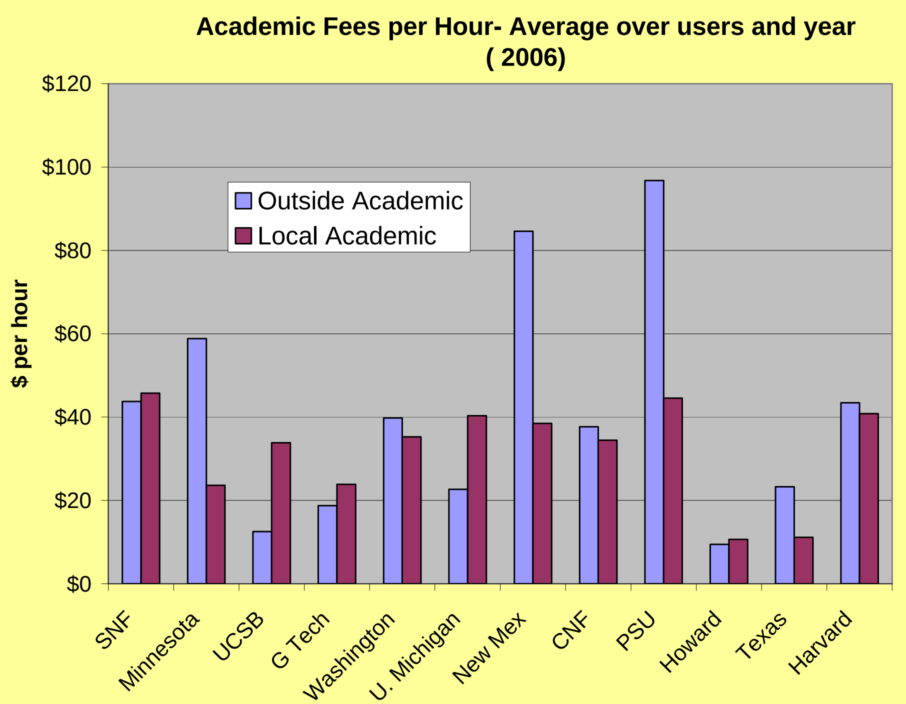


Figure 39: Academic fees per hour in NNIN facilities.



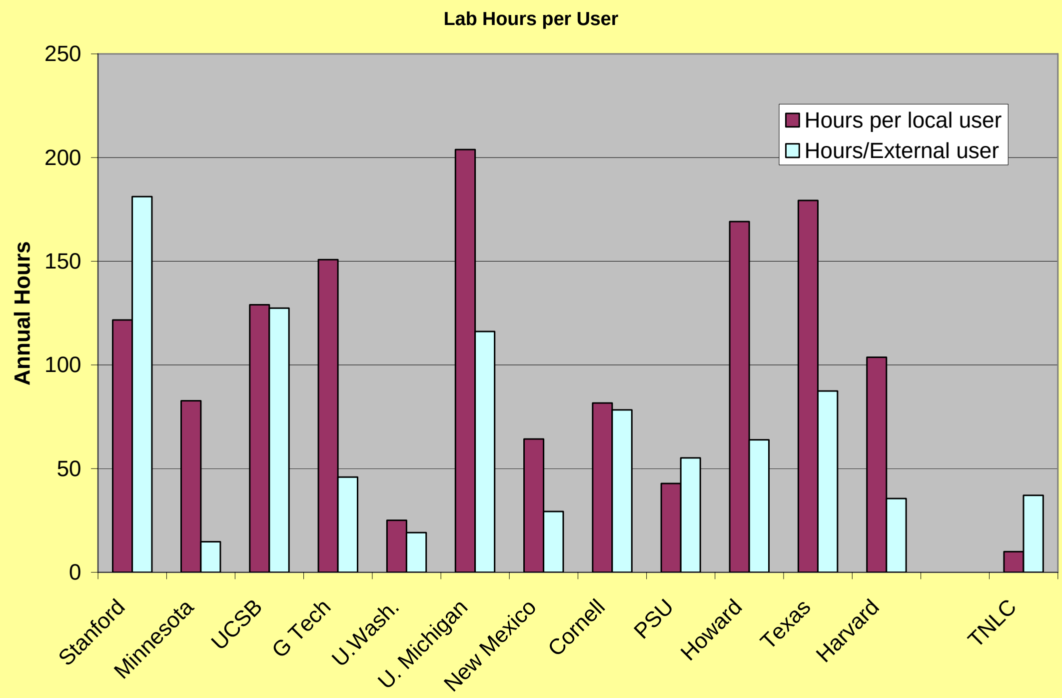
The point of these plots is not any individual variation, either between sites, or between local and outside users at a given site; there is far too much variation in complexity of projects and the available equipment sets to draw those conclusions (although actually most use falls in the $20-40 per 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 $3077 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.

11.1.5 Hours per user

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 year) (fig. 40) 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 100s 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 40. 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. Stanford's outside user base is the notable exception to this; that is, however, probably the result of the geographical proximity of many of Stanford's external industrial users.

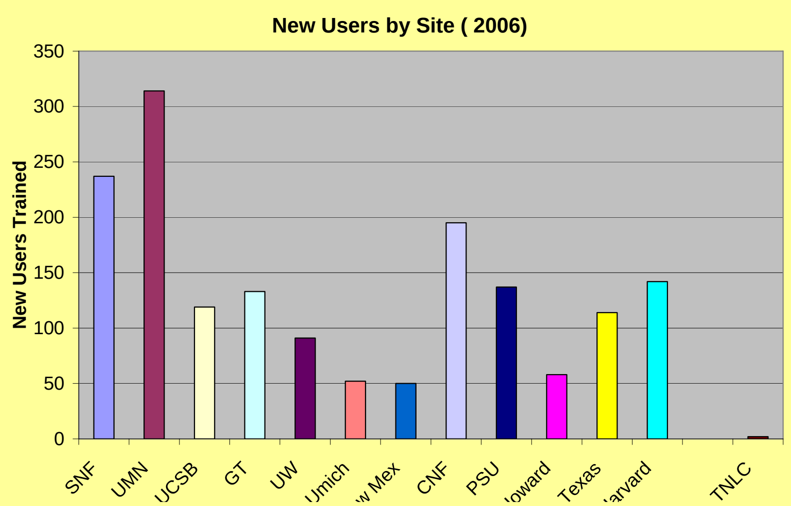
Figure 40: Laboratory hours per user (local and external).



11.1.6 Hours per user

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. Here (Fig 41) we

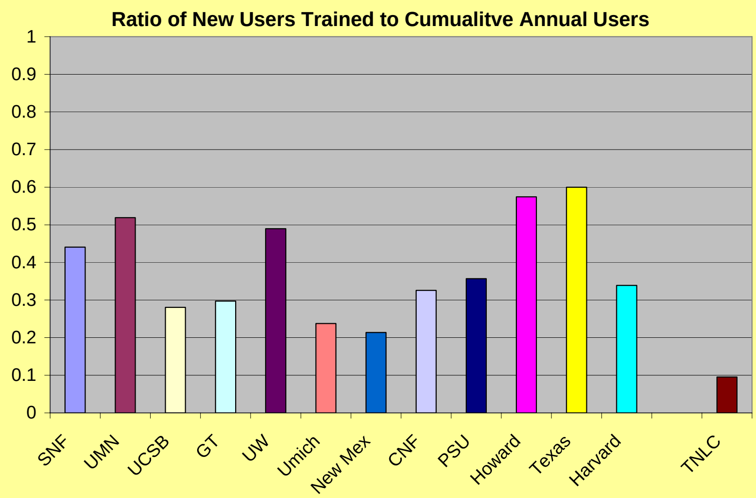
Figure 41: Training load for new users (internal and external).



show the number of new users trained in FY2006 by site. Note that at some sites (Stanford, Cornell, and Minnesota) new users average almost 5 per week.

There needs however to be a balance between new users and total users. Figure 42 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 42: Sustained usage and new usage of sites.



11.2 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.

Usage:

The research usage within NNIN encompasses 46 of the 48 continental states . South Dakota and Oklahoma are the two states that are not represented in our user population. The users are across the broad range of areas that we partition across disciplines related to nanotechnology. Among these, geology/earth sciences is the smallest, but still with greater than 50 different users in the network. The areas of materials, MEMS, electronics and physics are the next largest with double digit percentages. The largest external usage, the focus of our efforts, by user numbers and hours, is at Cornell and Stanford. Many of the new sites that joined the network three years ago have made excellent progress and contributions. The largest number of users in the network at this point is at University of Minnesota where three laboratories, two of whom are focused on remote usage, are part of the network. The largest intensity of usage by external user measured in hours per user includes University of Michigan.

External Usage and Cost of Usage:

The largest number of external users is at Cornell, Stanford, Minnesota, and GeorgiaTech. Viewed from the number of hours of usage, which reflects the intensity of usage, the largest number of external use hours is at Stanford, Cornell, UC Santa Barbara and Michigan. Our statistic of external user hour utilizes different measures at different sites (clean room hours versus paid instrument hours). The intensity of this usage when an external user visits, reflecting the hours per external user is largest at Stanford, Michigan, UC Santa Barbara and Cornell. External usage is reflected in largest cost recoveries at Cornell, Stanford, UC Santa Barbara and Michigan, with the highest external academic cost per hour at Penn-State, Minnesota, U. of New Mexico and U. of Washington. For Cornell 41% of the usage hours are from external users and for Stanford 53% of the usage hours are from external users. For the network as a whole, 25% of the usage hours are from external users. The average cost of academic usage per year is ~$3077, a sum that is well within the capacity of most research projects supported by federal agencies.

The NNIN is employed as a nanotechnology resource by 168 universities and 250+ companies. The largest academic usage is at Cornell with users from 55 universities and the largest industrial usage exists at Stanford with 64 small companies. In understanding the specifics of the external usage at various sites of the network, it is important to reference the type of usage (many research projects, such as those using advanced characterization resources are staff intensive, while many others may involve much smaller level of facility effort).

Network Research Impact:

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. 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 (these are collected at different time points in the year, but cover one year's summary) shows a very significant output, particularly for work performed by external users at Cornell and Harvard University. Among the publications that received wide publicity during the past year, are the work of micro-nano measurements that pointed to the quantum back-action resulting from the momentum when a precision position measurement is made using superconducting single-electron measurement of the position. Bringing nanotechnology to the benefit of society through commercialization is another area where the network has made major contributions.

Similar achievements also exist for impact from the educational and broader impact effort from the network. During the past year, these outreach efforts resulted in young groups and individual supported by the network winning national competitions for high and middle school students (National TSA competition of middle school science clubs and science and technology fairs) and for participants at college levels (Sigma Xi society best paper award and Fulbright scholarship).

The funds supporting NNIN make possible research of 4000+ research users, 250+ small companies, trains nearly 1600 new research users each year, and results in more than 1200 PhD awards each year. 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.

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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 2005-June 2006) collected in June, 2006 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 Sep. 2006 covering the period Oct. 2005-Sep. 2006.

Appendix 1: NNIN Network and Site Principal Contacts

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