Annual Report of the National Nanotechnology Infrastructure Network

10 month period
March 1, 2008 through Dec 31, 2008
"Year 5"

Cooperative Agreement: ECS-0335765

Feb. 2009

***Participating Institutions**:* Cornell University, Georgia Institute of Technology, Harvard University, Howard University, 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 Cooperative Agreement ECS-0335765
PI: **Sandip Tiwari**
Cornell University

The National Nanotechnology Infrastructure Network (NNIN) started on Mar. 1 2004 as a collective of university-based laboratories with the mission to enable rapid advancements through open and efficient access. NNIN's approach has been to focus efforts on serving the external user. The resources are optimized by connecting specific technical leadership offerings at a site to the intellectual strengths of the home institutions, thus offering the most advanced knowledge and instrumentation to the user. When coupled with geographic diversity, this community approach also enables balanced and broad outreach.

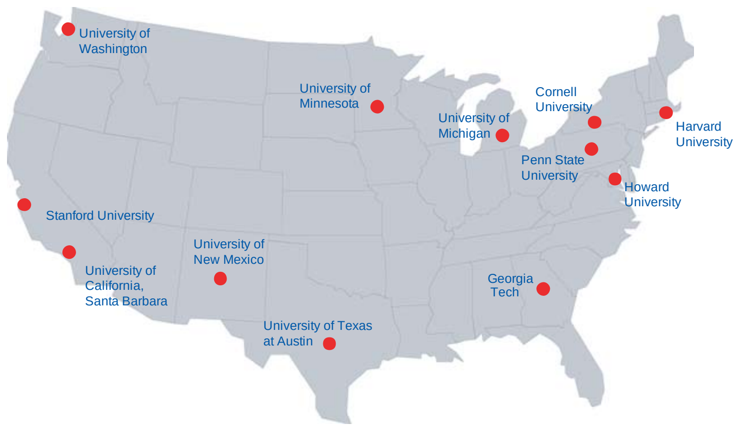


Fig. 1: NNIN Sites (2008)

The NNIN approach has transformed the culture of pursuit of advanced research and development and has made possible major intellectual and broader achievements. During the 10 month period of this report, NNIN served 4739 unique users, of whom 3906 were academic users, 758 industrial users ,32 from US State and Federal laboratories, and 34 from foreign institutions. More than 1600 new users were trained during the ten month period. Over a period of a year, NNIN enables in excess of 1,000 PhD awards, $400M dollars in research, and activities of 250 companies. The users' interests reflect a broad diversity of disciplines. During the last complete year of data collection, more than 4,300 publications and presentations were derived from NNIN usage. NNIN's research-focused workshops were attended by more than 750 technical personnel and its public outreach activities reached in excess of 24,000 participants. NNIN's children's magazine, *Nanooze*, and its mobile laboratory, *NanoExpress*, have found compelling new ways to encourage young people towards science. Nearly half of undergraduate research program participants are going on to obtain a PhD. NNIN has extended the learning from its educational and research support effort to provide enhanced experiences in support of human resource and leadership development through programs such as Laboratory Experience for Faculty (LEF), international Research Experience for Undergraduates (iREU), and international Winter School for Graduate Students (iWSG) among others. NNIN's success also draws on its dynamic evolution based on its learning and on the input that it receives and collects.

The network's integrated efforts for intellectual, transformative and broader impact arises from its infrastructure for research: the network, through complementary technical strengths, provides on-site and remote external user access that permits efficient and rapid execution of projects at low cost with thorough training and equipment access. The research infrastructure includes advanced top-down processing, and bottom-up synthesis and self-assembly based on hard and soft materials; comprehensive integration capability for system scale; capability to explore interdisciplinary applications across the breadth of physical and life sciences and engineering where nanotechnology plays a role. The network capabilities continue to evolve leveraging new techniques that are discovered, invented and developed within the facilities and elsewhere. These resources allow the exploration of the most advanced experiments at the nanoscale in physical sciences, life sciences, engineering and their interfaces, including molecular-scale structures, new nanomaterials and nanoscale devices, integrated mechanical, electronic, fluidic and bio-systems, energy converters, sensors and sensing systems, and other promising areas exploiting the inorganic-organic interface. The highlights included in the report describe several of these accomplishments.

The network also supports, with active staff, computing resources, and open informational data bases, providing the ability to the advanced scientific users to tackle the major theoretical problems, particularly those that require interdisciplinary knowledge and those that connect experiments with theory using diverse scientific modeling and simulation tools. More than 200 advanced computation users, working on advanced interdisciplinary and advanced scientific problems utilize the network's resources in hardware and software. The network web-infrastructure resources continues to expand, organizing and distributing the rapidly growing knowledge base of nanoscience and engineering, building open community and making available the network's learning resources for education, outreach, and for societal and ethical consciousness.

The network also has extensive collaborations and external interactions that advanced the agenda of learning, research and outreach. During 2008, new initiatives in external collaborations included focus on education and technical research that integrate with societal and ethical consciousness: (a) a winter school where 12 graduate students and 7 faculty members including two social scientist and ethicist travelled to India for an intensive one week, semester-scale, graduate course on "Organic Electronics and Optoelectronics" integrated with exposure to use of technology in the local community, and (b) a second summer experience for selected REU students from the network guided by senior scientists at NIMS (Japan), Forshungzentum (Jülich, Germany) and NIST (Gaithersburg). The Laboratory Experience for Faculty provided opportunity to 5 under-represented faculty or faculty from universities primarily devoted to under-represented community to come and work in NNIN laboratories during the summer period.

In education, development of human resources and societal and ethical consciousness, and outreach, NNIN's goals are to spread the benefits of nanotechnology to new disciplines with understanding of the societal context and technology risks, educate a dynamic workforce, be a resource for all ages and educational background, and to do this at the national scale for the undergraduate and higher levels while also pursuing efforts of local relevance. The national-scale efforts include REU, RET, laboratory experience for faculty, a nanotechnology showcase that travels to professional conferences with large under-represented student attendance, advanced Symposia with changing topics for graduate and post-graduate personnel, an international winter school for graduate students, hands-on laboratory based technical courses, and the premier children's magazine devoted to nanotechnology - Nanooze. Locally, the efforts include "NanoCamps" for high school students, remote school demonstration projects, and teacher workshops. Diversity is a major consideration in all network efforts - in participant reach, selection and activity development. In research support and education and outreach efforts, the ethical and societal considerations are incorporated as discussions through network-developed material.

2.0 National Nanotechnology Infrastructure Network

2.1 Scope of This Report

This report covers ten months of the year 5 of the operation of NNIN - the period from March 1, 2008 through Dec. 2008. NNIN is funded via a cooperative agreement between Cornell University and NSF, which commenced on March 1, 2004. The current award period runs through Feb. 28, 2008.

During 2008, NNIN was reviewed for extension of the cooperative agreement for 5 years, until Feb. 2014. A site review was held in May 2008, and the decision was made in late 2008 to extend the cooperative agreement. An amended cooperative agreement has been negotiated between NSF and Cornell University.

Operation of NNIN has been documented extensively in prior reports, in the renewal proposal, and in the site review documentation. This report will focus on reporting highlights and activities of 2008, including statistics of use, with relatively less emphasis on describing NNIN functions and operations discussed extensively earlier.

2.2 Network Overview

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

The network is focused on providing infrastructure to support nanotechnology research by "outside users" —students and professionals from institutions outside of NNIN. In NNIN's view, infrastructure consists of much more than advanced equipment (Figure 2). While an extensive set of state-of-the-art equipment is a necessary condition it is not sufficient for the operation of an effective user facility. Key to NNIN operation and thus a key part of the "infrastructure" are the committed staff resources to enable effective use of nanotechnology equipment and a focus on service. NNIN's group of facilities are committed to this culture and operate as an organization supporting and complementing each other so that together, the network can be effective across the breadth of disciplines and geographically.

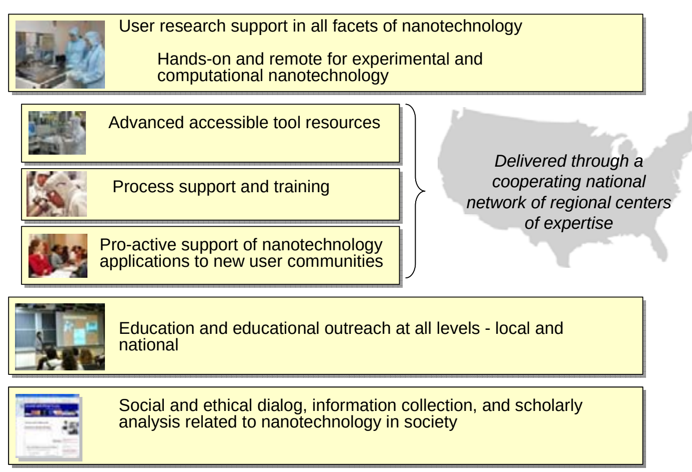


Figure 2: The scope of NNIN programs and impact.

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

NNIN was established in March 2004 as a result of an open national competition for a nanotechnology infrastructure network to succeed the former National Nanofabrication Users Network (1993-2002). While funded through the ECCS division of NSF, funds for the network are drawn internally at NSF from most major NSF divisions. For year 5, the period covered by this report, primary NSF funding for NNIN was $14.0M per year. Individual sites are funded, by sub-award, at levels ranging from $500,000 per annum to $2.5M per annum. Additional operational funding at each site is obtained in various amounts from university and state sources, from user fees, and from industry. The network also competes separately for funds from various NSF equipment and educational programs (e.g. REU, RET).

The vision of a nanotechnology future is also critically dependent upon the availability of appropriate human resources. Education, human resource development, societal and ethical implications, and outreach activities are thoroughly integrated throughout the network. These broader impact activities are discussed in this report in Sections 5 and 7. Our goals to spread the benefits of nanotechnology to new disciplines, to educate a dynamic workforce in advanced technology, and to become a teaching resource in nanotechnology for people of all ages and educational backgrounds, are served through a number of local and national educational programs and discussed here.

This is the report of most of the 5th year of operation of NNIN — 10 months — March 1, 2008 – Dec, 2008. During the 10 months reported here (March 2008- Dec 2008), the network supported the research objectives of over 4700 users from academia, industry and the national research laboratories. More than 350 small companies employed the network resources to reduce their ideas to practice. In addition, more than 24,000 students and professionals participated in NNIN educational activities, many of them gaining their initial hands-on experience with tools and techniques of nanotechnology.

Details of NNIN operations are covered in the following sections.

2.3 Mission and Approach

NNIN's mission is to enable rapid advancements in science, engineering and technology at the nanoscale through efficient and affordable access to nanotechnology infrastructure (Figure 3). Our approach to accomplishing this goal is based upon:

- A commitment of openness that focuses on external users,
- State-of-the-art equipment resource, distributed across sites, supported by a high level of technical staff expertise
- A commitment to technical excellence that focuses on bringing key instrumentation and knowledge and training to users
- Effective and leveraged use of scarce resources, enabled by the critical mass of users engendered by the user facility concept and the scope and visibility of the network,

- Geographically distributed resources with distributed technical responsibilities, building upon the research and technology strengths of each site while serving the broadest community, and
- A synergistic set of local and national activities to support education of users, potential users, human resource development, and provide public outreach.

Accomplishing this mission requires that we place the highest priority to the needs of external users; each NNIN facility is focused on this aspect, with significant equipment, staff, and training resources devoted to accommodating both new and ongoing users from other institutions.

Each NNIN site has technical area responsibilities that are tied to the technical area strengths of the institution. NNIN sites, thus, do not provide identical capabilities but do provide a set of common widespread fabrication techniques together with specialized technical area capabilities. This allows one to provide world-leading expertise that is unique to each site based on its history, interests and resources. The network is a distributed set of laboratories, each with distinctly local flavor, but all working to a common goal and with a common approach. This shared vision is critical to the operation of the network. To achieve this vision, all sites have committed to these common principles:

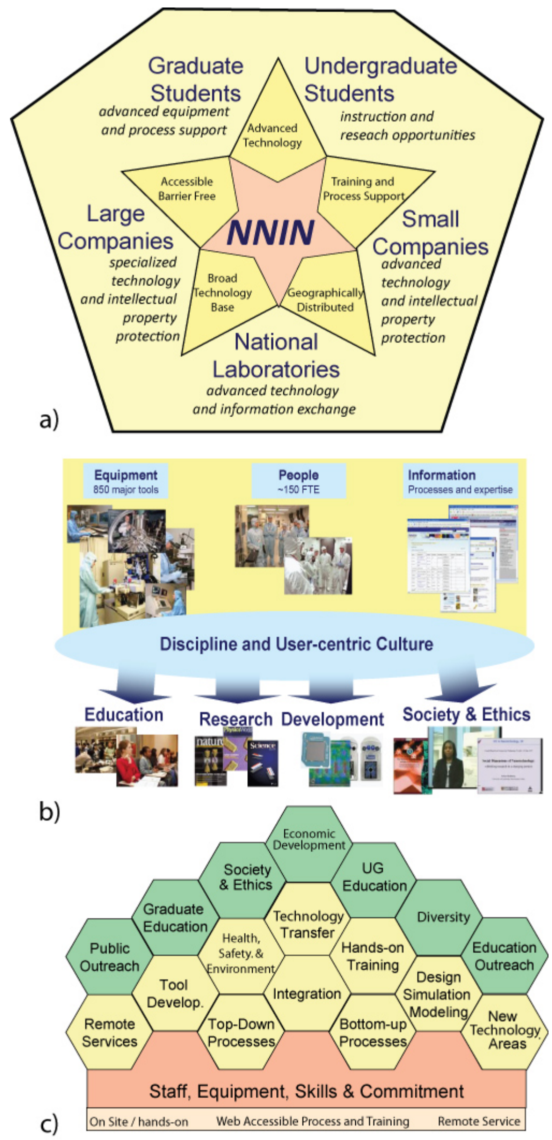


Fig. 3: Overview of NNIN operations

- Open and equal access to all projects independent of origin
- Single-minded commitment to service of external users
- Commitment to support interdisciplinary research and emerging areas
- Commitment to deepening social and ethical consciousness
- Facility control, not individual faculty ownership, of instruments and other resources
- Openness to new materials, techniques, processes, and applications
- Commitment to maintaining high equipment uptime and availability
- Commitment to comprehensive training and staff support
- Facility governance independent of interference from other local organizations
- Commitment to no intellectual-property barriers

These principles are key to NNIN's operational success; they separate NNIN facilities from other research facilities which try to support user access as a secondary rather than a primary mission.

This approach also avoids any conflicts of interest that arise in conduct of research when multiple investigators are pursuing similar directions. These principles have served NNIN well and have allowed it to make the unique and large-scale contributions as a successful national infrastructure resource.

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

2.4 Technical Expertise Responsibilities of Network Sites

The breadth of nanotechnology cannot be covered by any one facility or by a set of identical facilities. NNIN sites are all different, for geographical, cultural, historic, and scientific reasons, but all operate within NNIN under the same guiding mission, vision and open approach. Each site has been assigned different responsibilities within the network (Fig. 4), some with responsibilities in traditional areas and others with primary responsibilities in emerging areas such as geosciences and life sciences. Some sites have been assigned leadership positions in certain thrust areas, while others are contributors. This ensures that leading state-of-art resources are available at these sites directed towards these areas. Similarly, responsibilities for education and SEI activities are distributed across the network. We obtain efficiencies in the use of the scarce financial resources by leveraging the individual sites' research strengths to provide network technical leadership in each major technology area. This provides a path for new developments, knowledge and ideas to become nationally available in a timely manner.

Site specific reports, as submitted by sites to NNIN management, are contained in Appendix 3 and describe the progress of the sites towards their objectives.

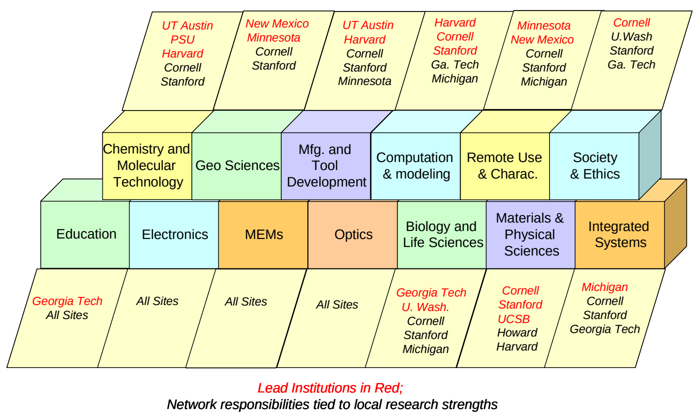
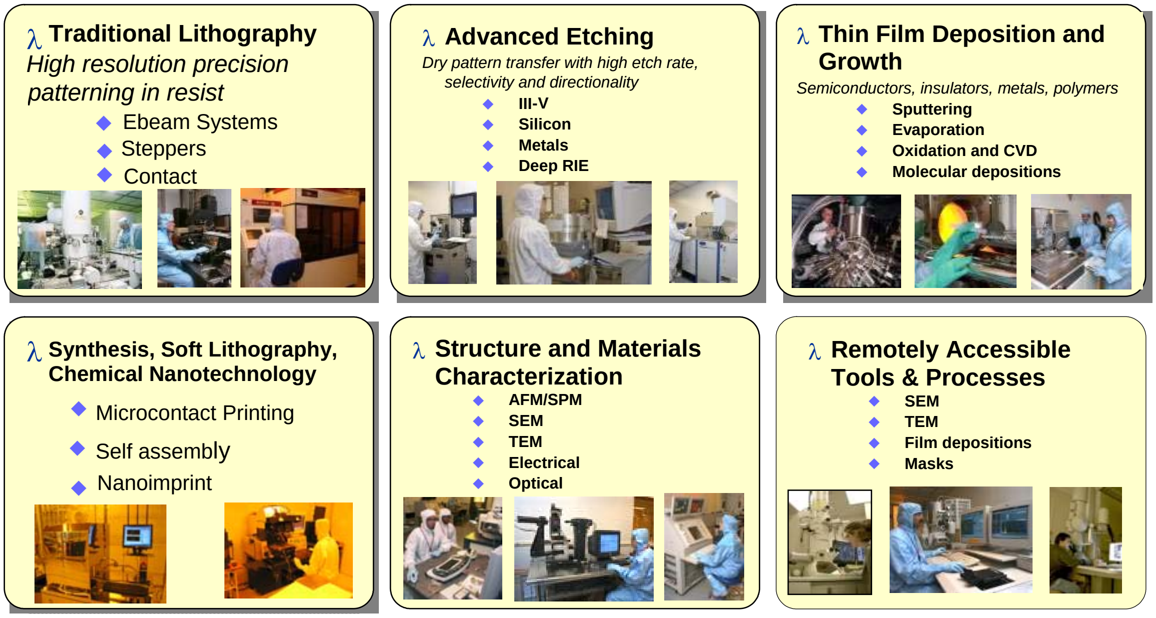


Figure 4: Technical responsibilities of NNIN sites.

2.5 NNIN Technology Resources

Critical to any user facility or network of facilities is modern state-of-the-art equipment and broader technology resources. 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 hundreds of million dollars with significant resources available to support all the facets of nanotechnology research. A database of available NNIN equipment resource is accessible via the NNIN web site. Some of the available technologies are highlighted in Figure 5.

Figure 5: Major technology capabilities available from NNIN.



2.6 Practices for User Support

NNIN has developed practices to support and train users, and to bring in new users, by learning and experience derived over several decades starting with the first open facilities of its kind. External user support, training, and procedures are the focus of this approach which also benefit the internal users. While simple to explain, they are difficult to implement in a traditional university environment where multiple interests co-exist. Through the leadership of NNIN derived from its evolving experience, the participating sites in NNIN have adopted, implemented, and embraced these methods. This section summarizes the NNIN practices and mechanisms implemented by NNIN to enable effective research and development support.

2.6.1 Concept of a User Facility

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

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

2.6.2 NNIN Project Support , Process Support, and Training

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

Each site is responsible for providing sufficient staff resources to enable comprehensive training and support for external research projects. Currently, NNIN trains approximately 1800 new users per year, with a total of over 4700 different users taking advantage of NNIN facilities each year. Safety training is mandated for all users prior to any activity. Each external user project is assigned to a staff mentor who is the primary contact for the technical support. This is particularly important for new users and for users from outside the domain of electronics. Instruction in all phases of nanotechnology is provided as necessary in addition to direct equipment instruction. The NNIN staff act only as facilitators; the technical and intellectual direction of each project remains with the user. As projects progress, users become more independent of NNIN staff support, many to the point of being self-sufficient. NNIN staff remains available, however, to provide support as necessary.

Accommodating large numbers of new users arriving weekly and training them to operate safely and creatively in a shared-facility environment is the most critical aspect of network operation. With a high level of training and process support delivered by a dedicated professional staff, complex technologies such as e-beam lithography and complex multi-step integrated processing procedures can be made available to a large user community in an efficient and timely manner. At the same time, new techniques and processes, developed either by the staff or by the user community, can be efficiently and effectively made available for the mutual benefit of all users, at the site and across the network.

3.0 Activities Overview for 2008

Two thousand eight continued as an active year for NNIN. In addition to continuation of existing facilities and programs, NNIN established a number of new programs and activities, and significantly expanded its building and equipment infrastructure.

3.1 New Facilities

New laboratories at Harvard and the University of Michigan were dedicated and occupied during 2008. These are just two of the seven major facilities built or under construction at NNIN sites since 2004. In total, these seven entirely new facilities (Cornell, UCSB, prior; Harvard, Michigan, 2008; GTech, PSU, Stanford, under construction) represent an investment by the universities and state governments of almost 1 billion dollars. The affiliation with NNIN is a powerful driving force that helps universities and state governments justify these expenditures, and the critical mass of users enabled by NNIN is a key factor in the business model that makes these facilities affordable. While these expenditures are obviously made to enhance the local university's capabilities and stature, NNIN and its users receive enormous benefit from this significant investment in infrastructure.

3.2 New Equipment

Two thousand eight was a particularly active year for the acquisition of new process and characterization equipment in the network. The NNIN facilities house over one thousand major pieces of nanotechnology equipment, with a replacement value of hundreds of millions of dollars. (A searchable database of available NNIN tools is located on the NNIN web site). This does not count the cost of the supporting infrastructure (gas cabinets, gas detectors, etc). This equipment has been collected, installed, and characterized over many years: some of it is brand new in 2008 and some of it is over 20 years old. As the user base expands, and as the state of the art advances, NNIN sites must make expansion and renewal of the capital equipment base a priority. This is not an easy task, as the depreciation on the tool set far exceeds any available funding sources. NNIN sites, however, have a variety of mechanisms available which help them maintain a competitive tool set.

A list of some of the tools added to NNIN facilities during 2008 is given in table 1.

Table 1: NNIN Equipment Additions in 2008	
Kurt Lesker ITO Sputter Deposition System	Cornell
Oxford FlexAl plasma assisted ALD	Cornell
Yield Engineering (YES) single wafer resist strip system	Cornell
Suss SB8e Wafer Bonder	Cornell
Nanonex NX-2500 Nanoimprint Lithography system	Cornell
Custom Reynolds Tech Cluster Tool for Vapor Phase Polymerization of Organic Conductors	Cornell
Agilent Series 5500 Atomic Force Microscope	Stanford
EV 620 contact printer	Stanford
Laurell self-contained spray rinse cleaner	Stanford
Vertical tube wash system	Stanford
Ontrak DSS 200 post-cmp clean track	Stanford
ASML 5500/60 stepper	Stanford
First Nano graphene growth system	Georgia Tech
STS Pegasus inductively coupled plasma etching tool	Georgia Tech
Oxford ICP system	Georgia Tech
Plasma-Therm dual chamber RIE/PECVD system	Georgia Tech
Toray flip chip bonder	Georgia Tech
Suss Microsystems SB-8 wafer bonder	Georgia Tech
Rame-Hart Contact angle goniometer	Georgia Tech
Q-Sense quartz crystal microbalance	Georgia Tech
Dage-Group, Inc placed a XD7600NT X-ray tomography	Georgia Tech
Nikon infrared microscope	Georgia Tech
Parylene deposition system SCS PDS 2035 CR	Michigan
Veeco® NanoMan V AFM	Michigan
Tempress 6" High-Temperature Furnaces for LPCVD and	Michigan

atmospheric processes (19 process tubes total).	
STS Pegasus DRIE	Michigan
Biacore Surface Plasmon Resonance (SPR)	Washington
Nanonex Nanoimprinter	Washington
Oxford Plasmalab 100 Reactive Ion Etchers (RIE) (x2)	Washington
Oxford OpAL Atomic Layer Deposition system.	Washington
Applied Materials DPS system	Penn State
GCA 8000 *i*-line Step-and-Repeat Optical Lithography System:	Penn State
OAI DUV Flood Exposure System:	Penn State
Cambridge Savannah 200 Atomic Layer Deposition System	Penn State
AMAT 5000 PECVD System	Penn State
Kurt Lesker Lab 18 Evaporator	Penn State
Kurt Lesker CMS-18 Sputter Tool:	Penn State
Panasonic E620R&D ICP etching system	UCSB
Six target RF/DC AJA sputtering tool	UCSB
Nanonex B200 Nanoimprint system	Minnesota
NanoSight LM10 system	Minnesota
Hysitron PicoIndentor	Minnesota
Zeiss Neon 40 SEM w/ Elphy Quantum Pattern Generator from Raith	Texas
Ion Assisted E-Beam Evaporator from CHA Industries	Texas
VeecoDektak150 Stylus Profilometer	Texas
Veeco Atomic Force Microscope (AFM) with Scanning Capacitance	Texas
Denton load-locked quick pump e-beam evaporator	Harvard
STS ICP etcher for Si/SiO2/SiNx	Harvard
Fujikura fiber splicer	Harvard
Lakeshore cryo (1.5K) microwave probe station	Harvard
Zeiss Orion Helium microscope	Harvard
Wet process hoods (x6) and resist spin/develop hoods (x6)	Harvard
CNS Savannah Atomic Layer Deposition system	Harvard
Finetech Fineplacer Lambda manual sub-micron flip-chip bonder	Harvard
Olympus TIRF Microscope	Harvard
Two multi-tube Tystar Tytan systems furnace systems	Harvard
Omniprobe AutoProbe™ 300 nanomanipulator subsystems	Harvard
X-Tek MicroCT 3-D X-ray imaging system	Harvard
Trion Minilock Phantom II RIE ICP With Load Lock	Howard
Chemical Spray Pyrolysis System	Howard
Electron Spin Resonance for the NanoExpress	Howard
Hall Effect Measurement System (80°K-580°K)	Howard
Blackbody with Chopper CI Systems Inc SR20	Howard
Bruker Optics Model: Tensor 27 FTIR	Howard
Stanford Research Systems Dynamic Signal Analyzer	Howard

Details can be found in the individual site reports. Evaluated conservatively, these 65 major instruments are valued at over 16 million dollars. Very little of this equipment, however, was purchased with NNIN NSF funds.

Major equipment can be acquired by donation, purchase of used or refurbished equipment, or purchase of new equipment from the vendor. In addition to NSF NNIN funds, funding for such purchases can come from state and university sources, from other individual PI grants, or from other center grants. Four of the above instruments were purchased via special NSF (e.g. MRI) equipment awards. To a small extent, user fees can be used to provide small capital items, but these are generally not a primary source of equipment funding. In general the high visibility of NNIN facilities and the critical mass of quality users provide powerful leverage for significant discounts or donation of equipment. Similarly, the NNIN and the baseline NSF funding provide significant leverage to enable the investment of funds from other state, industry, and university sources.

Many of these acquisitions are opportunistic—the right combination of available funds from other sources, available user and faculty interest, and desirable instrumentation available by discount or donation. In some cases, the expertise of NNIN staff is valued by vendors, resulting in cooperative development agreements with favorable terms. Since very little of the equipment acquisition funds come from NNIN, central planning of equipment acquisitions is generally extremely difficult and, in many cases, counter-productive. NNIN, however, periodically surveys equipment needs through internal processes. The site-based process nonetheless works generally and, as demonstrated in Table 1, has been effective in providing expanded state-of-the-art resources to NNIN users across the country.

3.3 New Programs

The NNIN cooperative agreement gives NNIN flexibility to allocate resources to support new programs in areas of critical need and in response to learning from ongoing programs. Ideas for new programs can come from individual sites or from NNIN management. These new activities can be funded either from site funds or from reallocation of central network management/activities funds. In some cases, programs can start at an individual site with limited size and funding, and, if successful, later expand to multiple sites with alternative funding mechanisms.

During 2008, the following new programs were established, with funding from NNIN budget, or in the case of iREU, with supplemental NSF program funding:

- **iREU: international Research Experience for Undergraduates;** a summer research program at a National Laboratory in Japan (NIMS) and Germany (Jülich), building upon the NNIN REU program. Eight students undertook a successful international research experience under close supervision of a senior scientist, not only expanding their technical horizons but, equally as importantly, providing them early career practical experience operating as globally aware researchers. The ability to embrace the international aspects of nanotechnology research will be increasingly critical in the 21st century. These students will be well prepared for these challenges.
- **iREG: international Research Experience for Graduates;** As part of the partnership with NIMS for the hosting of our iREU students, 5 Japanese graduate students were hosted at NNIN laboratories for a summer research experience. Penn State, Harvard, U.Texas, and UCSB participated in this program. The costs of the travel, housing, and stipend for the participating students are borne entirely by NIMS.
- **iWSG: international Winter School for Graduate Students**; a technical and global awareness activity as part of both the NNIN education program and the NNIN SEI program. Twelve students and seven faculty traveled to IIT Kanpur, India for a course on Organic electronics and Optoelectronics, a course taught jointly by US faculty and IIT faculty and involving more than 25 IIT graduate students in lab, and nearly a hundred

attending the lectures. A key part of the school was a second week in a rural village in India, exploring the interface of technology to the social conditions of the 3rd world. This was a significant cultural awareness experience for both the US and Indian participants.

Each of these three programs had the additional effect of establishing important relations between NNIN and major research international research institutions.

- **LEF: NNIN Laboratory Experience for Faculty Program;** a summer REU-like program for minority faculty or faculty at minority serving institutions. Five faculty from 4 institutions participated in this new program, performing research at the Cornell, U.Texas, and Georgia Tech sites. The goals here are to 1) help establish viable research program involving minority faculty, and 2) provide nanotechnology experiences which can be incorporated into their classroom environment. Both of these are designed to improve the diversity of the nanotechnology user pipeline.

These programs will all be repeated and, in some cases, expanded in 2009

3.4 Expanded Continuing Programs

During 2008, the following existing NNIN programs were expanded significantly:

- **Workshops and Conferences:** NNIN provides a variety of workshops and conferences to both its user community and the broader nanotechnology community. These range from hands-on laboratory based short courses to workshops and symposia exploring the frontiers on nanotechnology. Major workshops and conferences in 2008 included, among others,
    - **Innovations in Nanotechnology for Cancer Research Symposium**: in conjunction with the National Cancer Institute, at Cornell University, Sept 26, 2008
    - **Nanotechnology as an Enabler for Neuroscience, Neuroengineering, and Neural Prosthetic Systems**: at Stanford University, December 11-12, 2008, Stanford University
    - **Commercialization of Nanotechnology**: Workshop at Cornell University, April 10, 2008
    - **Nanotechnology as an Enabler for Ocean Observatories**: A NNIN-OCEAN SCIENCE-UW Center for Nanotechnology Workshop April 18-19, 2008
    - **Technology and Characterization at the Nanoscale** (TCN): a lecture and laboratory short course at Cornell University, January and June 2008.
    - **Kavli Symposium on Computing Challenges**: Cornell University Oct 12-14, 2008
- **Nanotechnology Showcase for Students:** The NNIN Nanotechnology Showcase was started in late 2007 and expanded into full swing in 2008. This is a pipeline event to increase awareness of nanotechnology opportunities among under-represented undergraduates. An introduction to nanotechnology, complete with demonstrations, is provided at prominent undergraduate engineering conferences. Two events were held in 2008, both involving the Society of Hispanic Professional Engineers.

- **Nanooze, the Magazine:** After several years as a web-only resource, Nanooze, the NNIN science magazine for children, made its print debut in Dec. 2007. During 2008, three major issues of this 8 page color magazine were printed and distributed to schools across the country, with a print run of 50,000 copies per issue. Nanooze is one of the few nanotechnology resources available at a level appropriate for use in elementary and middle school classes.

Details of these accomplishments as well as other activities are given in subsequent sections of this report, and in some cases in the individual site reports in Appendix 3.

3.5 Network Restructuring and Renewal

At the beginning of the 5th year, our affiliate node at the Triangle Lithography Center at North Carolina State University left the network. NCSU had been an unfunded affiliate of NNIN through the first 4 years, specifically for the role of providing access to advanced deep UV (193 nm) photolithography technology and for the assessment of the need of this approach by the broader user community. There turned out to be very limited demand for this technology within the user base. With the NNIN decision not to add funding to the site, NCSU chose to withdraw from the network.

The most significant event of 2008 was the renewal proposal and its subsequent review. As part of the proposal and renewal process, NNIN conducted an extensive evaluation of its sites and their niche within the network. As a result of this analysis, one site (University of New Mexico) was dropped from the network and three new sites, at Arizona State, the University of Colorado, and Washington University at St. Louis, were added to the network, beginning in year 6 (March 2009). The new sites augment the network's technical expertise in significant new areas and provide additional geographical diversity. As a result of the proposal and subsequent review, the NNIN cooperative agreement was extended until February 2014 at a level of $17.0 M per year. This renewal and additional funding allow NNIN to continue to serve the growing nanotechnology community, building upon its prior success while instituting important new programs.

Additional details of this renewal are contained in Section 8.

4.0 NNIN User Major Research Accomplishments

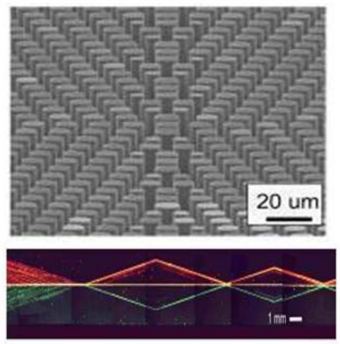
Serving users remains the primary mission of NNIN; this mission receives approximately 80% of the NSF/NNIN funds, as well as essentially 100% of the user fees generated.

The success of NNIN's research infrastructure efforts are ultimately shown by the research results of its users, by their publications and patents, and by the contracts won and products developed. Digesting the research output of almost 5000 individuals each year is a daunting task. Even collecting publications is challenging as it demands response from users and because of the delay between the research and the publications. None the less we have collected over 2700 citations to publications and presentations from the period July 2007 - June 2008 resulting from work of NNIN users. These are included as an appendix in this report. We expect that due to collection efficiency the number of outside user publications is significantly undercounted.

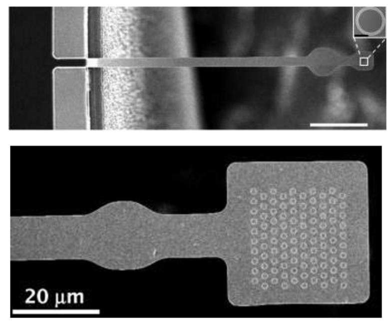
Research highlights have been collected from each NNIN site, a total of more than one hundred sixty examples of NNIN impact. These are included in Appendix to this report and have been previously submitted to NSF. Because of issues related to the release of intellectual property, the examples are more heavily weighted toward academic projects than our industrial projects. A few examples of outstanding research enabled by NNIN are shown in Figure 6.

Figure 6

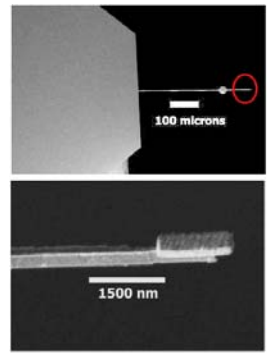
a)



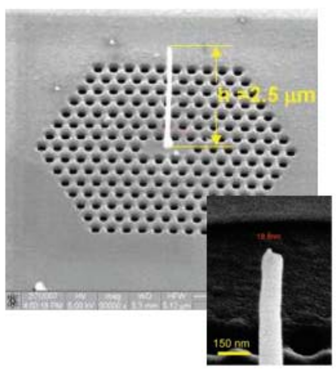
b)



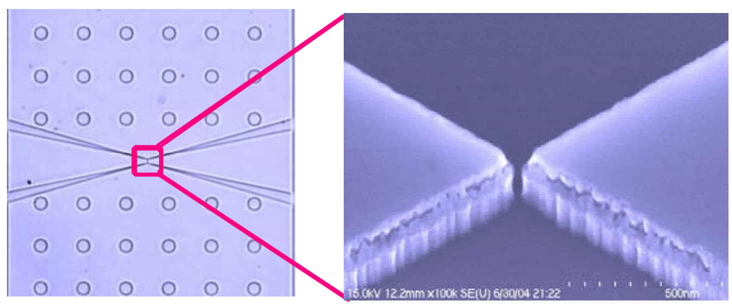
c)



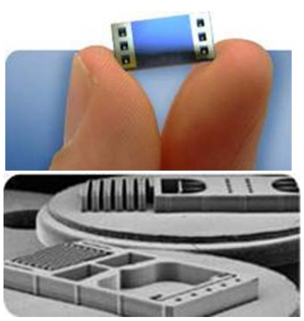
d)



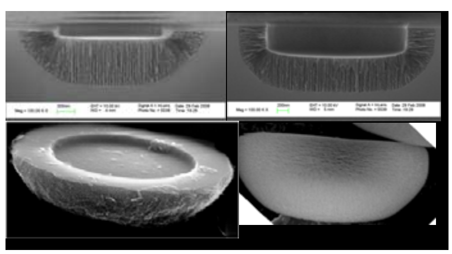
e)



f)



g)



h)

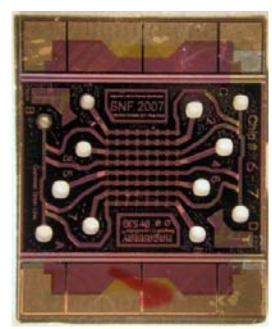


Figure 6.

a) Hydrodynamic Metamaterils; Nanofabricated Arrays to Steer, Refract, and Focus Streams of Biofluids; Robert Austin, Princeton; Work performed at Cornell

b) Cantilevers with Integrated Mesoscopic Samples; Jack Harris, Yale; Work performed at Cornell.

c) Ultrasensitive Magnet-tipped Cantilevers for Magnetic Resonance Force Microscopy; John Marohn, Cornell; Work performed at Cornell

d) Hybrid Plasmonic-Photonic Nanodevice for detection of a Few Molecules; E. Di Fabrizoion, Trieste, Work performed at Minnesota.

e) Nanoscale Molecular Traps for DNA and Protein Preconcentration; C.F.Chao, ASU; Work performed at Stanford.

f) Silicon Microvalve; Microstag,Inc.; Work performed at U.Texas Austin.

g) Nanoporous Silicon Microparticles for Drug Delivers; M.Ferrari, Alliance for NanoHealth; Work performed at UT Austin

h) Magneto-Nano Biochip for Cancer Diagnosis; X. Wang, Stanford, University, Work performed at Stanford.

5.0 Education and Human Resources

5.1 Objectives and Program Challenges

In completing its fifth year of operation, the NNIN Education and Outreach (NNIN E&O) program continues to offer numerous activities at the local, network, and national level. The graphs below demonstrate how the program has grown and continues to maintain a high level of activity since we began collecting data on events in 2005. Figure 7 demonstrates that we have reached our capacity in the number of events offered across the network sites, while the number of participants continues to increase.

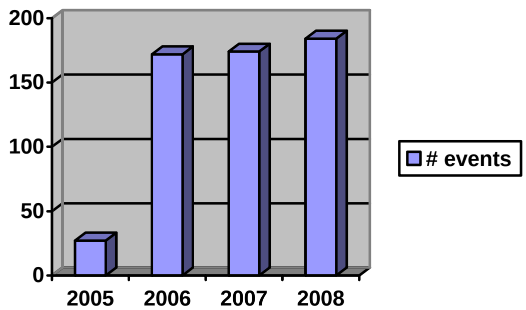


Figure 7.A

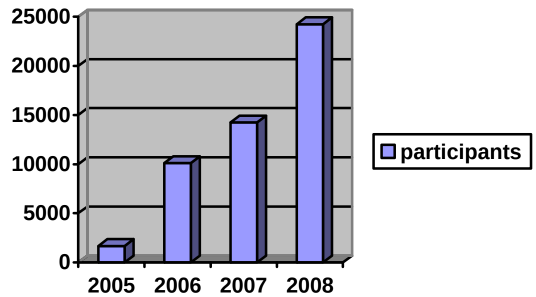


Figure 7.B

To set the framework of our activities, it is important to provide an understanding of our goals and objectives. 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. NNIN has established the following goals for its network-based educational outreach and training:

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

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

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

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

This report provides updates on 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 directly reached more than 24,000 individuals during the past twelve months.

To attain each of the NNIN's education objectives, a variety of innovative activities has been defined, developed, and implemented. NNIN E&O components include network-wide programs to address needs at the national scale and more specific efforts for communities that are local to network sites. Table 2 illustrates the type of programs offered by NNIN and the scope across the network. The various facets of the NNIN E&O program are reviewed in following sections of this report.

Table 2. Local and National NNIN education activities and programs

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

5.2 Coordination and Collaboration

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

The education site coordinators meet one to two times per year at one of the NNIN sites for a minimum of two days. The NNIN E&O program has reached a point where sharing of ideas, approaches, and materials is a regular practice among the sites and often occurs outside our scheduled meetings. During the past year, the coordinators met at Georgia Tech February 27-29, 2008 and October 29-30, 2008. Coordinators also meet informally at various professional meetings/conferences and the REU convocation.

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, the impact in terms of numbers served, etc. In 2006, we launched the Education Events Manager (EEM), an online tool for sites to register their educational activities. All sites are required to regularly update the system by posting their events and activities. Tracking of events is done by Georgia Tech and Cornell which can monitor entries and use the system to generate reports.

5.3 Activities and Programs

5.3.1 NNIN REU Program and RET Programs

NNIN REU Program

The NNIN has developed, operated, and managed a highly successful Research Experience for Undergraduates (REU) Program in nanotechnology since 1987 (begun under NNUN). This program is a highly coordinated network activity which has 70-80 students participating each summer across 12 NNIN sites. In 2008, 25 students were supported by funding from the NSF REU program. Additional funds from the NNIN management budget were allocated to sites to assure a minimum of 5 students were hosted at each of the 12 sites. Additional students were supported by industrial (Intel) funds to make a total of 73 NNIN REU interns.

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

The NNIN REU draws top quality participants from a diverse applicant pool. Due to the size and visibility of our program, we have been successful in recruiting a large number of women, minorities, and students from non-research institutions (non-doctoral granting). Our program remains a popular choice among students with 553 applications received in 2008. We have been committed to providing research opportunities to students who have the most to gain from the NNIN REU experience—67% of the 2005, 53% of the 2006, and 75% of the 2007, and 69% of the 2008 participants had no prior summer research experience. Table 3 shows the demographic make-up of applicants, participants, and their type of home institution for 2006, 2007, and 2008. Women and minorities are well represented in the applicant pool but **more importantly** at an even higher level of participation.

Table 3. Demographics of NNIN REU applicants and participants 2006-2008.															
	Applicants			**Applicant Pool (%)**			**Participants**			**Application Success Rate**			**Participation (%)**		
	'06	**'07**	**'08**	**'06**	**'07**	**'08**	**'06**	**'07**	**'08**	**'06**	**'07**	**'08**	**'06**	**'07**	**'08**
Overall	354	403	553				64	70	72	18%	17%	13%			
Gender															
Women	97	134	194	27%	33%	35%	28	24	36	29%	18%	19%	44%	34%	49%
Men	257	269	359	73%	77%	65%	36	46	37	14%	17%	10%	56%	66%	51%
Race/Ethnicity*															
Minorities	68	57	93	19%	14%	17%	15	21	26	22%	37%	28%	23%	33%	37%
Non-Minorities	259	346	399	73%	86%	72%	45	43	45	17%	12%	11%	77%	67%	63%
Institution Type															
Ph.D. Level	231	258	376	65%	64%	68%	39	43	50	17%	17%	13%	61%	61%	68%
Master's Level	71	72	81	20%	18%	15%	12	13	12	17%	18%	15%	19%	19%	16%
Bacc. Level	40	60	94	12%	15%	17%	11	11	11	28%	18%	12%	17%	16%	15%
Assoc. Level	12	13	2	3%	3%	.04%	2	3	0	17%	23%	0%	3%	4%	0%

* Race/Ethnicity is only for students who reported this information; in 2008, 61 did not report;

**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.

The NNIN REU program culminates with the NNIN REU Convocation which is a "mini" scientific conference attended by all site coordinators and REU interns. The 2008 convocation was held August 9-13, 2008 at Cornell University (fig. 8). 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. To complete the program, all students write a research report that is published as the *NNIN REU Research Accomplishments*. The archived webcasts and the *Accomplishments* are online at www.nnin.org/nnin_reu.html.

Fig. 8: REU Participants at Convocation at Cornell.

Each year we contract with an external evaluator to assess the impact of the REU convocation and provide feedback on the overall program. Dr. Lawrence Josbeno, Department of Physics at Corning Community College served as the evaluator for 2008. His report indicates that "The presentations were the high point of the convocation. They demonstrated a promethium depth of understanding of their subject matter, and were informative, entertaining, motivating, and exciting. In short, they were outstanding. In each case, the presentation was extremely professional."

The NNIN REU program has continued in the Assessing Student's Learning Outcomes during Summer Undergraduate Research Experiences using the National Engineering Students' Learning Outcomes Survey. This study is being conducted by Dr. Olga Pierrakos of James Madison University. Her results indicate high learning gains of participants in 1) operating in the unknown (open-ended problems), 2) formulating the need and relevance of a problem/project, 3) applying experimental engineering/scientific tools, 4) conveying ideas verbally and in formal presentation, 5) recognizing contemporary engineering and scientific issues, 6) recognizing the need to consult an expert from a discipline other than their own when working on a project, and 7) designing an experiment. "Overall participants of the NNIN REU highly valued their research experience, which aided in validating graduate school aspirations for most and highly consider a Ph.D. as well."

"Thank you, this program was one of the best things I have ever done. My life, professionally and personally, has benefited greatly from the entire experience." Tom Hartsfield, Stanford REU

"This whole thing was a fantastic experience - it's hard to put into words the fun I had working hard and playing hard at UCSB. I am now strongly motivated to pursue graduate study there. The other interns, grad students, and PIs were really great to be around and have fun with -- I wish I could do it all over again. Thank you." David J. Christle, UCSB REU

"Thank you so much for giving me the opportunity to work with the people I worked with over the summer. It was an unforgettable and extremely valuable experience!" Andrew U. Abreu, Howard REU

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). Table 4 highlights the technical components of our 2008 program (Likert scale of 1-5 with 5 being the highest rating):

Table 4. NNIN REU Participant post-program survey

NNIN Post Survey 2008				
Question	**Avg.**			**Avg.**
Did the program offer you a substantial independent research project with a strong intellectual focus?	4.40		How well did the program provide you with an understanding of the graduate research life?	4.46
Were you able to execute the research project using the available equipment and facilities?	4.31		How well did the program provide you with an understanding of careers in nanotechnology?	3.90
Did you consider your project a "good" project- interesting, right scale, right complexity, etc.	4.46		Did the program assist you in making future educational & career choices?	4.27
Were you reasonably able to complete the project?	3.99		How likely is it that you will choose a career in nanotechnology?	3.85
Were you satisfied with how much you were able to complete, given the time constraints?	3.86		How likely is it that you will go to graduate school in science/engineering?	4.57
Did you receive significant scientific interaction with the faculty member/ senior staff in charge of your project?	4.23		Did the program assist you in developing presentation and writing skills?	4.30
Were you included in group meetings and seminars?	4.52		Was the Convocation a worthwhile experience?	4.11
Did the program provide you with experience that allowed you to see the breadth of	4.31		Would you recommend the program to a friend?	4.73

nanotechnology applications?				
How well did the program assist you in learning to use advanced equipment and processes in nanotechnology?	4.28		How likely is it that when you return to your home campus that you will share your experiences with fellow students and faculty?	4.52
How well did the program assist you in understanding the scientific basis of nanotechnology equipment & processes?	4.01		How do you rate the overall quality of the program?	4.59
			Did you think that your experience with the program was positive. Would you do it again?	4.61

Since its inception in 1997, the NNIN REU program has had over 600 participants. As noted above, the program began under the NNUN and expanded to twelve sites with the inception of the NNIN. The NNIN REU is a long-term investment in human resource development. The plans of those students who choose to go on to a research career plays out five to ten years after participation. Because of the long history of our REU program and its large number of participants, NNIN is uniquely situated to gather some fundamental data on the effect of REU programs on career choices. In 2006, we began a longitudinal study to determine the educational and career path of interns who participated in the 1997- 2003 period of the program.

We have chosen the 1997-2003 time period because participants will have graduated from their home institutions and will have entered or completed additional education and/or entered into the workforce. This study is a labor intensive analysis as participants have moved, changed names, and even home addresses are no longer valid due to family moves. However, of the 300 participants during this period, we have contacted 175 to complete the online survey. We are continuing this study and believe the highly positive results are not only of importance for the NNIN program but also for other undergraduate research programs in general. The results were presented at the 2008 meeting of the American Society for Engineering Education and published in the proceedings (http://soa.asee.org/paper/conference/paper-view.cfm?id=9506). Academic and career results are shown in Table 5. The results have remained consistent as the number of responses has increased.

Table 5 Academic/Career Paths	
NNIN REU Longitudinal Study	
Degree/Career	1997-2003
Doctorate	46%
Master's	30%
Baccalaureate	14%
J.D./MBA	5%
M.D.	5%
Science Career	95%
Nano (broadly defined)	48%

iREU (International Research Experience for Undergraduates)

Each summer, NNIN provides and introductory research experience for approximately 70 students. The training and experience these students receive is excellent and they are highly sought by employers, graduate schools, and other internship programs. While they almost all perform well, from out direct observation over the summer, it is clear that 15-25% of them are exceptional students and have exceptionally bright career prospects.

In 2007, we established additional programs within NNIN to further the nanotechnology experience of these exceptional individuals. We sought and received supplemental funding from the NSF International Research Experience for Students program (IRES) and the NSF International Research Experience in Engineering program (IREE) to establish a 2nd summer international research experience for the previous year's outstanding NNIN REU participants. This program is called the iREU, for international REU. NNIN established this program because we believe that globally aware scientists and engineers should be a priority in the 21st century. This program is only open to our prior year REU students – we are effectively using our REU program as a "filter" to select only the very best students for this enhanced research experience. We have two partners for this international program: the National Institute of Materials Science (NIMS) in Japan and the Forshungsentrum Jülich (FZJ) (a Helmholz Research Institute) in Germany who hosted 5 and 3 students, respectively in summer 2008.

The students spent between 11 and 12 weeks (site dependent) at the international labs. NNIN provided the stipend, travel, housing, and a food allowance. This program provided an excellent career growth opportunity for the participants. iREU interns have indicated that their prior NNIN REU experience allowed them to meet the challenges of a more advanced project, work in a different research environment, and live and work with colleagues from another culture. The participants indicated that they would be willing to pursue other international programs in their future education and career paths. The iREU also established important international linkages for the NNIN. Our arrangement with NIMS, for example, includes the reciprocal hosting of five graduate students from NIMS into NNIN facilities (at no cost to NNIN). NIMS graduate students spent 6-8 weeks at Pennsylvania State University (2), University of California Santa Barbara, University of Texas, and Harvard University.

In addition, NNIN placed two of its former REU students into the SURF undergraduate research program at NIST.

NNIN RET Program

Five sites participate in an NSF-funded Research Experience for Teachers (RET) Program which began in March 2006. Georgia Tech (lead), Harvard, Howard, Penn State, and UCSB hosted the teachers. The program is completing its final year of funding in spring 2009. The NNIN RET program has had a 3-year total of 60 diverse participants: 33 females (55%), 27 males (45%) and 42% from underrepresented populations. NNIN sites leveraged the RET award (45 participants) with NNIN funds to support additional participants each year for a total of 15 additional RET participants over the three years. We achieved our goal of having teachers from minority populations. We have also been highly successful in having teachers who teach at schools with high-minority populations—71% of the schools have a high percentage of underrepresented populations.

Each RET participant completes a pre- and post- survey based on one developed by the RET Network. The survey was modified to reflect specific questions regarding nanoscale science and engineering. Results from **some** of our survey questions are in Table 6. These reflect some of the results that address the issues of whether the program provided a research experience, had an impact on teaching, and was an overall positive experience.

Table 6. NNIN RET post-survey results			
Examples of Post-Survey Results (Likert scale 1–4)	**2006**	**2007**	**2008**
Program was responsive to professional development needs	**3.9**	**3.6**	**3.4**
Program provided opportunities to engage in inquiry/research activities that I will adapt for classroom use	**3.8**	**3.4**	**3.8**
I designed/implemented my own research/ investigation under supervision of a mentor	**2.8**	**2.8**	**3.0**
I collaborated in ongoing research with site staff	**3.2**	**3.6**	**3.3**

I operated instruments, equipment, & other technologies	3.5	3.4	3.4
Program increased interest in research & ways that STEM can be applied.	3.8	3.6	3.7
Program stimulated thinking about ways to improve my teaching.	3.7	3.2	3.5
Program increased my interest/ability in networking with teachers & other professionals	3.6	3.6	3.8
Program increased my motivation to seek out other experimental professional development activities	3.6	3.8	n/a
I believe I will be a more effective teacher.	3.4	3.0	2.8
Mentor's knowledge of roles & responsibilities of teachers in STEM	3.6	3.3	3.5
Mentor's interest in helping you develop a plan to improve education in STEM	3.6	3.6	3.8
Do you think it is important to include nanotechnology in the science curriculum?	4.0	4.0	3.9
As a professional development program, how do you rate the NNIN RET program? *	4.5	3.6	3.9
Would you recommend the NNIN RET program to your colleagues?	4.0	4.0	3.7
Likert scale 1= not at all; 2= small extent; 3= moderate extent; 4= great extent *Likert scale 1-5 this question only			

The results indicate that teachers were actively engaged in research, were stimulated to improve their teaching, and that nanotechnology should be included in the science classroom. An overwhelming majority of participants indicated that they learned about nano-education, learned about materials and resources for use in the classroom, learned about professional development opportunities, and learned how to include nano in their classroom. The project mentors showed that they had an understanding of teacher roles and responsibilities and wanted to help the teachers in improving education. Interviews with teachers followed up on the lower response rating for the "more effective teacher" question. RETs indicated that they believe they were already quite effective in their classroom and the program just supported their efforts in effective classroom practices. Similar responses occurred for the "improving teaching" question.

During the school year, each site supports the teachers in their classroom to help introduce nanotechnology into their courses. The program culminates at the National Science Teachers Association (NSTA) annual meeting. All of the sites meet for a half-day session (NNIN REU Share-a-Thon) where materials are shared and critiqued. Teachers interact with their fellow NNIN RETs which builds a sense of community. Each participant develops instructional units for their classrooms, which are then reviewed and field tested before placement on the NNIN education portal (http://www.education.nnin.org).

The University of Washington supported two RET participants in a larger RET program offered by the MRSEC at UW (Genetically Engineered Materials Science and Engineering Center). This program engages teachers in a two week program that includes a week long workshop that results in the development of teaching modules during the second week.

5.3.2 Development of Materials for Education and Training

NNIN has as one of its goals providing education and outreach for K-gray individuals. We have developed materials suitable for use with elementary grade students through adult professionals (teachers, industry and government personnel, etc.). The underlying philosophy that guides the development of our K-12 instructional materials is that they should support the teaching of currently taught science concepts and meet the National Science Education Standards (NSES) and/or a site's state science standards. Teachers we have worked with indicate that nano-focused education materials must connect to required concepts (state standards) taught in the science classroom. A pre-survey of participants in Georgia Tech workshops indicates that teachers teach "facts," cover the district's curriculum, and prepare students for standardized tests.

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, magnetism, among others.

The NNIN RET program has been important in the development of materials suitable for students in middle and high school. Units developed by our RETs undergo review, refinement, and field testing before posting on the education portal for use in other classrooms.

Stanford, in collaboration with Mid-continent Research for Education and Learning (McREL) and Aspen Associates, has developed two high school curriculum modules that address nanoscale science and national standards. The program is also funded by an NUE award to McREL. *NanoLeap* consists of two modules: one for physical science and one for chemistry (http://www.mcrel.org/nanoleap). NNIN actively recruited teachers to be part of the second year of field testing which occurred during the 2007-08 school year. As part of the *NanoLeap* program, Stanford has developed the use of NNIN remote access tools and capabilities for use with the units. The idea is to bring students into the nanofabs through the web, for a live and interactive experience, and to include and make real many of the concepts in the *NanoLeap* modules. An example of a remote tour of Georgia Tech's cleanroom can be viewed at: http://www.mcrel.org/nanoleap/remote_access/cleanroom.asp. An outgrowth of NNIN's collaboration with McREL has been the recently funded NSF-supported project NanoTeach. This 5 year, professional development program will develop a combination of face-to-face and online professional development experiences for high school science teachers who teach physical science topics. Georgia Teach and Stanford are partners in the program and NNIN sites will be involved in the latter part of the project by recruiting teacher participants and offering support for the developed materials.

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 is geared towards upper undergraduate and beginning graduate student level courses. The majority of the chapters have been completed and posted on the web. Table 7 provides a list of the chapters and the status of each. The NNIN Open Textbook can be viewed at http://www.nano.unm.edu/nnin_opentext/

Table 7. Open Textbook Status

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

5.3.3 Education Workshops

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

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

Georgia Tech offers a variety of workshops ranging from half to all day workshops on including nanotechnology in science classrooms. All of the instructional materials are tied to Georgia Performance Standards to ensure that teachers are using standards-based units. Workshops have also been presented at the annual meetings of the Georgia Science Teachers Association and the South Carolina Science Council. Georgia Tech has reached at least one teacher from 54 of Georgia’s 159 counties.

The University of Michigan offers a one day workshop for middle and high school teachers and community college faculty. The participants are introduced to education modules through hands-on activities and lectures. The University of Washington provides its RETs with a weeklong workshop focused on bio-nanotechnology. The focus of the workshop is to introduce middle and high school teachers to bionanotechnology and molecular biomimetics, and foster creation of classroom materials to engage their students in these fields.

The University of New Mexico provides teacher workshops one of which is in conjunction with a middle school summer camp. The later immersed teachers and middle school students in nanoscience from a variety of perspectives, had teachers evaluate and improve 30 nanoscience activities, and provided teachers with supplies, materials, activities, and other resources for classroom use. Other professional development workshops have focused on introducing secondary teachers to nanoscience research at UNM, providing an experience in the lab, and providing teachers with lesson plans and materials to take back to their classrooms.

In September 2008, NSF funded the Mid-Continent Research for Education and Learning’s (McREL) NanoTeach project. Stanford, Georgia Tech, and University of Colorado Boulder are the university partners for this professional development program. Since its inception, the NNIN sites at Stanford and Georgia Tech have been involved in the development of the initial professional development workshop that will occur in July 2009.

5.3.4 Other K-12 outreach

Numerous outreach activities have occurred in 2008 which include K-12 field trips to facilities, visits to schools, summer/weekend camps, workshops, and demonstrations. In order to provide these activities, the NNIN sites have developed hands-on activities, demonstrations, and presentations on nanotechnology. These resources have been posted or are being compiled for inclusion on our website. We also adopt and adapt activities developed by other centers and programs such as University of Wisconsin-Madison MRSEC & NSEC, Nanosense (SRI), NBTC (Cornell), among others.

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

- UCSB "Chip Camps" provided hands-on nanofabrication to students from area high schools.
- Georgia Tech's *Nanotechnology Explorations* camp for high school students and *Explore Nanotechnology* for GT's Women in Engineering middle school girls camp
- Penn State's *NanoCamps* hosted 8 groups during summer 2008 and reached over 165 students.
- U. of Minnesota and Dakota Technical College offer NanoScience Class for High School Students.
- University of Washington provides one week of nanotechnology activities as part of a four week summer science program for underrepresented minorities – *Science for Success.*
- University of New Mexico provides a combination teacher workshop (two weeks) and middle school student summer camp (three weeks) in collaboration with Albuquerque Academy, Sandia National Laboratories, and NM MESAAISES.

In addition, several sites provide on-site activities for visiting school groups. These typically involve hands-on activities, demonstrations, lab tours, and cleanroom tours. Most include discussions on career and educational opportunities to encourage students to consider careers in STEM and in particular nanotechnology. Sites are also involved in career days at schools, family science nights, and science fairs. The University of Michigan judged local science fairs and provided awards for the best experiment in nanotechnology. Besides receiving a plaque for the achievement, the students were special guests for a day at the MNF. Cornell, University of North Carolina, Howard University, and University of New Mexico hosted NanoDays using materials supplied by NISENet. Howard University visited the US Capitol with the NanoExpress (see below for full description) for its NanoDays activity.

5.3.5 Community Outreach

NanoExpress

Howard University launched the NanoExpress in summer 2006. This is a mobile laboratory which presents the world of nanotechnology to the general public from K-Gray (fig. 9). The NanoExpress is a mobile van with 208 square feet of lab space designed to facilitate hands-on experiments but also capable of doing nanotechnology research. Experimental areas include: Introduction to Passive Nanoparticles, Introduction to Self Assembly, Introduction to Micro and Nanofabrication, "Chips are for Kids", Instruments for NanoScience, Shape Memory Alloys, and

Soft Lithography. Undergraduate, graduate lab assistants, and RETs help supervise experiments. The NanoExpress has visited D.C. area schools, the FDA, US Patent and Trademark Office, George Washington University, and Exxon Summer Camp.

Fig. 9 Nanoexpress

Nanooze

Nanooze is the NNIN children's science web magazine. Nanooze was developed at Cornell University and led by Prof. Carl Batt. The target group for Nanooze is grades 3 through 8 and it is written at a level and style appropriate for this age group. Since 2005, Nanooze has been available on the web at http://www.nanooze.org. Nanooze is organized into four main sections: a primer, original articles, Web blog on interesting science topics in the news, and interviews with scientists and engineers. The original articles address interesting topics in nanotechnology, often taken from current events. Interactive science learning games are also available. An Editorial Board of teachers and a testing group of children advise the developers on matters of content. Nanooze is also available in Spanish and Portuguese on the web.

In late 2007, Nanooze became available in print as an 8 page full color newsletter (Fig. 10). Production and distribution went into full swing in 2008, with the production of 4 issues with a print run of 50,000 per issue. Nanooze, the print edition is distributed through direct mail, through workshops and activities at NNIN sites and through major educational conferences, including NNIN's exhibit booths at NSTA, Georgia Science Teachers Association and South Carolina Science Council. Nine thousand copies, for example, were distributed at the national conference of the National Science Teachers Association, where NNIN has traditionally been the only nanotechnology focused exhibitor. Classroom packs of 30 (or more) are mailed out to teachers on request at no cost to the teachers. Individual copies are not mailed due to excessive distribution costs. In addition to distribution to hundreds of classrooms by individual request and "subscription", we have arranged for large scale distribution to all middle schools within two large school districts; Detroit, Michigan and Clayton County, Georgia. In total, about 120,000 copies of Nanooze were distributed in 2008.

Fig. 10 : Covers of Nanooze, the magazine

A major theme in Nanooze this year was Nanotechnology with respect to the Five Senses. This content maps well onto the middle school curriculum in every state. In addition to articles on the web site, three issues of Nanooze (print) edition were devoted to the 5 Senses.

Other Community Outreach

Community and open house activities are also part of the efforts of the NNIN education and outreach programs. For example, the University of New Mexico had nanotechnology booths (with demos) at the New Mexico State Fair's "Celebra la Ciencia" Day, Native American Day, and Pathways to College Day. They also supported Celebra la Ciencia at the Atomic Museum and Balloon Explorium.

NNIN has also reached out to professional organizations by developing symposia for national meetings. The NNIN Georgia Tech staff co-chaired with NISENet, NCLT, and the European Commission a special symposium titled - *The Role of Lifelong Education in Nanoscience and Engineering.* NNIN participated in the Spring 2008 MRS Education Outreach Showcase by providing a tabletop demonstration for attendees during the evening poster session. NNIN had its fourth annual exhibit booth at the NSTA conference. We are the only nano-education exhibit at the NSTA and we will have our booth at the New Orleans conference in March 2009. We also had exhibit booths and workshops at the Georgia Science Teachers Association and the South Carolina Science Council.

5.3.6 Technical Workshops

The NNIN is committed to workforce development 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. A variety of multimedia is also available on the website including talks, symposia, short courses, and equipment training - http://www.nnin.org/nnin_multimedia.html. Individual sites also offer online training materials which are downloadable. Many of these video demonstrations and lectures are downloaded by individuals worldwide for use in classrooms and training activities.

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.

The University of Minnesota provided several workshops during the past year. Some of the topics addressed include BioMems and microfluidics, aerosol and particle measurement, and synthetic biomaterials and biointerfaces. The University of Michigan presented a one day workshop on X-ray Energy Dispersive Spectrometry with the EDAX Genesis System.

In April 2008, UW-NNIN organized a workshop entitled “Nanotechnology as an Enabler for Ocean Sciences” that brought together 30 participants with expertise in integrated microsystems design, sensor design, nanotechnology, and in the chemical, biological and physical aspects of marine and aquatic sciences. The objectives of the workshop were: (i) to build bridges and promote collaborations between nanotechnologist and oceanographers; (ii) to focus and energize research in underwater sensing technologies made possible by recent advances in micro- and nanotechnology; (iii) to identify limitations in current technologies and critical needs for underwater observatories; (iv) to determine how the NNIN can leverage its tools, user base and staff expertise to enable underwater observation; and (iv), to identify priorities for funding agencies. A report detailing findings and recommendations was released in Fall 2008 and is available at https://depts.washington.edu/ntuf/outreach/workshop4-08.php

Georgia Tech has developed *NanoFans* (**Nano** **F**ocusing on **A**dvanced **N**anoBio **S**ystems) a twice yearly forum to connect the medical/life sciences/biology and nanotechnology communities. *NanoFans* seeks to reach out to researchers in the biomedical/life sciences areas to inform them about what nanotechnology can offer them in the advancement of their research. The second series in the program was offered in October, 2008 and was attended by 83 individuals representing medical, technical, federal, and university communities.

Fig. 11: NNIN iWSG participants

5.3.7 iWSG

NNIN has developed the International Winter School for Graduate Students. The first of these two week programs was held in December 8-18, 2008 at Indian Institute of Technology in Kanpur, India. The topic for the winter school was Organic Electronics and Optoelectronics and 19 US faculty and graduate students participated along with 30 Indian colleagues (fig. 11). The winter school is a combination of course/lab experience taught by US and Indian faculty in conjunction with a field trip to rural areas to see how the workshop topic will improve the lives of the world's poor. The iWSG is thus part of both the NNIN Education effort as well as the NNIN SEI effort.

"The field trip to Paralakeumundi has lots of importance to me. I came from a village which is surrounded by both tribal and non tribal villages. So there are lots of problems which I know, but I never pay attention to them. After the trip, I feel that I will pay attention to solve them as far as I can do." *Arup Rath, Indian graduate student*

Applications were accepted on an open basis, nationwide, and 12 students were accepted; 3 from Cornell, 2 from University of Washington, 1 from U. Mass Amherst, 1 from MIT, 3 from Harvard, 1 from the University of Texas, and 1 from Northwestern.

"…the time spent at AID, JITM, and the villages made me acutely aware of the possibilities for socioeconomic development in rural India. Group discussions about the challenges and opportunities to raise the standard of living in rural India demonstrated that the Indian students are deeply aware and that gave me a lot of hope." *Tricia Bell, University of Washington.*

The iWSG was conceived as an effort to merge technical education with an investigation of the social context of science and technology in the third world. In addition to the 12 US graduate students and 6 technical faculty, two NNIN faculty members with expertise in the social sciences accompanies the group: Prof. Robert McGinn of Stanford and Prof. Jameson Wetmore of Arizona State. The entire course was structured to provide ample opportunity for interaction between the US and Indian students, and appreciation of the surrounding society. After the 6 day technical course in Kanpur, the group ventured on a 1000 mile train trip to the rural village of Paralakamundi in south Orrissa and to a neighboring tribal village (Fig.12). This was an eye-opening experience both for the US students as well as for many of the Indian participants.

Fig. 12: Lunch at the AID facility in Paralakeumundi.

Students (US and Indian) completed an evaluation instrument for the event and the results are presented in Table 8.

Table 8. Evaluation results for iWSG	
To what extent did this event:	**Average**
Introduce you to theoretical techniques	3.95
Introduce/discuss transport & injection phenomena	4.35
Introduce/discuss chemical synthesis techniques	3.36
Introduce/discuss self assembly	3.00
Discuss organic light emission devices	4.45
Discuss thin film transistors	4.17
Discuss photovoltaic devices	4.00
Discuss sensor and displays	4.02
Discuss fabrication of devices	3.70
Provide effective forum to discuss critical technical issues	3.90
Discuss Indian context of organic devices	3.41
Allow you to identify/perceive the world context of technology	3.95
Allow you to think and discuss about ethics in scientific research	4.05

Likert scale 1= not at all; 2= not significantly; 3= somewhat; 4= significantly; 5= great extent

The comments section of the survey form indicated that students were extremely positive about the workshop and the field trip. Students indicated that they enjoyed the interaction between US and Indian students and faculty, the linking of science and society, seeing a foreign university (US students), learning about the life of the majority of Indians (US students), and addressing ethical issues of science (Indian students). In terms of improving the workshop, the primary recommendations were laboratory fabrication rather than simulations, pre-trip cultural information (US students), and more time to interact with colleagues.

5.3.8 Diversity Related Activities

A primary focus of NNIN E&O is inclusion of underrepresented populations and 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.

NNIN REU and RET

Our REU program places a special emphasis on providing research opportunities for women and minorities. Specifically, the program requirements indicate, “Sites are encouraged to select applicants who are female, minority members, or from non-research institutions.” The REU program has quantifiable benchmarks regarding participants which include 50% women participants, 20% from underrepresented minorities, 50% from schools with no Ph.D. program in science and engineering, and 50% from outside the 100 largest research universities. The results reported in the REU section of this report demonstrate that women and minorities have a higher participation rate in our program in comparison to the applicant pool and that in 2008 we nearly reached our goal of 50% female participation in the REU program (49% in 2008).

The NNIN RET program recruits teachers who are themselves from underrepresented groups or teach at schools with a high percentage of underrepresented students or low socio-economic status. Since inception in 2006, there have been 60 RETs - 33 females (55%), 27 males (45%)

and 42% from underrepresented populations. Our RET program has been very successful in including teachers who teach at schools with high-minority populations—71% of RET schools have a high percentage of underrepresented populations.

Individual sites make every effort to ensure participation by underrepresented groups in the K-12 programs. With our new data management system, gender and ethnicity is being tracked for all activities (when possible). Sites that are located in diverse areas of the country have the best opportunities for recruiting underrepresented participants to the events. However, all sites make an effort for reaching out to diverse populations. University of Michigan and the University of New Mexico exhibited at the regional NSBE conference and the Celebra la Ciencia and Native American Days at the New Mexico Sate Fair, respectively. The University of Michigan and Harvard University represented the NNIN at our exhibit booth at the October 2008 HBCU-Up meeting in Atlanta.

Nanotechnology Showcase for Students

NNIN has developed the *Showcase for Students* which is an all day workshop on nanotechnology with morning lectures and activities and demonstrations in the afternoon. The focus is on undergraduate students who attend conferences sponsored by underrepresented professional science and engineering organizations. NNIN held two workshops in 2008; February 2008 at the Hispanic Eastern Technical Career Institute and November 2008 at the Society of Hispanic Professional Engineers (SHPE) Annual Conference (Fig. 13) . We reached approximately 500 students at these two events. The afternoon demonstration session is particularly well-received by attendees and they have indicated that they enjoy learning about nanotechnology but also interacting with NNIN researchers and staff who support the technical/demonstration session. At the SHPE conference, we also participated in the one day career fair as a recruitment activity for our REU program. Our next Showcase is scheduled for the National Society of Black Engineers convention in March 2009.

Fig. 13 Demonstration of SEM at Nanotechnology Showcase.

Laboratory Experience for Faculty

In 2008, NNIN introduced a new program, the NNIN Lab Experience for Faculty. The program focuses on supporting underrepresented faculty or faculty from minority serving institutions to perform research at one of our facilities. In some cases, the participants may become NNIN users in the future; in others, they will relate their experience to their students. Either way, NNIN has an impact on participation of underrepresented populations in nanotechnology. Five awards of $12,000 each were made to Georgia Tech, Cornell, and the University of Texas. Faculty spent 8-10 weeks in the summer of 2008 undertaking their own research project in nanotechnology. Table 9 summarizes the LEF participants.

Table 9. NNIN 2008 LEF participants			
Faculty	Home Institution	NNIN Site	Project
Prof. Jean-Marie Dimandza	Spelman	Georgia Tech	Microfluidic Device for Gas Chromatography
Prof. Nelson Sepulveda	Univ. Puerto Rico	Cornell	Energy disipation in nanocrystaline diamond and Vanadium oxide nanomechanical resonators
Prof. Abdenaceur Karoui	Shaw University	Cornell	Nanosensors
Prof. Stella Quinones	U. Texas El Paso	University of Texas	Epitaxial growth of CdTe
Prof. David Zubia	U. Texas El Paso	University of Texas	Nanopatterning of CdTe/CdS Solar Cells to Increase Efficiency

5.4 NNIN Education Web Portal

Figure 14: 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 14). Events and activities and information that would be of appeal to a wide audience are presented on the front page. Additional information and events are sorted into separate sections for the main audiences: K-12, teachers, undergraduates, graduates and professionals and public. The site is a repository of all the training materials, lesson plans, and activities developed by NNIN sites that have been found useful. In addition, content generated outside NNIN may be distributed by mutual agreement. The site features a custom back-end tool for managing content on a rotating basis. In addition to network content, the site contains summaries of educational activity at each site.

5.5 Evaluation of Programs and Activities

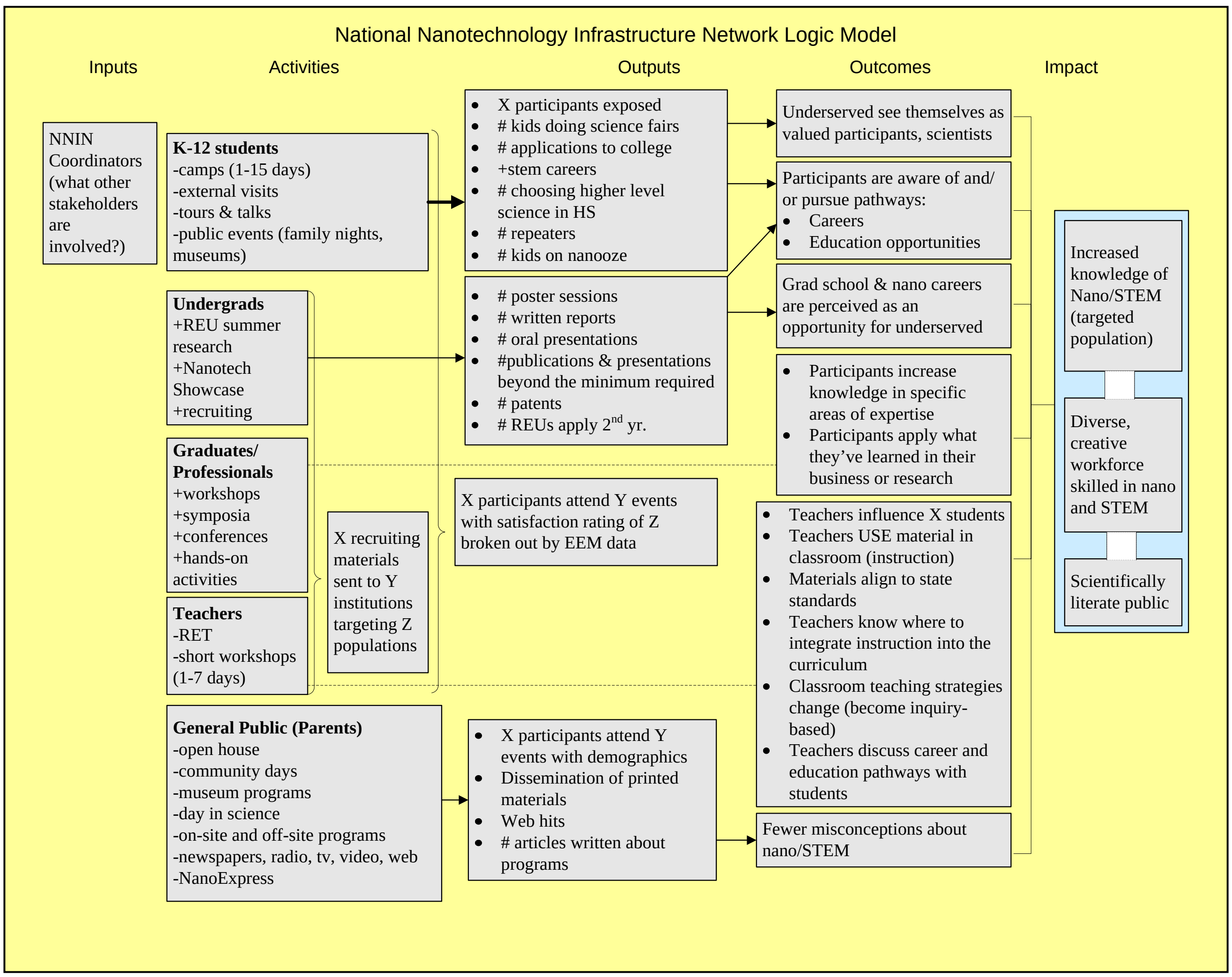
NNIN has a variety of evaluation instruments for its major programs that include the REU, RET, workshops, and camps. Results from some of these surveys have been presented throughout the E&O report. At the February 2008 NNIN Education Coordinators meeting, we had a consultant (Tom McKlin, The Findings Group) provide a one day workshop on assessment and evaluation. From this workshop, we have developed a logic model and evaluation plan for NNIN education and outreach.

At the October 2008 NNIN Education Coordinators meeting, we spent a half day reviewing logic model and evaluation plan we developed during the February 2008 coordinators meeting. Our work focused on specific programs and developed knowledge, attitudes, and behaviors that we expect for these programs. We discussed what learning goals we have for various activities and shared ideas of how we can assess these. From this information, we are currently developing evaluation instruments for the nanofabrication camps offered at UCSB and the University of Michigan. It is also our plan that once these instruments are developed we can adapt them for use with other outreach programs focused on middle and high school students.

5.5.1 Logic Model

Logic models are the standard framework for structuring the evaluation of a program. The logic model for a program or set of programs enumerates the inputs, activities, outputs, outcomes, and impact, and their relationship to each other. It is a necessary starting point for any serious program evaluation. Below is the logic model and evaluation plan that has been developed for NNIN education and outreach (Fig. 15).

Figure 15: NNIN Education Logic Model



5.5.2 NNIN Evaluation Questions:

Based on the above program logic model, the following evaluation questions emerge:

1. How many participants attended what events and past events? Provide information by EEM categories for the following stakeholder groups:
   a. K-12 students
   b. Undergrads
   c. Graduates/Professionals
   d. Teachers
   e. Public
2. What recruiting and other material was disseminated? Where was it disseminated? What populations were targeted? Include how many have visited the website(s).
3. To what extent do participants perceive that Nano/STEM pathways are available to them?
   a. K-12 students
   b. Undergrads
   c. Graduates/Professionals
4. To what extent do participants choose pathways in Nano/STEM education and careers? Track among:
   a. K-12 students
   b. Undergrads
   c. Graduates/Professionals
5. To what extent do participants demonstrate increased content knowledge in Nano/STEM. Possible demonstration avenues include performance on Nanoquiz, course taking patterns, and business applications.

5.5.3 Methods and Plans:

Each of the above evaluation questions may be answered as follows:

Question 1: How many participants attended what events?

	Types of Data Collected	***Methods for Collecting Data***	***Analysis***
# K-12 Students	Simple counts of participants	EEM	Count of participants by event by all EEM categories
# Undergraduates			
# Graduates/Professionals			
# Teachers			
# General Public (Parents)			

Question 2: What recruiting and other material was disseminated? Where was it disseminated? What populations were targeted?

	Types of Data Collected	***Methods for Collecting Data***	***Analysis***
Available Recruiting Material	Count of brochures, web pages, postcards, & rulers. generated and	Print orders (Nancy & Lynn do most print orders)	Count

	available for distribution		
Delivered Recruiting Material	Count of distributed material	Available material at event start – available material at event end	
Locations targeted for recruiting material	Count of distributed material by location		
Populations targeted for recruiting material	Count of distributed material by target population		
Effect of recruiting material	Feedback form self report	Feedback form item asking how participants found out about this event	Descriptive statistics and analysis of open-ended responses

Question 3: To what extent do participants perceive that Nano/STEM pathways are available to them?			
	Types of Data Collected	*Methods for Collecting Data*	*Analysis*
Participant perceptions of available pathways	Self-reported, perception data collected at each event (possibly pre/post)	Participant feedback form	Descriptive statistics and qualitative analysis of emergent themes (disaggregated by target population, race/ethnicity, and gender)
	Self-reported, perception data collected months after each event	Participant survey	

Question 4: To what extent do participants choose Nano/STEM education and careers?			
	Types of Data Collected	***Methods for Collecting Data***	***Analysis***
Nano/STEM course-taking patterns	High school, undergraduate, and graduate enrollment and retention data	Telephone contact with guidance counselors and registrars; possibly via state-maintained databases	Descriptive statistics

Question 5: To what extent do participants demonstrate increased content knowledge in Nano/STEM?			
	Types of Data Collected	***Methods for Collecting Data***	***Analysis***
Changes in content knowledge	Knowledge questionnaire	Nano quiz	Descriptive statistics
Best Practice Demonstrations	Reported business applications	Best Practices website or seminar	Number and quality of best practice documents

For 2009, NNIN management, the NNIN Education Coordinator, and the NNIN site education program staff will work on implementing this evaluation scheme and adapting it across the broad range of NNIN programs.

5.6 Program Summary

NNIN has and will continue to offer a variety of education and outreach activities at the local and national level. Table 10 below summarizes the major network wide programs

Table 10 Education Program Summary

Program	Participants	Purpose	Status
REU	Undergraduates	Research experience for a diverse population of undergraduates; introduction to nanotechnology research & careers	Upcoming 13th summer in 2009
iREU	Undergraduates – former NNIN REU participants	Develop globally aware scientists and engineers from the most successful REU participants	Upcoming 2nd summer in 2009
2REU	Undergraduates – former NNIN REU participants	Develop enhanced nanotechnology interest by placing superior students in national labs	2 Students from NNIN REU complete a 2nd summer experience at NIST through the SURF program
iREG	Graduate students from Japan (NIMS)	International outreach; reciprocity for iREU Japan; No cost to NNIN	Upcoming 2nd summer in 2009
RET	Middle and high school science teachers	Introduce teachers to nanotechnology and experimental design; develop nanotechnology classroom activities	Completed NSF funded program 4/1/09
LEF – Lab Experience for Faculty	Underrepresented faculty and/or faculty from minority serving institutions	Increase diversity in NNIN user base and in STEM/ nanotechnology pipeline	Upcoming 2nd summer in 2009
SFS – Nanotechnology Showcase for Students	Undergraduates	Expose diverse population of undergraduates to education and career opportunities in nanotechnology	Plan to offer twice per year – March 2009 at National Society Black Engineers
Nanooze	Upper elementary and middle school students	Stimulate and maintain interest in STEM at a young age	Classroom packs distributed in 2009; special editions on the five senses.
iWSG	Graduate students	Develop globally aware scientists and engineers; Provide technical workshops in nano to US and foreign students; Encourage international collaboration	First two week workshop held in Kanpur, India in December 2008.

6.0 Computation

6.1 Objectives

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.

6.2 Technical Scope

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

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

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

6.3 NNIN/C Activities

The principle activities of NNIN/C in the past year have taken place through the Harvard University and Cornell University sites. The separate reports of activities of those site is provided below. From the network-wide point of view, the major activity in the past year has involved a detailing of the most critical future areas where NNIN/C can make a considerable impact in the renewed phase of NNIN. During the review meeting in April-May 2008, we presented our perspectives on the future of high performance computing and the role that NNIN/C, with its traditional focus on helping high-end, state-of-the-art computational science research in a fully hands-on manner, could play. The summary reports from the Harvard and Cornell sites, followed by the proposed new initiatives are presented below.

6.3.1 Harvard University Computation Activities

During fiscal year 2008 the computation project of NNIN at Harvard University continued its support of individual users and collaborative projects and held two workshops dedicated to specialists in the particular areas of General Purpose Graphical Processing Units (GPGPUs) and Photosynthesis (with an emphasis on computational approaches). In addition the national program NNIN/C, directed from Harvard University by Michael Stopa, established a plan of activities for the second phase of NNIN that includes databases for pseudo-potentials and inter-atomic potentials, plans for a GPGPU computational cluster and increased integration with the computational program of the Network for Computational Nanotechnology (NCN) at Purdue University.

Hardware Resources and the GPU Cluster Purchase

The main computational hardware that NNIN maintains at Harvard University consists of the twin clusters of 28 nodes each of dual processor AMD Opterons. In addition, NNIN/C at Harvard maintains a set of four SUN large memory machines, also based on AMD architecture. A major expansion of these facilities is currently underway in collaboration with the "Cyber Discovery Institute," an NSF funded program recently awarded to researchers at Harvard University.

Graphical Processing Units (or GPUs) are dedicated graphics devices whose ancestors date to the 1980s and the graphical chips at the heart of Atari Game consoles and others. In order to render computer graphics, GPUs are optimized to perform various linear algebra functions, such as matrix multiplication with a high degree of parallelism. Recently it has been discovered that the highly parallel functionality of GPUs makes them potentially useful for accelerating various kinds of scientific calculation and simulation. The Harvard node of NNIN/C is currently in the process of purchasing a set of Nvidia Tesla S1070 computers with associated host CPUs. NNIN/C joined together with the NSF-funded Cyber Discovery Institute at Harvard University to propose an NVIDIA Center for Excellence in GPU Computing which has since been awarded (in January 2009). The principal research computer for the Center will consist of a cluster of S1070 GPUs obtained with support from Nvidia Corporation. NNIN/C is providing funds for a portion of that cluster, which will be accessible to the NNIN/C community.

Recent Software Acquisitions

Regarding software, in the past year NNIN/C installed the code "octopus," which is a first principles electronic structure code developed at the University of Basque.

Other acquisitions include "libatoms," a library of routines for running molecular dynamics simulations developed at the Naval Research Laboratory.

Workshops

In the past year, NNIN/C at Harvard sponsored two workshops on topics of special interest to the computational community. The first workshop, held at Harvard University Chemistry Department and the Laboratory for Integrated Science and Engineering (LISE) under the Center for Nanoscale Systems (CNS), was a two day symposium on GPGPU computation. The second workshop, also held in the Chemistry Department, was a one-day symposium on Photosynthesis – from Elementary Processes to Quantum Simulation, with special emphasis on energy transfer mechanisms and computational and modeling methods applied to large molecules such as chromophores.

Collaboration with other Agencies
Finally, in the past year, NNIN/C at Harvard continued its institutional relations with the Department of Energy's Sandia Laboratories and the Center for Integrated Nanotechnologies (CINT) by participating in a joint project on the computation of the electronic structure of silicon nanowires (collaboration with Normand Modine and Thomas Picraux of Sandia). Also, NNIN/C has participated in the Harvard University project on surface enhanced Raman spectroscopy, helping in the winning of a $1M grant from the Defense Advanced Research Projects Agency (DARPA).

During 2008, the NNIN computational branch at the Cornell Nanoscale Facility continued to help foster nanoscale research and education through direct consultation and access to a wide array of simulation tools on the CNF cluster.

6.3.2 Cornell University Computation Activities

Symposium on Computing Challenges, Oct. 12-14th, 2008
Nanotechnology offers the potential to develop gigantic arrays of 10 nm computing devices on a single chip. However, there are several potential problems that must be addressed before this computational power can be put into action. This symposium brought together experts in parallel algorithms, network structure, neuroscience, and approximate computing to address this challenge. This symposium was a joint project with the Kavli Institute at Cornell for Nanoscience which provided funding and support for the event.

http://www.research.cornell.edu/KIC/events/computing2008/

Publications 2008
10 research articles were published in 2008 based on work done on the CNF cluster. This brings the total number of publications to 26 since the cluster was brought online in Feb. 2005. The 2008 papers included articles published in *Physical Review Letters, Journal of the American Chemical Society, Nano Letters, and Journal of Physical Chemistry*. Research topics ranged from graphene nanostructures, quantum Monte Carlo simulations of m-benzyne, thermal transport in boron-nitride nanotubes, and molecular dynamic simulations of organic molecule thermolysis.

New Users for 2008
In addition to usage from several veteran users of the CNF cluster, 14 new users were granted accounts in 2008. During 2007, the CNF cluster was used during the CNF Fall Workshop and also as part of a computational materials science course. Several participants in these events have continued to do work on the CNF cluster as users. The new users included researchers from the University of Richmond, Shaw University, and Arizona State University. During the summer, two REU students (Garron Deshazer, Emory University & Eric Smith, Columbia University) used the CNF cluster for their research projects. Prof. Karoui Abdennaceur from Shaw University worked at Cornell on a NNIN Laboratory Experience for Faculty grant. During his stay, he made use of the CNF cluster to simulate carbon nanotubes in a processing environment.

Cluster Simulation Options
Five new software packages were added to the CNF computational resources available for users in 2008. With this addition of these new tools, CNF users now have access to over 20 different computational packages for topics including nanophotonics, fluidics, molecular dynamics, and electronic transport in nanostructures. The new software additions include an open source tight-

binding code (*Plato*) to simulate nanostructures, crystals, and molecules. The all electron full potential electronic structure code WIEN2K was also purchased in Spring 2008. This code provides one of the most rigorous platforms for density functional calculations and is often used as a standard to compare other approaches against.

Two codes developed at NNIN partner site, University of Texas, Austin, were also made available to users at the CNF. UT-Marlowe provides a software platform for Monte-Carlo simulations of ion-implantation. TOMCAT from UT Austin builds on the code UT-Marlowe code and provides Monte Carlo simulations for arbitrary 2-D surfaces.

An electronic transport density functional package (ATK-VNL) from Quantum Wise was purchased in 2008. This approach can provide information about how chemical bonding on nanotubes affect current flow or how defects affect doping in graphene nanostructures. Since a primary focus of nanoscale research is in developing the next generation of electronic devices, this tool provides an unique window in nanoscale electronic transport.

In addition, the computational branch at the CNF provides the only public access point for the UTQuant code which is used to calculate C-V characteristics for MOS structures. In 2008, this code was requested from researchers at institutions including Yale, George Mason, Micron Corp., IIT Kanpur, India, and Taiwan.

Code Development

Through a NSF grant, Derek Stewart has also been working to expand the simulation capabilities available at the Cornell Nanoscale Facility. With collaborators at Boston College and CEA-Grenoble, Derek has been working to develop a new *ab-initio* approach to model thermal transport in bulk materials and nanostructures. With this new approach, they have been able to accurately predict the thermal conductivity of bulk silicon, germanium, and diamond. They have also used this approach to explain a 50% enhancement in thermal conductivity of isotopically pure boron-nitride nanotubes. Work on this new approach is continuing with the long term goal of making this code publicly accessible to the research community.

6.4 New Initiatives and Changes – Plans for the Future of NNIN/C

NNIN/C's greatest impact has resulted from close consultation with NNIN/C research associates and direct access to a diverse library of nanoscale simulation packages for cutting-edge experiment and theory. The demand for such intensive collaboration, however, continues to outstrip resources. We believe that a carefully-planned, cost-effective expansion of computational capabilities will dramatically enhance the ability to leverage simulation in the NNIN program and, indeed, in nanoscience as a whole. The specific form which we envision for project advancement can be subdivided into: coverage, a virtual vault for computational nanoscience, information technology and high performance hardware.

6.4.1 Coverage

Users in the network sites and particularly those sites without a computational node remain insufficiently informed of their access to computational facilities and domain specialist support. Additional researchers from other sites can be included by providing a brief overview of the NNIN/C resources in standard introductory programs and materials at each site. To facilitate this we propose to set up a computational representative at all NNIN sites to provide, at a minimum, contact between interested researchers and the main computational nodes.

The existing computational node at Stanford will also be expanded with the addition of 512 cores with donated CPU and memory. A wide range of software packages will be installed and supported on the new server. One of the main focuses will be a comprehensive range of packages for first principles simulations. These encompass most of the major Ab Initio simulation packages widely used in chemistry, biology, and material sciences, including NWChem, VASP, ATK, COLUMBUS, GAMESS and CHAMP.

6.4.2 Virtual Vault for Computational Nanoscience

We propose the development of cyber resource that will provide information on crystal structures and components for calculations for nanoscience. By allowing researchers to work collaboratively to build trust in calculation components and crystal structure models, this resource to serve as an important nexus for nanscale simulation. For both of these endeavors, a key aspect will be vigilance in determining the accuracy of the information made available in order to gain trust from the community as a whole.

While numerous simulation packages are currently available for research, they often rely on specific components to describe the effects of atoms in their calculations. In particular, electronic structure calculations depend on pseudo-potentials which are vast in number and whose implementation is highly complex. Furthermore, for molecular dynamics simulations, the inter-atomic potentials in use range from simple phenomenological potential to complex tight binding models. Databases exists for these components, but there is no guarantee that these potentials will work for all situations. It is up to the end user to verify the robustness of these potentials for their calculations. This forces researchers to repeat a common set of calculations for standard systems to determine the veracity of these components. This time consuming process could be avoided by providing a virtual vault for computational nanoscience where crucial components such as verified before being made available for distribution. Several measures of the robustness of these potentials such as predicted lattice constant and bulk modulus would be listed. In addition, lists of publications where these components were used would be included as well as comments from active researchers.

A common issue for new researchers modeling nanostructures is the ability to proper envision the placement of atoms in their proposed structure. By providing a database of common crystal structures, crystal surfaces, and nanostructures (*i.e.* nanowires, nanotubes), we can help accelerate this initial phase of research. Researchers can upload input files that they have used in their research and also include relevant publications where these files have been used. By encouraging major publishers and funding agencies to push for full transparency in simulation work, we may have the ability to provide a robust library of crystals and nanostructures that would allow future researchers to expand rapidly on previous work.

6.4.3 Information Technology

Parallelization is essential to high performance computing. It's utility for nanoscience, with its large system sizes and realistic environments is clear. In some cases, the computational tasks can be easily divided among different nodes (*i.e.* embarrassingly parallel scenarios) and implementation should be fairly straightforward. However, in other cases, the distribution of large scale files and communication between nodes can make the transition to a parallel format a challenging computer science problem. In addition, the efficient utilization of multiple cores on the new generation of processors is a notable problem. We propose to incorporate a parallel unit in NNIN/C to provide parallel computing basics to our users and extend our consultation to the broader user community. New versions of codes developing during this process would be made openly available in order to have the greatest impact to the nanoscale simulation community.

In addition, we propose to employ students to help maintain the collection of simulation packages, conduct routine builds and aid users in apply parallel processing techniques to their codes.

6.4.4 HPC hardware

A surprising recent development in HPC is the recognition that video cards (GPUs), produced by game manufacturers, provide a dedicated and highly efficient means of performing thousands of numerical operations in parallel. The application of these cards to scientific computing has enormous promise but remains in its infancy. The cost of the hardware is minimal, indeed corporations such as Nvidia have shown a willingness to provide their hardware for little or no cost to scientific researchers thereby broadening the market for their commodities. The programming and application of these devices to quantum chemistry has recently begun at Harvard University. We propose to include these cards in the NNIN suite of hardware and explore their specific application to nanotechnology.

7.0 Societal and Ethical Issues in Nanotechnology

7.1 Introduction

The Societal and Ethical Issues (SEI) component of NNIN seeks to increase national capacity for exploring the social and ethical issues associated with nanotechnology. To accomplish this goal, the SEI component has developed an infrastructure for conducting research and disseminating information about SEI. That infrastructure serves both the NNIN and the broader community interested in nanotechnology.

The internal infrastructure 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. The output of these activities is then distributed via the SEI website, workshops, presentations, and ultimately traditional peer-reviewed publications.

Prof. Doug Kysar served as NNIN's SEI Coordinator in 2007-2008 and left Cornell in August 2008 for a faculty position at Yale University. In September 2008, Dr. Katherine McComas, an associate professor in the Department of Communication at Cornell, became the new SEI Coordinator. She was assisted September to December 2008 by Christopher Clarke, a doctoral student in the Department of Communication at Cornell. In December 2008, Dr. Debasmita Patra joined the Cornell team as a postdoctoral associate.

7.2 Network-Wide activities

7.2.1 SEI web portal

To increase its usefulness and visibility, the SEI web portal (http://sei.nnin.org/) is undergoing a major revision under the leadership of Debasmita Patra. In addition to retaining some of the original information, the site will now include current issues concerning several aspects of nanotechnology in society, such as risk, regulation, environmental issues, nanotoxicology, green nano, technoscience, and interdisciplinary research. Our intent is to make this a destination for researchers interested in SEI, as well as for the larger community of NNIN users.

7.2.2 Evaluation of the Use of SEI Training slides

In 2007, Doug Kysar and Anna Viseu, working in concert with David Guston of the Center for Nanotechnology in Society at Arizona State University, developed a set of SEI introductory training slides for use as part of the training of all new users at all NNIN sites. These slides are posted on the NNIN's home page, as well as on the SEI web portal. Starting in 2008, all NNIN sites were asked to incorporate the SEI slides into their NNIN training sessions.

In the Fall of 2008, Katherine McComas, with the assistance of Chris Clarke, conducted a follow up survey with program managers at 12 NNIN sites to determine (1) how coordinators at each of the sites design SEI training programs; (2) how they use the SEI training slides; and (3) general views about SEI training. The results found that most of the sites were using the slides and found them important and thought-provoking; however, several sites questioned whether the slides were adequately tailored to capture the audience's attention and interest. Some suggestions for increasing the value of the SEI training included making the information more personally relevant such as by the use of vignettes or stories by NNIN users who encountered SEI in their work. At this point, these results are being considered in relation to ways to improve SEI training at NNIN facilities to better meet NNIN and its users' needs. Additional research related to SEI training for NNIN users is planned in 2009 (see below).

7.2.1 NNIN iWSG-International winter school

The first NNIN International Winter School for Graduate Students was held in December at IIT in Kanpur, India. This activity, which is both part of the NNIN Education Program and the NNIN SEI Program, is described under the education section.

7.3 SEI Research

Four of the NNIN sites have specific (NNIN funded) resources allocated to SEI research and activities: Stanford, Georgia Tech, University of Washington, and Cornell. The SEI research and activities at these sites include:

- Ethical issues in nanotechnology as viewed by nanotechnology researchers;
- Technology transfer, intellectual property, and commercialization of nanotechnology;
- Workforce development issues related to nanotechnology;
- Trust and nanotechnology;
- Nano scientists' perceptions of SEI related to nanoscale science and engineering; and
- Nanotechnology and society—ecology, risk, and environmental law.

Research activities of these sites are described below. In addition, planning is underway for future research activities that will entail greater collaboration among the four sites, including:

- Improving SEI training for NNIN users;
- Increasing the use of the NNIN as a research pool among NNIN SEI researchers and other SEI researchers;
- Convening a face-to-face meeting of SEI coordinators in September 2009 at the inaugural meeting of the Society for New and Emerging Technologies (SNET) in Seattle, WA.

Further, plans are underway to use the Seattle (SNET) conference as a venue to meet and discuss networking issues with SEI directors and coordinators at Arizona State and UCSB in an effort to increase research collaborations and broader the visibility of SEI research.

7.3.1 Stanford University

Ethics and Nanotechnology: Views of Nanotechnology Researchers
Robert McGinn

Dr. Robert McGinn continues to conduct research and teach courses on ethical issues related to nanotechnology. In particular, he is continuing work on a ground-breaking survey of 1037 NNIN researchers at the 13 NNNIN sites, begun in 2005.

Dr. McGinn also expects to give a lecture on nanotechnology and ethics once again as part of the spring 2009 "What Is Nanotechnology?" course at Stanford University. Moreover, he is developing a new course entitled "Ethics and Nanotechnology." The intended audience is graduate students and new users of the Stanford Nanofabrication Facility.

Dr. McGinn also participated in NNIN's 2008 Winter School for graduate students in India.

Publications and presentations related to the research are listed below:

1. McGinn, R. (2008). Ethics and Nanotechnology: Views of Nanotechnology Researchers. *Nanoethics*, 2 (2), 101-131.

2. Tiwari, S. and McGinn, R. (2008). The Art of the Invisible: Achievements, Social Benefits, and Challenges of Nanotechnology in *Frontiers of Knowledge*, Fundacion BBVA: Madrid, 93-101.

7.3.2 Georgia Tech University

Technology Transfer and the Commercialization of Nanotechnology
Marie Thursby
Under the direction of Dr. Marie Thursby, Georgia Tech continues to pursue questions such as: What determines the ability of industrial firms to capitalize on technical developments in nanotechnology? Which firms and industries are successful in innovating at the nanoscale and how is success related to firm research focus, alliances and types of alliance partners? How does university research contribute to industrial innovation at the nanoscale? Dr. Thursby recently gave a presentation to the Technology Transfer Society at the State University of New York at Albany on the challenges and opportunities facing new Ph.D. graduates in the technology research and development field (specifically, those from engineering, management, business, and law programs).

Publications and presentations related to the research are listed below:

1. Tan, J., Jiang, L., & Thursby, M. (2008). The creation of emerging technologies by incumbent firms in established industries. *Working Paper*

7.3.3 University of Washington

Social and Ethical Issues in Nanotechnology
Prof. Susan Brainard
Under the direction of Susan Brainard, the SEI effort at the University of Washington is housed within the Center for Workforce Development (CWD). CWD conducts original research that addresses diversity within the global engineering and science workforce; establishes partnerships with industry, education and government; provides mentoring programs; assesses educational climates; and evaluates programs designed to increase the representation of diverse groups in science and engineering fields. Additionally, since 2004, CWD has added a research specialization in identifying and analyzing social and ethical issues posed by emerging science and technologies, with a particular emphasis on nanotechnologies. A specific research interest is scientists' perspectives on nanoscience and engineering (NSE), including

(1) Public health and nanotechnology perceptions

> This study surveyed 52 University of Washington faculty associated with either the Center for Nanotechnology or the Department of Occupational and Environmental Health Sciences in order to measure and evaluate differences between nanotechnologists/nanoscientists 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. (Study ended 2006).
>
> The results of this study mirrored previous findings including 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. Results of this study also confirm findings from preliminary interviews that there is a lack of definition for nanotechnology and that

researchers are reluctant to identify themselves primarily with nanotechnology or nanoscience.

(2) Scientific communication about social and ethical issues related to nanotechnologies

This research builds on the research in the ethnography of communication to identify how scientists and engineers talk about science, society, and ethics. The study is based on four years of fieldwork and in-depth interviews with 20 nanoscience faculty at the University of Washington Center for Nanotechnology. Specific notions about scientific responsibility, interdisciplinary collaboration, and communicating with other scientists and the public are examined. (Study ended in 2008).

(3) Inter-disciplinary communication

This research involves surveying and interviewing faculty and staff throughout the NNIN in order to identify best practices in interdisciplinary communication. (Study will begin in 2009).

(4) Nano-ethics education for graduate students

The CWD has received an Ethics in Engineering and Science Education grant from the National Science Foundation to address what prior CWD research has identified as a need for nano-ethics graduate education in science and engineering. The three-year project, Nano-ethics on the World Wide Web: Helping Faculty Enhance Graduate Education, will involve the development of a graduate seminar in nano-ethics to be piloted at the UW, distribution of nano-ethics educational resources online, and hosting an international symposium on nano-ethics together with the University of South Carolina’s first meeting of the Society for Nanoscience and Emerging Technologies (Sept. 8-11, 2009 in Seattle, Washington).

Publications and presentations related to the research are listed below:

1. Allen, E. & Bassett, D. (2008). Listen up! The need for public engagement in nanoscale science and technology. *Nanotechnology Law & Business*, 5 (4). 429-439.

7.3.4 Cornell University

Trust and Nanotechnology; Nano Scientists Perceptions of SEI
Katherine McComas and Debasmita Patra
Trust has been a growing concern in risk communication research for some time, as well as part of a much broader movement toward investigating this concept by disciplines across the social sciences. It also figures centrally in organizational justice research, as the perceived trustworthiness of authorities can influence perceptions of fairness. This work seeks to extend research on trust and organizational justice into the realm of new and emerging technologies. Research examines audience attitudes toward scientists engaging in nanotechnology, as well as scientists’ attitudes toward the public. With regard to the latter, McComas and Patra have independently conducted research examining scientists’ views of social and ethical issues related to nanotechnology. Publications and presentations related to the research are listed below:

1. McComas, K. A., Besley, J. C., Yang, Z. (2008). Risky business: Perceived behavior of local scientists and community support for their research. *Risk Analysis, 28*, 1539-1552.

2. Greiner, A., Black, L., McComas, K.A., Clarke, C. Scientists' understanding of nanotechnology, nanoscience, and the public. (2008, August) Paper presented at the AEJMC Annual Convention, Chicago, IL.
3. Patra, D., Haribabu, E., Basu, P.K. (2009). Nanoscience and Nanotechnology: Ethical, Legal, Social and Environmental (ELSE) Issues. *Current Science* (in press).
4. Patra, D. (2008, March). Nanoscience and technology in India: Where is the society? Invited talk at the National Workshop on "Science-Society Interface in Emerging Technologies", jointly organized by TERI and NISTADS, New Delhi.

Nanotechnology and Society

Ana Viseu and Doug Kysar, formerly Cornell

Until August 2008, the research effort at Cornell was overseen by Ana Viseu and Doug Kysar and was focused on risk assessments and understanding of regulations and regulatory mechanisms and development of approaches for the nanotechnology area. These questions have been explored and form part of a large group of public discussion set and framed in a broader societal framework. Presentations related to this subject are listed below:

1. Kysar, D. Conference Commentator, Harnessing the Power of Information for the Next Generation of Environmental Law, University of Texas-Austin School of Law, Austin, Texas, February 1-2, 2008
2. Kysar, D. *The Point of Precaution: Economics and the Forgetting of Environmental Law*, University of British Columbia Faculty of Law, Vancouver, British Columbia, January 28, 2008
3. Kysar, D. *The Point of Precaution: Economics and the Forgetting of Environmental Law*, University of California-Davis School of Law, Davis, California, January 17, 2008

8.0 Network Management

8.1 Network Management Structure

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 16: Network Management Structure

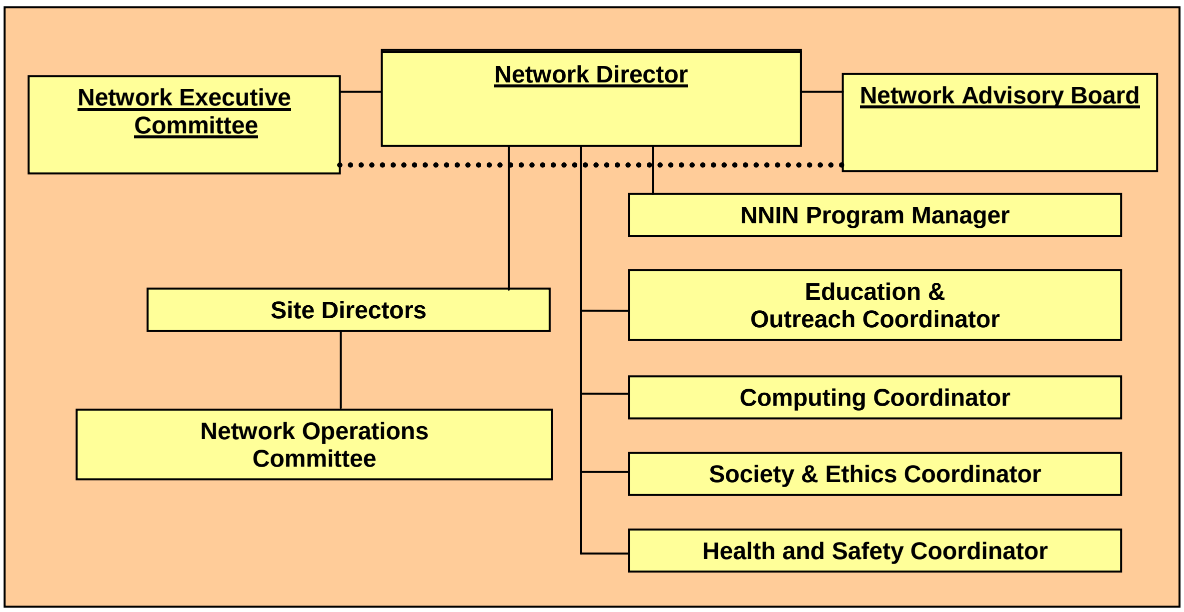


Figure 16 shows the broad outline of the organizational structure. Prof. Sandip Tiwari, Cornell University, the NNIN Network Director, is the point of contact with NSF, and is responsible for implementing the network policies and program. Dr. Lynn Rathbun, Cornell University, serves as the NNIN Program 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).

Starting in 2009, Dr. Dong Qin (Washington University in St. Louis) has agreed to be the NNIN Coordinator for Environment, Health and Safety

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 The NEC meets monthly by conference call, or more often, if necessary.

For 2008, the Network Executive Committee consisted of

- Dr. Sandip Tiwari
- Prof. George Malliaras
- Prof. Yoshio Nishi
- Prof. Thersa Mayer (expires 2010)
- Prof. Francois Mayer (term expires 2010)
- Prof. Sanjay Banerjee (term expires 2009)

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**; Entrepaneur and consultant
- **Dr. Tom Theis**; Director of Physical Sciences, IBM Research
- **Prof. Vivian Weil;** Director, Center for the Study of Ethics in the Professions, University of Illinois, Chicago

During 2008, Prof. Karen Wooley resigned from the Advisory Board. Also, during 2008, Prof. Vivian Weil was added, bringing new representation in the area of society and ethics.

Portions of the Advisory Board were present for the NNIN Review at Stanford in May 2008. They were consulted by phone and email by the NNIN Director at critical times during the proposal and renewal process.

8.2 Network and Site Funding-Year 5 (2008)

NNIN has been funded by a primary cooperative agreement between NSF and Cornell University. The NNIN sites participate as sub-awardees from Cornell University. For the first 5 years, this funding was at the level of $14M per year. Funding levels for NNIN sites for year 5 are given in table 11.

Table 11 NNIN Annual Funding by Site-year 5

Site	**Baseline Year 5 Funding**
Cornell	$2,500,000
Stanford	$2,500,000
Georgia Tech	$1,400,000
Michigan	$1,200,000
Penn State	$750,000
University of Washington	$650,000
UCSB	$925,000
Minnesota	$875,000
Texas	$650,000
Harvard	$750,000
New Mexico	$500,000
Howard	$500,000
NNIN Management and National Activities (NNIN office at Cornell)	$850,000
Total	**$14,000,000**

Additional supplemental fund transfers from management to the sites, for example for the REU, Laboratory Experience for Faculty program, or for the REU convocation are not shown.

8.3 Renewal and Renewal Funding 2009 (year 6)

As a result of the renewal proposal submitted by NNIN in Feb. 2008, and the subsequent review, the cooperative agreement for NNIN has been extended and funded at the level of $17.0 M for years 6-10. As part of the process, the University of New Mexico was dropped from the network, and three new sites were added; Arizona State University, the University of Colorado at Boulder, and Washington University in St. Louis.

Also as part of the renewal , funding for a considerable number of programs was consolidated in the management/activities budget at Cornell, under the direction of the NNIN Director. Some of these program were in the past funded by separate grants. Included in this new Network Activites Budget are funds for REU, iREU, iWSG, as well as other evolving programs. In some cases , these funds will be spend directly from the NNIN Activities budget; in other cases, they will be subawarded to sites on an annual basis as supplements to base funding. The budget also calls for the hiring of a Network Activities Director at the NNIN office to help plan and coordinate various network activities. The budget for the upcoming year is outlined in Table 12.

Table 12 NNIN Annual Funding by Site-year 6 – March 1, 2009-Feb. 28,2010	Yr 5 budget in current NNIN award	Year 6 baseline budget
Cornell	$2,500,000	$2,675,000
Stanford	$2.500,000	$2,675,000
Georgia Tech	$1,400,000	$1,590,000
Michigan	$1,200,000	$1,275,000
UCSB	$925,000	$875,000
Harvard	$750,000	$825,000
U. Minnesota	$875,000	$775,000
Penn State	$750,000	$750,000
U.Washington	$650,000	$725,000
U. Texas	$650,000	$700,000
Howard Univ.	$550,000	$550,000
Arizona State		$500,000
U. Colorado		$500,000
Wash. Univ. in St. Louis		$500,000
(New Mexico)	$500,000	$ 0
Network Coordination	$800,000	$372,855
Network Activities	included in above	$1,712,145
Total	$14,000,000	$17,000,000

Approximately $1.0M of the NNIN Activities amount is budgeted as participant support for various programs (REU, LEF, iWSG); much of that will be subawarded to sites on an annual basis.

9.0 Network Performance

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

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

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

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

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

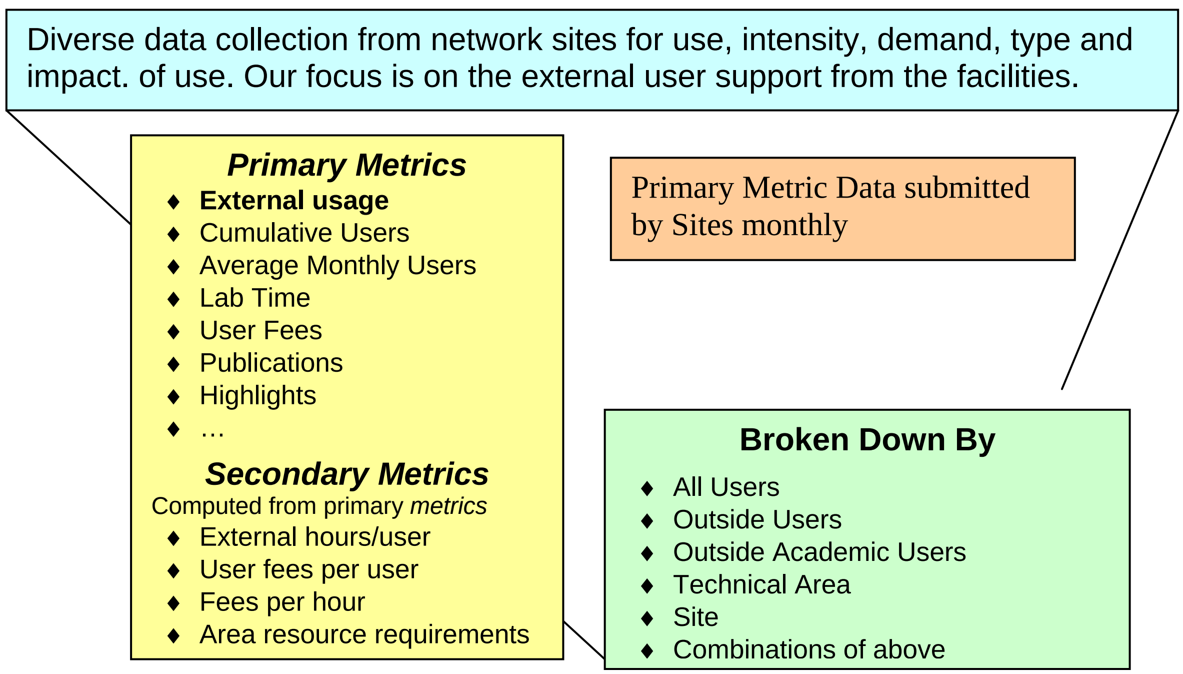
- The range and volume of service that each site can, now and in the near future, provide to outside research users in specific technical areas assigned to it;
- The infrastructure needs of the technical focus areas that are supported by each site;
- The infrastructure needs for the educational efforts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

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

A variety of metrics can be used to measure and characterize network performance. Figure 17 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 only. 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 17: Network information collection



No single “best” indicator

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

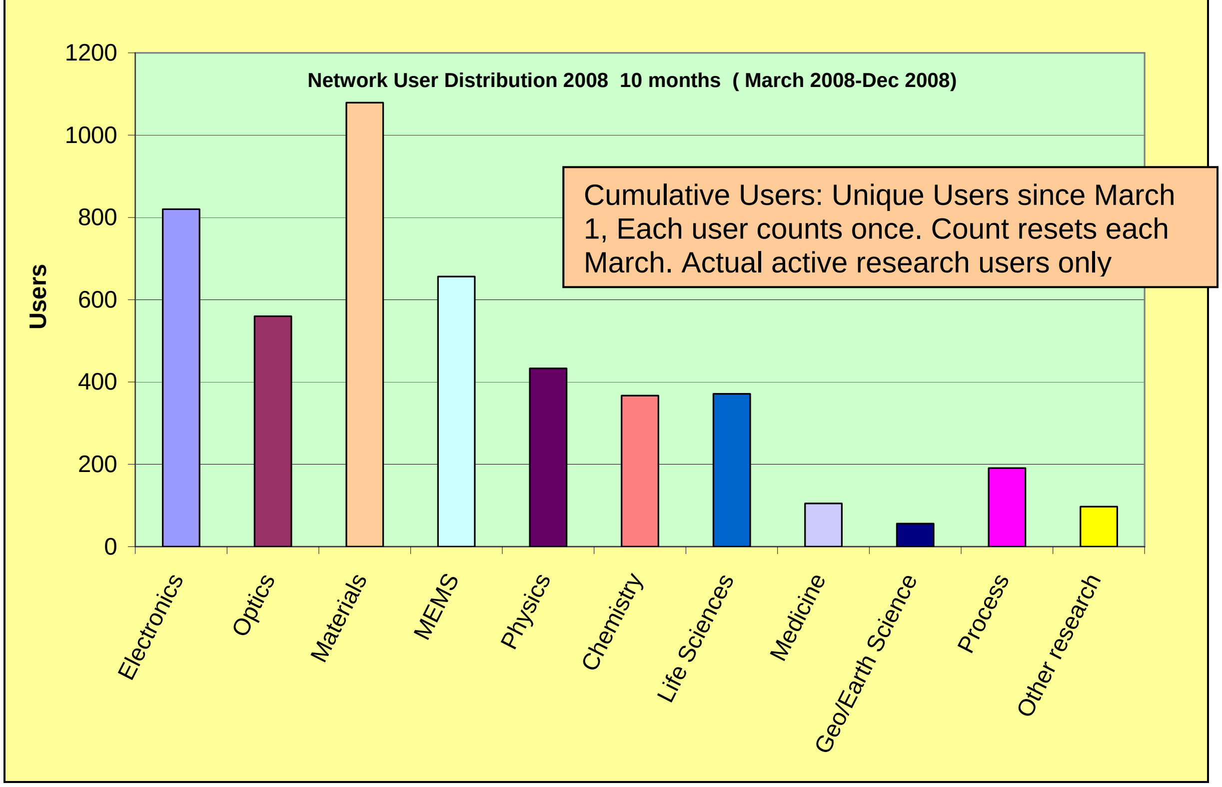
Unless otherwise noted, all data is for the 10 month period March 2008-Dec. 2008. Data will be updated after Feb. 28, 2009 to reflect the full fifth year.

Note: persons exclusively using NNIN Computation resources for scientific simulations are not currently counted as part of the NNIN Users. As used here , “users” refers to laboratory users only.

9.1 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. Figure 18 shows the distribution of users by field (10 months, cumulative users) across the network. Overlap between technical areas is inevitable and may users could be assigned to multiple categories. None the less, the broad coverage of nanotechnology subareas is apparent.

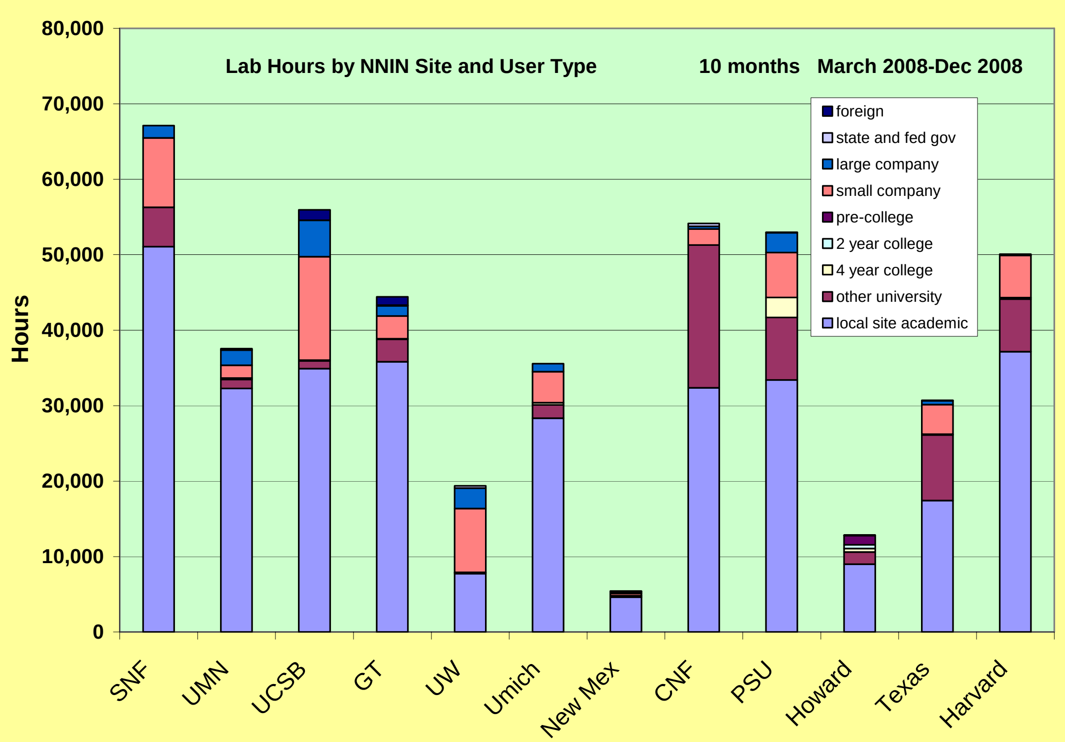
Figure 18: Network User Distribution by Technical Area.



9.2 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 or none. Thus, while there is correlation between the two measures, they are different in between sites. We accept this variation in counting methods as part of the uncertainty. However, laboratory hours are an important way to track intensity of laboratory activity at each site and across the network.

Figure 19: User Lab Hours by NNIN Site.



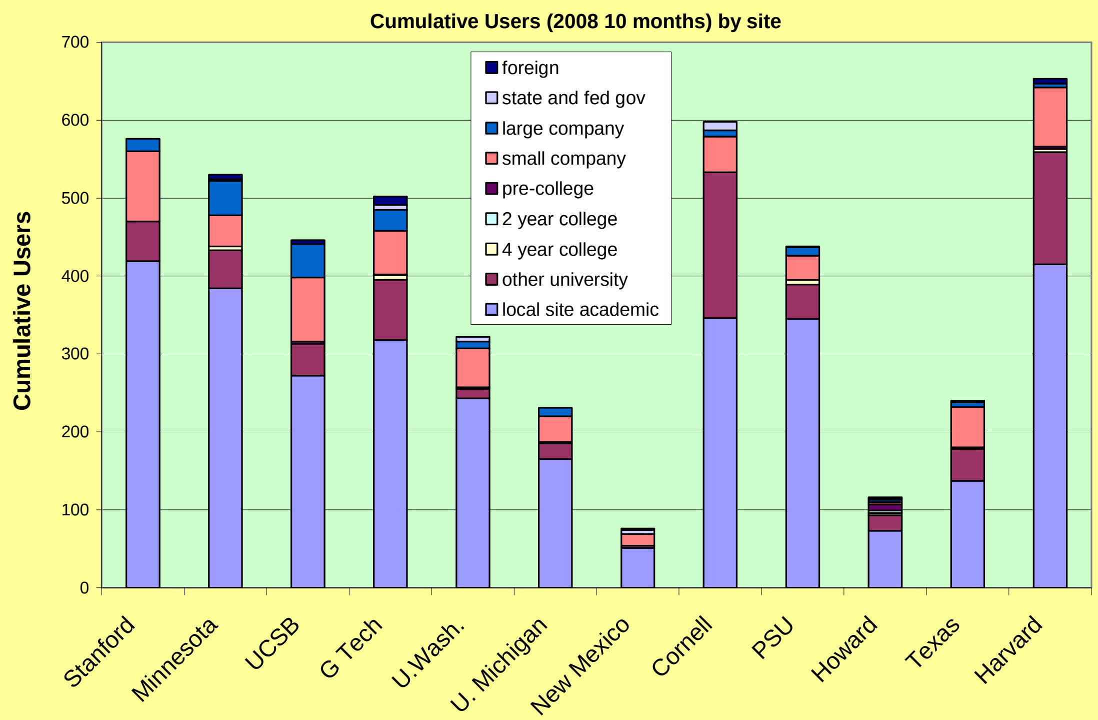
The chart in Figure 19 represents total lab hours during the 10 month period (March 2008-Dec 2008). The size of each NNIN facility and its associated funding varies significantly and each includes different amounts of "associated" facilities (.e.g. characterization facilities). Nonetheless, they reveal 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.

9.3 Cumulative Annual Users

Cumulative Annual Users **is the primary user counting metric employed by NNIN; this is often just referred to as "users"**. 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 (at the end of February via the current NNIN funding calendar) 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 many times over the year.

Figure 20 shows the distribution of users across the network by site and institution type. This figure can also be contrasted with the chart for laboratory hours (either laboratory time or equipment time) (fig. 19). Cornell reflects a large and good balance between internal and external users, with Stanford, U. Minnesota, UCSB, Harvard, Texas, and Georgia Tech showing a significant amount of external usage.. There is considerable variation in the number of users and in their distribution between sites, and this should be considered together with the technical focus responsibility area at the specific site. In this metric, each user counts the same regardless of whether he/she uses the facility 4 hours per year or 400 hours per year. To gain a fuller picture of the effectiveness of each site one has to look at other metrics as a supplement to this.

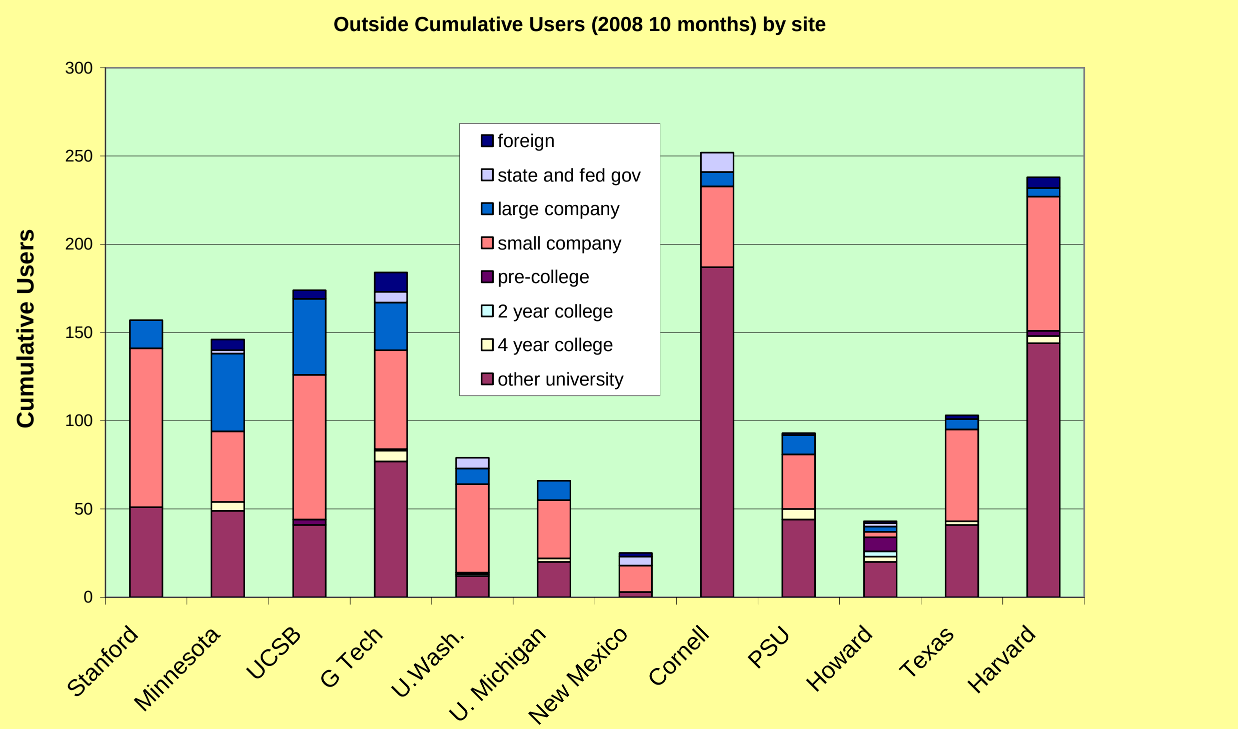
Figure 20: Cumulative Users at each site. (March-Dec)



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

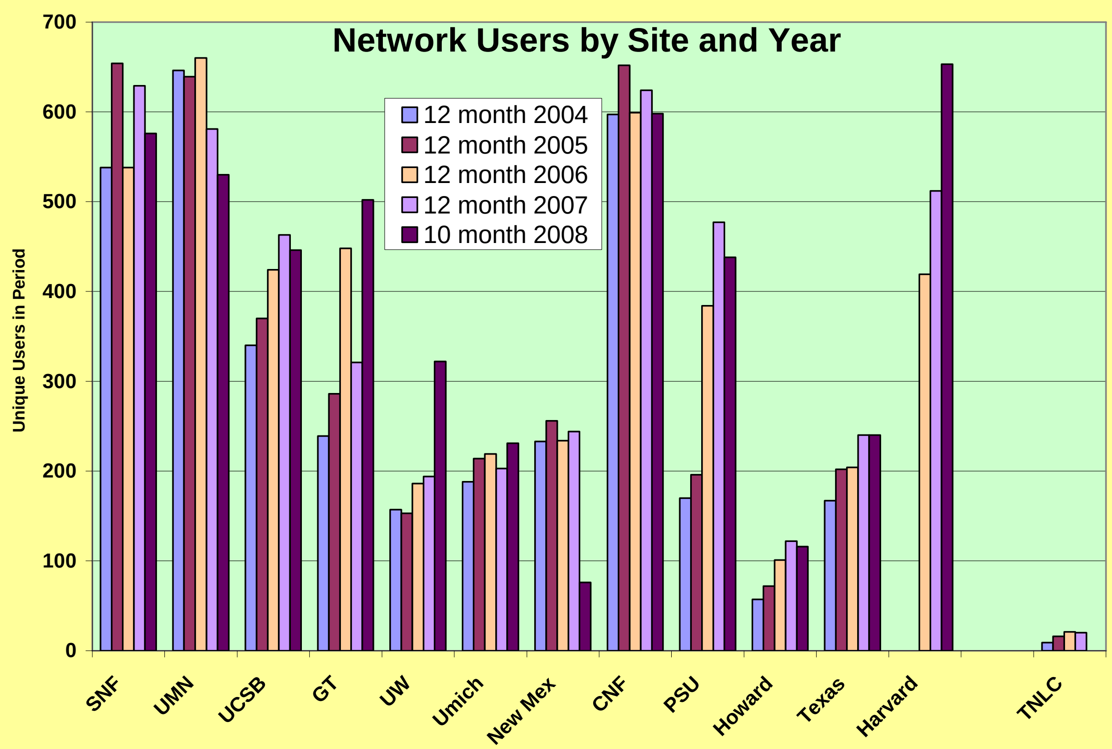
Figure 21 show the distribution of outside (external) users only, i.e. local site users have been removed for clarity. Nearly all sites continue to make progress towards the objectives. Five major sites of the network, Cornell, Stanford, UCSB, and Georgia Tech, and Harvard all have 150 or more outside users each in the 10 month period, with both academic and industrial users benefiting from the network.

Figure 21: NNIN Outside Users by Site.



NNIN is a multiyear enterprise. Particularly for the new or smaller sites, it takes considerable time to grow an effective and vibrant user base. It is important to also view the progress in network usage since the inception of NNIN in 2004. Figure 22 shows the trends in usage of the network at the sites. Note that 2008 data is for 10 months only (March 2008-Dec 2008), and is thus approximately 10% less than it would be for the full 2008 NNIN year (March 2008-Feb 2009). While comparison of the 10 month period to prior 12 month periods is problematic, most of the smaller sites show steady growth. The larger sites, in general, are operating at or near saturation, given current resources and user base.

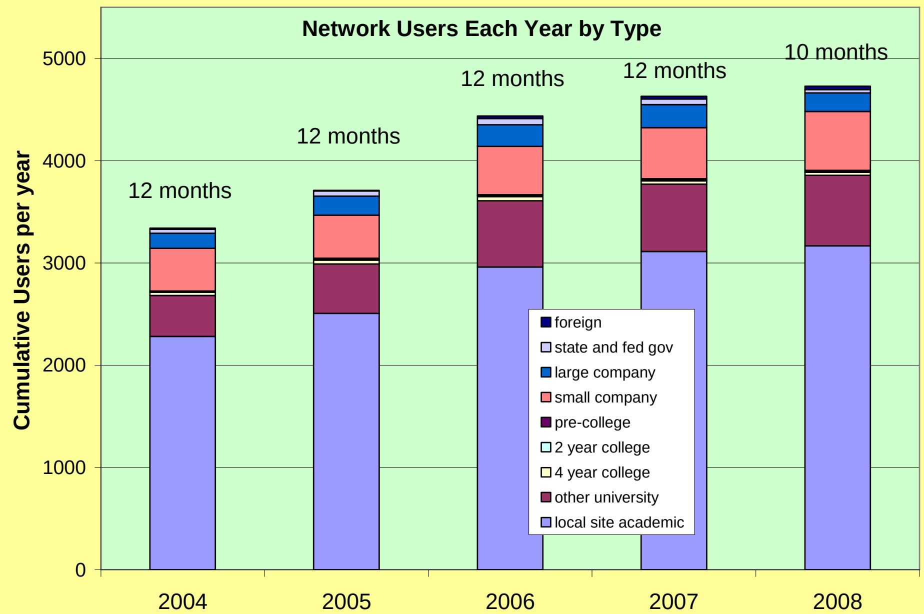
Figure 22: NNIN users by site in a three year comparison.



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

When an adjustment is made for the shorter reporting period of 2008, Figure 23 shows a general increase in network usage across all institution types, summed across the network (2008 data for 10 months March 2008-Dec 2008).

Figure 23: Network wide research usage



9.4 User Fees

Lab use fees supplement the NNIN funding at all sites. In addition, some sites have significant funding from the university. 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 toexisting, sometimes larger facilities and programs. As such, no attempt has been made to standardize fees across the network. NNIN only demands that external academic users receive the same rate as local academic users, and that the NSF funds be allocated 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. In short, 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 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. The amount of user fees collected at each site is shown in Fig. 24 (10 months). There can be several explanations for low fee recovery from outside users, among them: 1) low number of outside users, and 2) low average level of use by outside users.

Figure 24: User fee recovery in 2008.

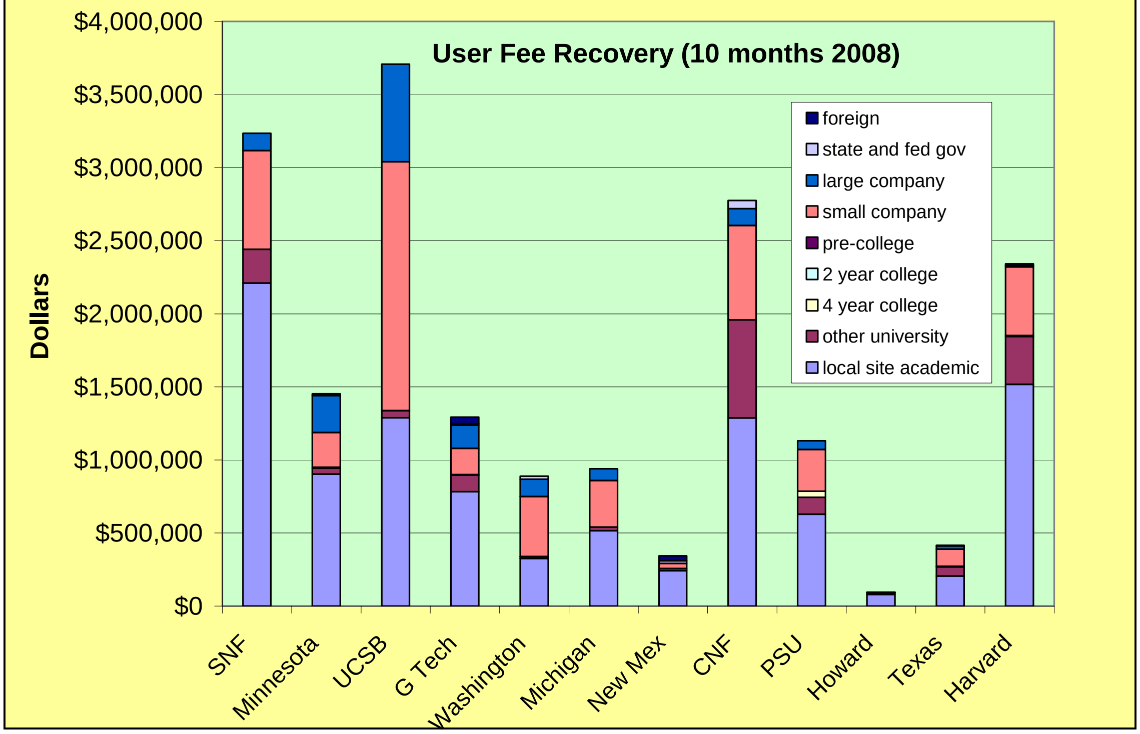
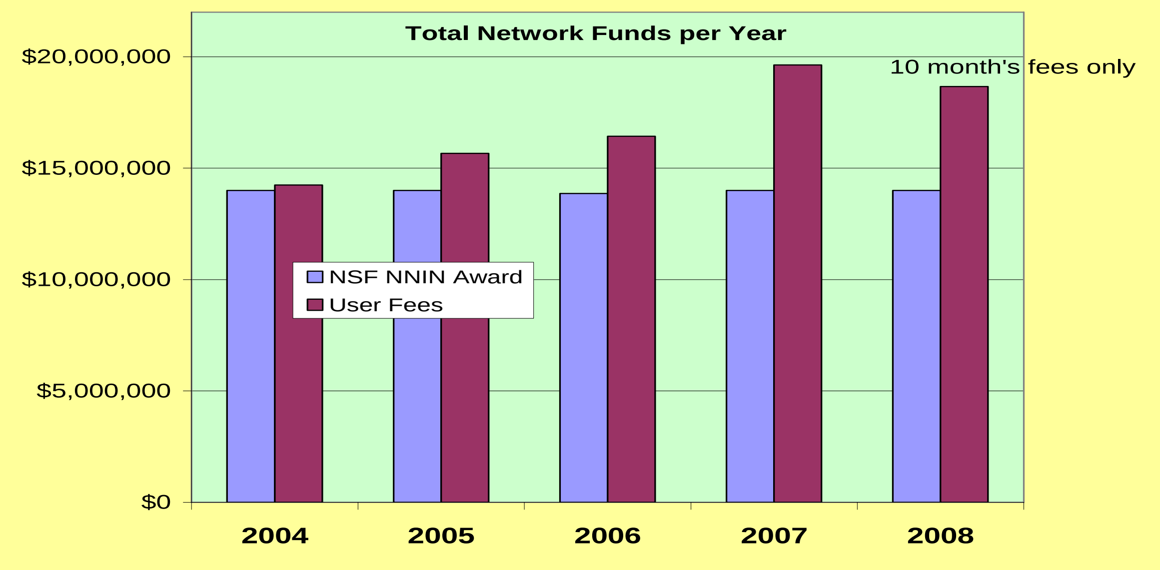


Figure 25 shows the overall high leverage of the NSF investment. Each dollar of the NSF cooperative agreement is more than matched by user fees. Both user fees and the NSF support are critical to operation of NNIN.

Figure 25: Two of network's major sources of funding: NSF and user fees.



One of the requirements of a successful user facility/network is that it be affordable. This is particularly the case for academic users whose work is paid by various government grants. Because of the economies of scale and the critical mass of users, NNIN is able to keep academic use charges low. Figure 26 compares the local academic (NNIN institution) and outside academic average user fees per user over the 10 month period (total academic fees/ total # of academic users). By NNIN mandate, local users and outside users pay the same rates for use. While there is some variation between sites, the most striking part is that the average users paid just over $3000 during the 10 month reporting period. This is an average; many heavy users paid significantly more, and many users paid significantly less. Similarly, average fees per hour (Figure 27) are clustered fairly tightly around $30 per hour, a quite reasonable fee for access to high technology equipment.

Figure 26: Average academic user fees.

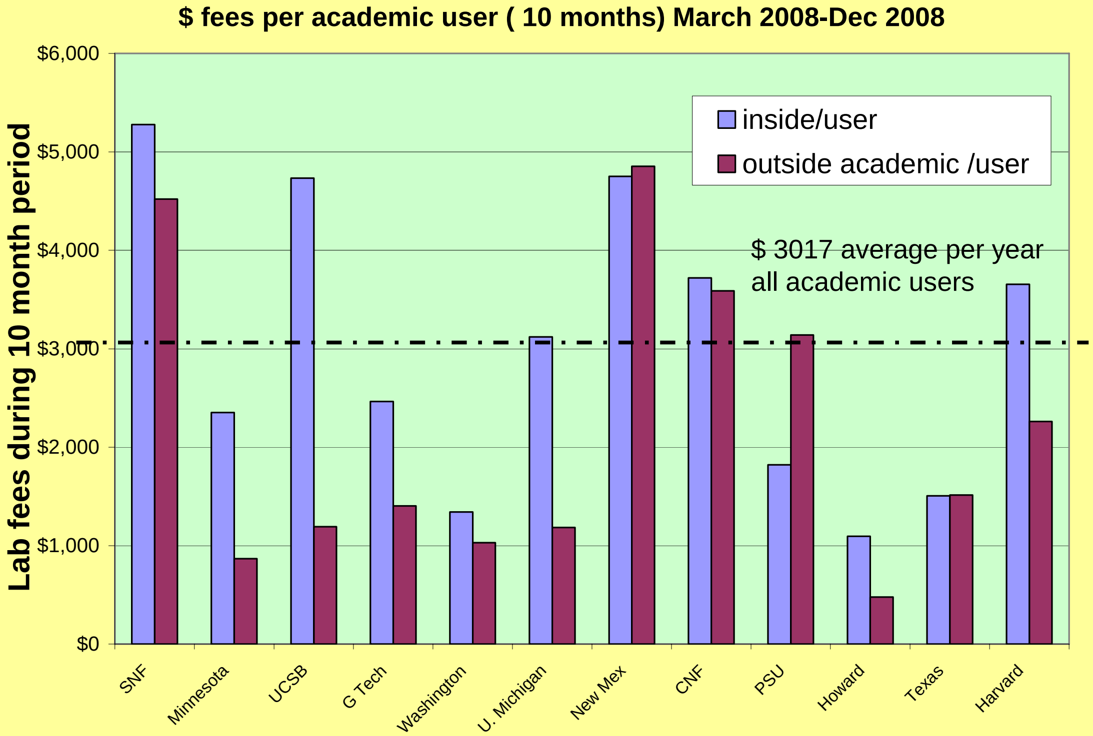
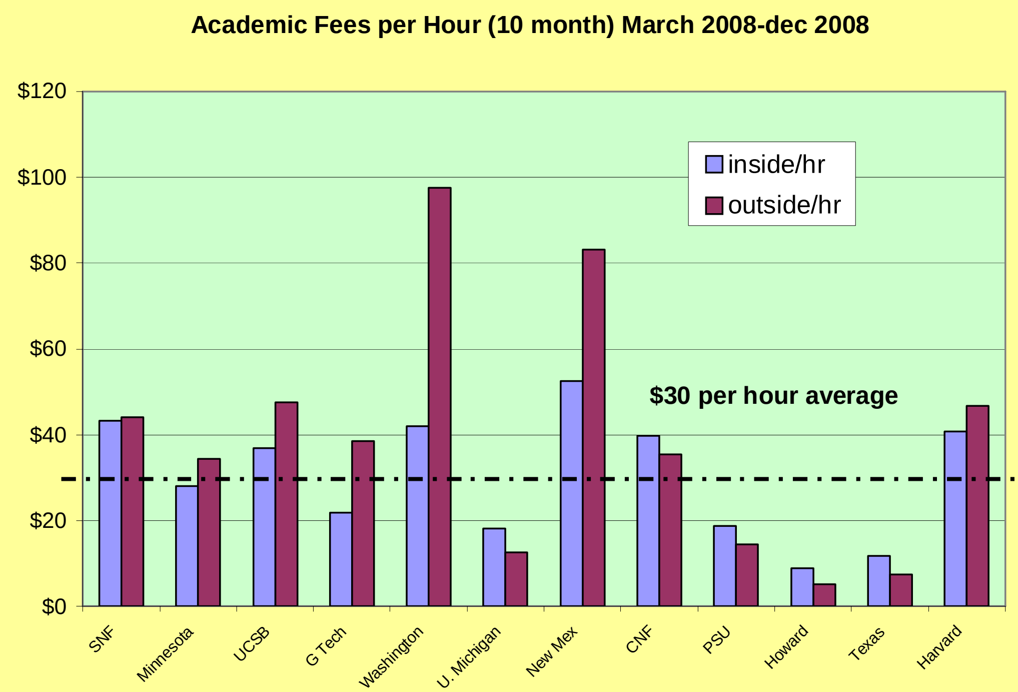


Figure 27: Academic fees per hour in NNIN facilities.

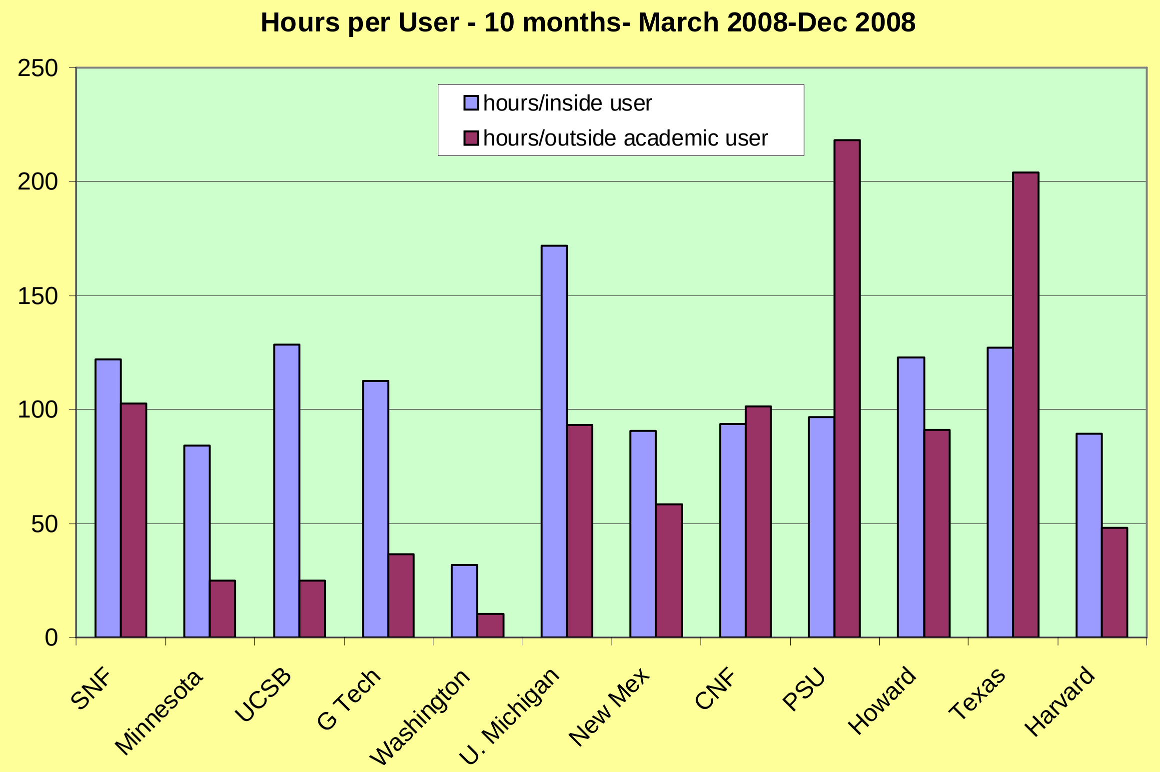


The point of these plots is not any individual variation, either between sites, or between local and outside users at a given site; there is far too much variation in complexity of projects and the available equipment sets to draw those conclusions (although actually most use falls in the $20-40 per 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 $3017 during a full year, quite within the budget of most research grants. In contrast, the average cost for a industrial users (small and large company) is $8816 (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.

9.5 Hours per user

Figure 28: Laboratory hours per user (local and external).



Hours per user is a particularly enlightening metric as it, in some sense, shows intensity of use. A site can more easily sustain a large number of users doing small processes than a similar number of users doing complex processing. Hours per user (per 10 months) (Figure 28) is an average secondary metric, gathered by dividing lab hours in a particular category by the cumulative annual users in that category. Average usages of 100's of hours per user would indicate a facility with more complex processing and a concomitant larger 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 28. 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.

9.6 New Users

Each facility is constantly accepting new users. This is not only necessary for growth but even to maintain steady state as users complete their projects and move on regularly. The number of new users is thus an excellent metric for measuring the demand for NNIN resources. Here (Figure 29) we show the number of new users trained in FY2008 by site. Note that at some sites (e.g. Stanford, Cornell, Harvard, and Minnesota) new users (inside + outside) average almost 5 per week.

In addition, there needs to be a balance between new users and total users. Figure 30 shows the ratio of new users to total users in FY2008 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 29: Training load for new users (internal and external).

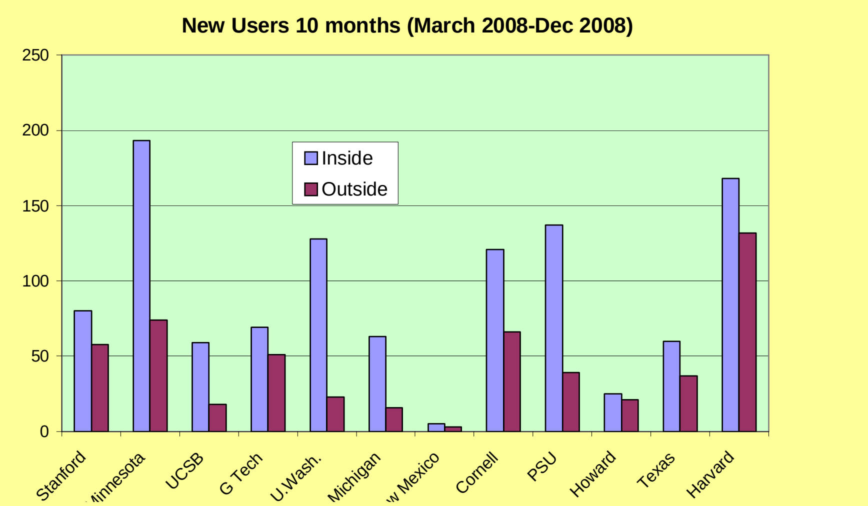
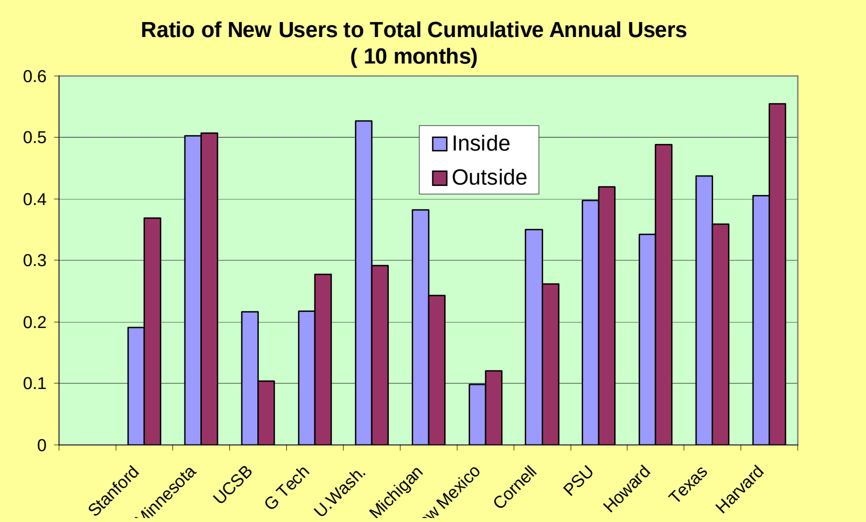


Figure 30: Sustained usage and new usage of sites.



10.0 Summary

NNIN is nearing the end of its 5th year of operation. This report covers the 10 month period from March 1, 2008 to Dec. 31, 2008. Our program covers support of nanotechnology research through advanced equipment and expertise, an extensive education program, and a specialized effort in the Social and Ethical Issues related to nanotechnology.

Extensie data have been shown on the numbers of researchers impacted by NNIN. That is only part of the story, however. 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. A number of publications, in the highly promoted journals – Nature, Science and Proceedings of National Academy of Science – have been from NNIN authors. The publication list and the highlights at the end of this report show a very significant output by both internal and external users. Bringing nanotechnology to the benefit of society through commercialization is another area where the network has made major contributions although this is more difficult to quantify.

Similar achievements also exist for impact from the educational and broader impact effort from the network. The NNIN Education Program has been particularly active with over 175 group events with over 24000 trackable participants. There is considerable interest in nanotechnology at all age levels; NNIN providing materials and activities to stimulate and cultivate that interest. The NNIN Education Program is recognized as a leader in nanotechnology education at all levels.

The funds supporting NNIN make possible research of 4700+ research users each year, including scientists from 250+ small companies. Our training process brings nearly 1600 new research users each year (>1300 in the most recent 10 months), and results in more than 1200 PhD awards each year. In the five years that NNIN has been active over 5000 new users have been trained in nanotechnology at NNIN facilities. This is a major impact human resources impact in the important growing area of nanotechnology. The rate of new users is particularly impressive and reflects a growing and continuing interest in nanotechnology and NNIN’s resources. The funds provided by National Science Foundation make possible in excess of 30 to 1 leverage in the research and development that advances the knowledge and commercial frontiers in the broad areas affected by progress in nanotechnology.

The research accomplishments of these users are extensive and well documented. NNIN has demonstrated an effective model for support of users in a high technology environment, with large leverage of government funds.

By any measure, NNIN continues to have a very major impact of the nation and continues to demonstrate an effective use of the nation’s research resources.

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 2007-June 2008) collected in July, 2008 and listed , by site, as (a) external user publications, (b) external user conference presentations, (c) internal user publications, and (d) internal user conference presentations.
4. Research highlights collected in October 2008 covering the period Oct. 2007-Sep. 2008.
5. Education highlights prepared in October 2008

Appendix 1: NNIN Network and Site Principal Contacts

Sandip Tiwari, Charles N. Mellowes Professor of Engineering, Network Director
st222@cornell.edu
Dr. Lynn Rathbun, Cornell University, NNIN Program Manager
Rathbun@cnf.cornell.edu
Dr. Nancy Healy, Georgia Tech NNIN Education Coordinator
nancy.healy@mirc.gatech.edu
Dr. Michael Stopa, Harvard University,NNIN Scientific Computation Coordinator
stopa@deas.harvard.edu
Dr. Mary Tang, Stanford Nanofabrication Facility, NNIN Health and Safety Coordinator
mtang@snf.stanford.edu
Prof. Katherine McComas, Dept. of Communications; NNIN SEI Coordinator
Kam19@cornell.edu

NNIN Executive Committee

Sandip Tiwari	NNIN
George Malliaras	Cornell
Yoshio Nishi	Stanford
Sanjay Banerjee	University of Texas
Francois Baneyx	University of Washington
Theresa Mayer	Penn State

Cornell University Site

George Malliaras, Professor, School of Applied and Engineering Physics, (Site Director)
ggm1@cornell.edu
Don Tennant, Director of Operations
tennant@cnf cornell.edu
Dr. Lynn Rathbun, Cornell University, Laboratory Manager and NNIN Program Director
Rathbun@cnf.cornell.edu
Prof. Katherine McComas, Dept. of Communications; NNIN SEI Coordinator
Kam19@cornell.edu

Georgia Institute of Technology

James Meindl, Professor, School of Electrical and Computer Engineering (Site Director)
james.meindl@mirc.gatech.edu
Dr. Nancy Healy, NNIN Education Coordinator
nancy.healy@mirc.gatech.edu
Dr. Kevin Martin, Assoc. Director
kmartin@prism.gatech.edu,
Greg Book
gregory.book@mirc.gatech.edu

Harvard University

Prof. Charles Marcus, Professor of Physics (Site Director)
marcus@physics.harvard.edu
Dr. Eric Martin
emartin@cns.fas.harvard.edu
Dr. Michael Stopa, NNIN Scientific Computation Coordinator
stopa@deas.harvard.edu
James Reynolds, Administrative Contact
Reynolds@physics.harvard.edu

Howard University

Gary Harris, Professor, Department of Electrical and Computer Engineering (Site Director)
gharris@msrce.howard.edu
James Griffin, User Contact
griffin@msrce.howard.edu

Pennsylvania State University

Theresa Mayer (Site Director)
tsm2@psu.edu
Bill Mansfield, Associate Director
wmm14@psu.edu

Stanford University

Yoshio Nishi, Professor, Department of Electrical Engineering (Site Director)
nishiy@stanford.edu
Dr. Mary Tang, Biology and Biotechnology Domain Expert, Stanford Nanofabrication Facility, NNIN Health and Safety Coordinator
mtang@snf.stanford.edu
Paul Rissman, Assoc. Director
rissman@stanford.edu

University of California, Santa Barbara

Mark Rodwell, Professor, Department of Electrical and Computer Engineering (Site Director)
rodwell@ece.ucsb.edu
Jack Whaley, User Contact
whaley@ece.ucsb.edu
Angela Berenstein, Site Education Coordinator
berenstein@ece.ucsb.edu

University of Michigan

Khalil Najafi, Professor, Department of EE and CS (Site Director)
najafi@umich.edu
Sandrine Martin, User Contact
Sandrine@eecs.umich.edu

University of Minnesota

Steve Campbell, Professor, Department of Electrical Engineering (Site Director)
campbell@ece.umn.edu
Greg Cibuzar, User Contact
cibuzar@ece.umn.edu

University of New Mexico

Steven Brueck, Professor, Department of Electrical Engineering (Site Director)
brueck@chtm.unm.edu
Rick Bradley, User Contact
rbradley@cthm.umn.edu

University of Texas, Austin

Sanjay Banerjee, Professor, Department of Electrical and Computer Engineering (Site Director)
banerjee@ece.utexas.edu
Marylene Pallard, User Contact
marlene@mer.utexas.edu

University of Washington

Francois Baneyx, Professor, Department of Chemical Engineering (Site Director)
baneyx@u.washington.edu

Appendix 2 Site Performance Data and Site Reports

<u>Introduction to Site Reports and Site Data</u>

Site reports for each NNIN site follow. Each site section, in a similar manner, contains the following items:

1) User data for site for 10 month period March 2008-Dec 2008 as well as prior year periods, compiled by NNIN Management from site submitted data

2) Site submitted report (unedited, except for format, by NNIN Management).