National Nanotechnology Infrastructure Network

Abridged

Annual Report

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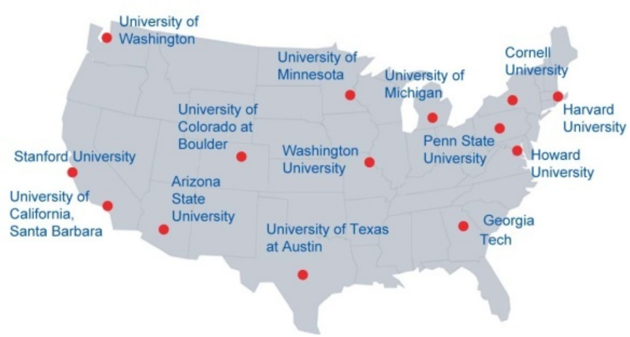
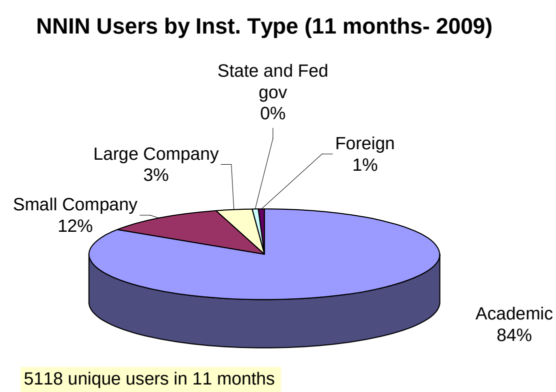
NNIN
www.nnin.org
Nanoscale Science,
Engineering & Technology

Executive Summary: National Nanotechnology Infrastructure Network

Introduction: The National Nanotechnology Infrastructure Network (NNIN) is a collective of fourteen university-based facilities with the mission to enable rapid advancements in nanoscale science, technology and engineering through open and efficient access for fabrication. It provides facilities-based infrastructure resource that is openly accessible to nation's students, scientists and engineers from academe, small and large companies, national laboratories, and others. It enables the reduction of ideas to practice by providing the capacity to explore materials, structures, devices and systems through access to tools, training and specialized knowledge for operating tools, hands-on and remote operation, learning from diverse disciplines – all at affordable cost, minimum barriers and a few weeks of latency. NNIN also supports this experimental effort and independent interdisciplinary theoretical effort through computational resources where the emphasis is on modeling and simulation in support of advanced scientific problems of nanoscale via open and tested software, hardware and basis information. NNIN also leverages its infrastructure resources and geographic and institutional diversity to conduct other activities with broader impact: in education, in enhancing diversity in technical disciplines, in societal and ethical implications of nanotechnology and in health and environment. During the current year, NNIN changed with the joining of 3 new universities to the network – Arizona State University, University of Colorado and University of Washington in St. Louis, and the elimination of one – University of New Mexico. In addition to the broader nanofabrication area efforts, the new sites place special emphasis in support of technical areas of inorganic-organic and bio-abio interfaces at Arizona State University, energy and precision sciences at University of Colorado and public health and environment at Washington University in St. Louis.

Figure 1: Institutions of NNIN and the experimental research & development usage of NNIN during 2009-10.

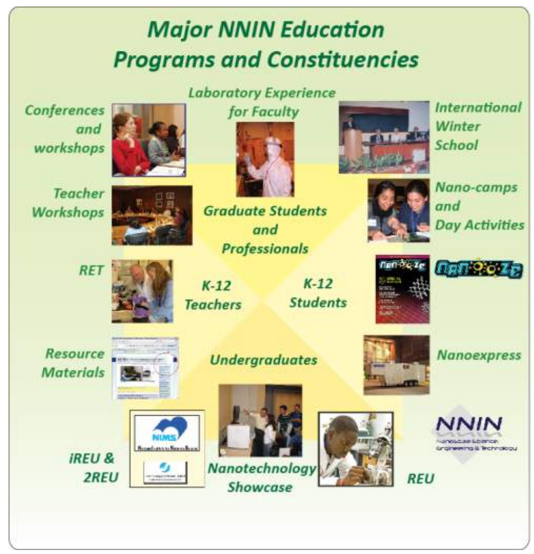




Approach and Usage: NNIN's approach for supporting research and development has been to focus efforts on serving the external user and to use resources provided by NSF to predominantly fund the staff that trains users and assists them with their research and development tasks. It is this staff, made possible by NSF funds and their leverage t hat helps users effectively utilize the large instrument set of NNIN sites. 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.

During the 11 months of operation ending in January, NNIN served 5118 (5049 in 12 months of 2008-09) unique users who performed a significant part of their experimental work at NNIN facilities. Of these, 4304 (4167 in 12 months of 2008-09) were academic users, most of whom are graduate students, 760 (811 in 12 months of 2008-09) industrial users, 25 (36 in 12 months of 2008-09) from U.S., State, and Federal laboratories, and 29 (35 in 12 months of 2008-09) from foreign institutions. 306 small companies (350 in 12 months of 2008-09) used NNIN facilities during the 11 month period. Nearly 3200 (3200 in 12 months of 2008-09) publications, several of them the significant scientific and engineering highlights of the year, resulted from the work of the user community. A major task of staff of NNIN is in training of this user community, particularly graduate students from across United States, where there is a continuous and significant turnover. During the 11 month period, 1762 (1840 in 12 months of 2008-09) new users were trained across the vast instrument set, large and small, of the facilities.

Figure 2: NNIN's major educational activities.



Education and Outreach: NNIN has a broad portfolio of effort in education and outreach drawing on its nanotechnology strengths, geographic and academe-based intellectual diversity, and its ability to leverage a national reach. This national focus is a major part of the portfolio (see Figure 2) that allows both broader and selective outreach with objectives ranging from providing a rigorous technical experience, enhancing knowledge and increasing diversity to providing a stimulating exposure and understanding to the young and the population at large.

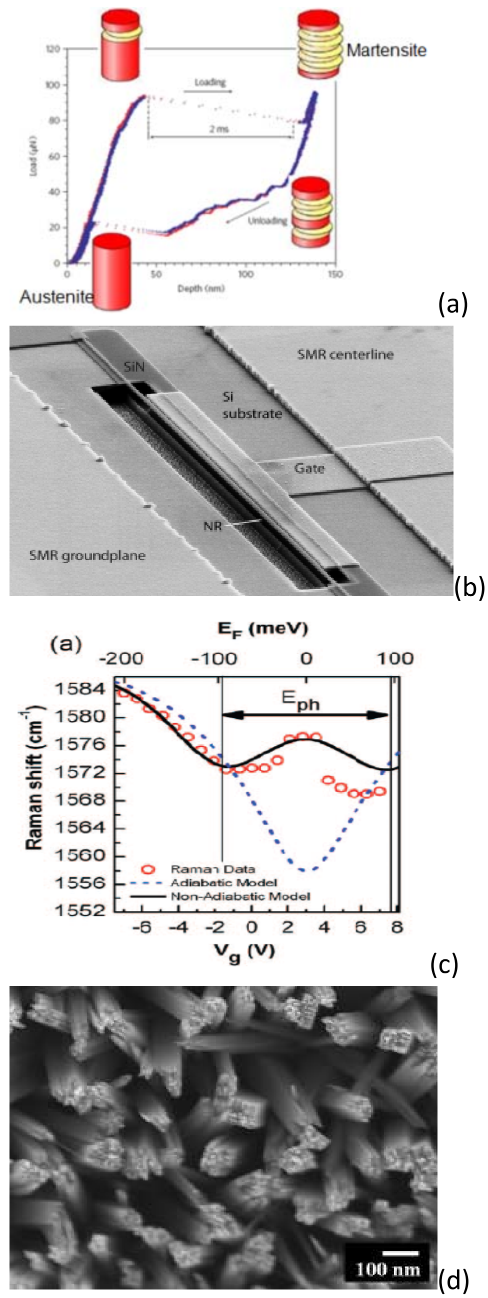
The national programs include: **(a) Research Experience for Undergraduates** (REU) for a thorough exposure to graduate-level research for undergraduate students across the breadth of nanosciences and engineering, **(b) International Research Experience for Undergraduates (iREU)** for an international laboratory exposure mentored by a senior research scientist to a select exceptional group of prior year REU students, **(c) Laboratory Experience for Faculty (LEF)** that brings research experience opportunity to faculty from under-represented communities or institutions devoted to under-represented communities, **(c) Showcase for Students,** which is a day-long showcase of nanotechnology at major conferences devoted to underrepresented science and engineering students (SHPE, SBE, SWE, etc.) featuring hands-on table-top laboratory demonstrations with short lectures presented at major conferences, **(d) international Winter School for Graduate Students (iWSG)**, which teaches an advanced emerging nanotechnology subject area to a select group of US graduate students at a3rd world institution combined with societal field work, **(e) Symposia** - four times a year on major technical themes that bring together leaders for talks and discussions with users/participants to define challenges of critical/emerging/changing areas and possible NNIN contributions to them, **(f) Nanooze,** whose magazine edition is an upper elementary-middle school centered web and print resource for science enrichment and an exhibit edition for a museum-scale exposure to the community, **(f) Open Textbook,** a web-based senior/graduate level text that grows and changes with learning of the field, and **(g) Technical Workshops & Symposia,** which are topical and hands-on workshops connected to research. Nearly 20,000 people have participated in these events during the year, including nearly a thousand in the technically rigorous workshops and symposia. Local activities from NNIN include day and longer camps for middle and high school students, local outreach through workshops for teachers, school and community-connected activities, and from Howard University, a laboratory on wheels that brings nanotechnology activities to high schools in eastern part of the country.

Computation and Modeling: NNIN has chosen to tackle the truly challenging science and engineering problems of nanoscale where software and hardware by themselves are insufficient. These problems are interdisciplinary or cross between theory and experiment. In such cases, a domain expert staff member helps with extracting information that is useful beyond the discipline for which a software was originally written, or where an academic software becomes useful for community at large. NNIN focuses on computation and modeling tools in support of problems that are interdisciplinary, that bring theory and experiment together, that require advanced knowledge between disciplines, and that address previously unsolvable problems that could benefit from availability and technical support of open codes. NNIN expert staff support mechanics-fluidics-electronics-optics-atomic-molecular dynamic- and related areas. Domain experts are in residence at Harvard and Cornell for science and engineering of condensed matter, at Stanford for interfaces, molecular dynamics and materials science, and at Michigan for fluidics and mechanics and sensors. These efforts are supported through advanced computation clusters where simulations can be performed. In addition, NNIN has also undertaken an initiative to be a repository and archival source for the research community by putting together, testing, and making available trusted pseudo-potentials, interatomic potentials, input file banks, etc. that are of use in a variety of scientific problems. One hundred nine scientific research users, most of whom are graduate students, employ these resources, with publications results appearing regularly in Nature, Science, Applied Physics-Physical Review-Nano Letters, and other leading journals on problems ranging from chaos, *ab initio* thermal transport, fluid dynamics, multi-phase phenomena, interface and molecular chemical dynamics, Casimir forces, etc.

Societal and Ethical Implications of Nanotechnology: NNIN seeks the integration and development of a social and ethical consciousness throughout the breadth of network activities while becoming the nation's leading open-access research facility for the study of science. SEI efforts within NNIN therefore embody both the network's research and educational pursuits. NNIN has organized its efforts to take advantage of the network's unique strengths as a national resource with geographic diversity, technical breadth and community interests. Within its user community, NNIN provides training and educational opportunities through SEI modules and supporting teaching materials employed in training and ongoing educational programs, selective incorporation of these in the network educational activities (REU, RET, workshops, symposia, etc.), and in broader outreach activities. NNIN stimulates and facilitates SEI research on the NNIN's unique world leading strength – the largest collection of nanotechnology users (students and professionals), communities (academe and industry) and technologies across the breadth of subjects. NNIN provides opportunities for national researchers via competitive travel and seed grants to support related SEI investigations. NNIN's research efforts also include examination and development of (a) understanding of interdisciplinary collaborations and their impact on research, (b) the impact on competitiveness and the process of technology transfer and industrial innovation and innovation by industry through NNIN, (c) impact of government-funded faculty research and the faculty's interaction with industry in technology transfer, (d) impact of intellectual exchange, openness and sharing such as in a network in conduct and impact of research, and (e) the ethical issues related to nanotechnology and fostering of ethical conduct.

Examples of Scientific Impact from 2009: The nearly 3200 publications resulting from work made possible by NNIN encompasses the breadth of engineering, and physical and life sciences where small scale brings exquisite disciplinary and interdisciplinary problems of materials, structures, devices, systems. These are available from NNIN's website and they range from fundamental measurements, to molecular and supra-molecular scale structures where technology and devices are practiced, and applications where significant integration is brought together in physical and life science and engineering disciplines. Figure 3 shows a few of the significant examples from the current year. In Figure 3(a), work by Prof. C. Schuh et al. from MIT, shows the shape memory recovery characteristics at nanoscale dimensions showing the large strain that crystalline phase change can withstand at extremely small dimensions and the complete shape recovery in nanoscale Cu-Al-Ni alloys – a property that could be use in many applications requiring mechanical strength and bistability at small dimensions. In Figure 3(b), Prof. K. Schwab et al. from CalTech have looked at the vibrational/phonon characteristics and come close to the lowest mode limits. They have achieved positional sensitivity of 4 times the zero point motion, and using back-action cooling reached 12 quanta through capacitive coupling between mechanical and electrical resonances using superconducting resonators. In the results summarized in Figure 3(c), from joint work between groups of Prof. S. Cronin

Figure 3: (a) shows shape recovery in shape memory alloys at nanoscale exhibiting the high strain possible (Schuh et al. from MIT), (b) shows a resonator (mechanical and electrical) that allowed positional sensitivity of 4 times the zero point motion and back action cooling to 12 quanta by Schwab et al. from CalTech, (c) breakdown of Born Oppenheimer approximation in a carbon nanotube structure by Cronin of USC and Bockrath of CalTech, and (d) the use of single crystalline titanium dioxide nanorods in dye sensitized solar cells.



(USC) and Prof. M. Bockrath (CalTech), Born-Oppenhimer approximation, the approach used to separate electronic and nuclear contributions in condensed matter and molecular calculations, is shown to break down in metallic nanotubes. Figure 3(d) shows an example of application of nanotechnologies to energy generation. Prof. E. Aydil et al. (U. Minnesota) achieve a 3% efficient dye-sensitized solar cell using short titanium dioxide nanorods and a potentially low cost approach.

Table of Contents

1.0 Introduction to the Report

This report covers eleven months of the 6th year of the operation of the National Nanotechnology Infrastructure Network (NNIN) - the period from March 1 of 2009 through January 31 of 2010. This is the first year following the renewal of the network for its second five year term. This renewal occurred together with several major changes. The network is undertaking a number of new technical and broader outreach initiatives drawing on its first five years experience. The network has also highlighted special additional areas of technical focus - areas that are major intellectual challenges in science or that need concerted effort in technology development and engineering to address societal challenges.

NNIN is funded via a cooperative agreement between Cornell University and NSF, which commenced on March 1, 2009. The current award period extends through Feb. 28, 2014.

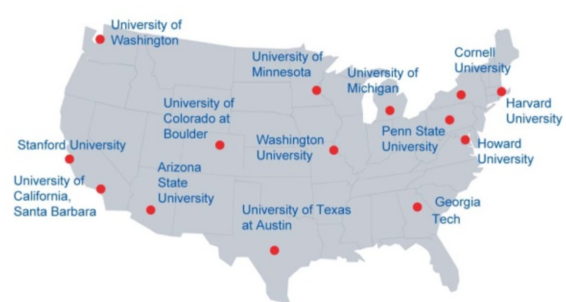
This report documents activities and highlights of the 2009 year. It includes statistics of usage and particularly focuses on progress and activities that NNIN initiated for renewed term. Earlier reports have described NNIN functions and operations extensively and will not be described here in detail. The major initiatives and changes of the network include:

- three new universities joining the network with new technical area emphasis on nanotechnology and environment and health, energy and precision, and the hard-soft (or organic-inorganic) interface and its use in physical and life sciences and engineering disciplines,
- an emphasis in geosciences towards ocean and environment leveraging sensors and systems,
- in society and ethics, leveraging NNIN community and its national reach for citizenship building and for research studies to assess implications of nanotechnology,
- new education and outreach initiatives for US student development with an international perspective, and helping open and explore new science and engineer frontiers through advanced symposia and workshops, and
- in computation and modeling, enhancing resources to support a broader group of interdisciplinary advanced research subjects, a stronger connection to experimental research, and building repositories for trusted information in support of advanced theory.

2.0 NNIN Overview

The National Nanotechnology Infrastructure Network (NNIN) is a collective of fourteen university-based facilities with the mission to enable rapid advancements in nanoscale science, technology and engineering through open and efficient access for fabrication. It provides facilities-based infrastructure resource that is openly accessible to nation's students, scientists and engineers from academe, small and large companies, national laboratories, and others. It enables the reduction of ideas to practice by providing the capacity to explore materials, structures, devices and systems through access to tools, training and specialized knowledge for operating tools, through hands-on and remote operation, and through learning from diverse

Figure 1: Participating institutions of the National Nanotechnology Infrastructure Network (NNIN).



disciplines – all at affordable cost, minimum barriers and a few weeks of latency. NNIN also supports this experimental effort and other independent interdisciplinary theoretical effort through computational resources where the emphasis is on modeling and simulation in support of advanced scientific problems of nanoscale via open and tested software, hardware basis information, and in-depth support from advanced practitioners. NNIN also leverages its infrastructure resources and geographic and institutional diversity to conduct other activities with broader impact: in education, in enhancing diversity in technical disciplines, in societal and ethical implications of nanotechnology and in health and environment.

During the current year, NNIN changed with the joining of 3 new universities to the network – Arizona State University, University of Colorado and University of Washington in St. Louis, and the elimination of one – University of New Mexico. In addition to the broader nanofabrication area efforts, the new sites place special emphasis in support of technical areas of inorganic-organic and bio-abio interfaces at Arizona State University, energy and precision sciences at University of Colorado, and public health and environment at Washington University in St. Louis.

2.1 Approach and Usage:

NNIN's approach for supporting research and development has been to focus efforts on serving the external user and to use resources provided by NSF to predominantly fund the staff that trains users and assists them with their research and development tasks. It is this staff, made possible by NSF funds and their leverage that helps users effectively utilize the large instrument set of NNIN sites. Resources are optimized by connecting specific technical leadership offerings at a site to the intellectual strengths of the home institution, 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.

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. 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.

NNIN enables researchers, experienced and novice, by sharing with them the breadth of tools and the intricacies and knowledge of integrated processing where numerous materials and environmental interactions occur, and by focusing resources to help the users complete projects rapidly. Essential to efficient and productive operation is training of users on a large variety of equipment, maintaining the equipment for high uptime, supporting the users by sharing knowledge and previous experience, and keeping the facilities open 24 hours a day. 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 palette. 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 and research challenges related to energy and, bio-sciences expand the materials of interest in science and engineering.

Our approach, in short, is:

- Openness at all sites that focuses on external users,

- Making available state-of-the-art equipment resource, distributed across sites, supported by a high level of technical staff expertise,
- Commitment to technical excellence that focuses on bringing key instrumentation and knowledge and training to users,
- Effective and leveraged use of scarce resources made possible by a critical mass of users engendered by successful projects 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.

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:

- 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, and
- Commitment to no intellectual-property barriers.

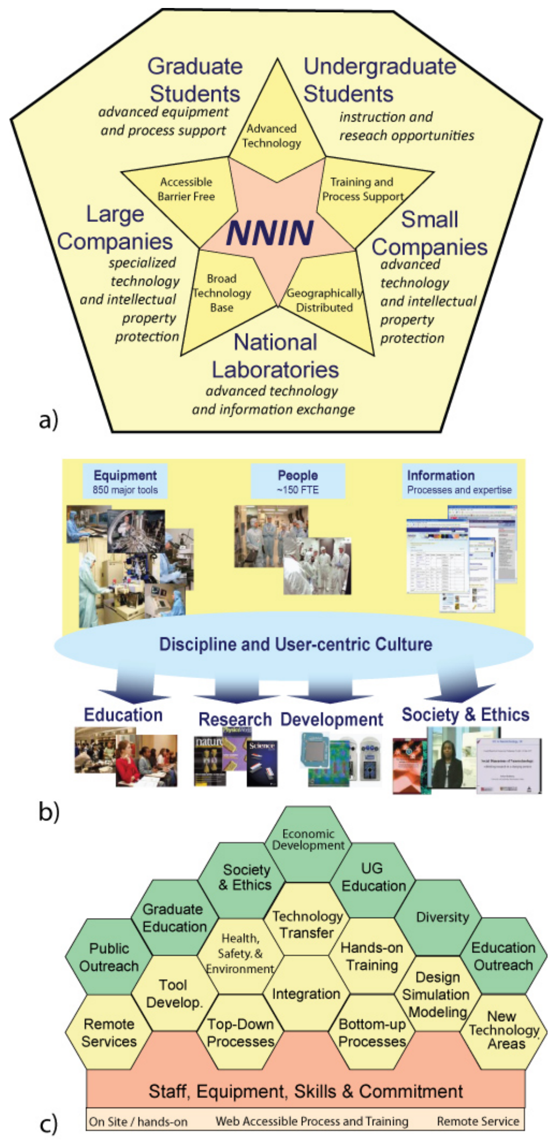


Fig. 2: Overview of NNIN operations

These principles are critical 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.

	Bio & Integrated Systems	Chem. & Molecular-Scale Tech.	Electronics, Optics & MEMS	Bio & Life Sciences	Materials & Physical Sciences	Computation	Geo-Sciences	Man'f Res. Support/Tool Dev	Remote Usage Support	Inorganic-Organic Interface	Energy	Precision Sciences & Engineering	Environment & Health	Society & Ethics	Education	Diversity Outreach
Cornell	x	x	L	x	L	L	x	x	L	x	x	L		L	L	x
Stanford	x	x	L	x	L	L	x	x	L	x	x	x	x	L	L	x
Georgia Tech	x		x	L			x		x					x	L	L
Michigan	L		x	x		L	L		x	x					x	x
Harvard	x	L	x		x	L		x				x			x	x
UCSB			x		L					x		x			L	L
Minnesota			x		x		x		x		L				x	x
Penn State		L	x		x			x		x					x	x
Texas		L	x					L							x	x
Washington			x	L			L						x	x	x	x
Howard			x		x										x	L
ASU	x		x	x						L					x	L
WUStL		x						x					L		x	L
Colorado			x		x						L	L			x	L

NNIN efficiently utilizes its resources by tying intellectual strengths of a university to leadership responsibilities for serving related disciplines. This assures that the state-of-art instruments and advanced knowledge, experience, and approaches (including processes and the idiosyncrasies that only time provides) is available to external user and the local university users also benefit. The table shows leadership and contributory responsibilities of the sites within the network.

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.

2.2 Practices for User Support

NNIN practices to support and train users and to bring in new users continue to evolve with learning and experience. External user support, training, and procedures are the focus of this approach. This in turn benefits the internal users also because of the efficiencies created. The procedures are however not simple to implement in a traditional university environment where multiple interests co-exist. Through the leadership of NNIN derived from its evolving experience, and their documentable impact – locally and nationally, 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.

2.2.1 User Facilities

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

NNIN also removes intellectual property concerns by placing the responsibility for protecting confidential information on the user. They are expected not to share information that they wish to protect for patents or as trade secrets. Being academic facilities, at least within the academic community – internal and external, NNIN fosters an environment of sharing so that researchers can focus on their own specific interests, rather than duplicating work or uncovering knowledge known to another practitioner.

2.2.2 NNIN Project Support, Process Support and Training

NNIN facilities are primarily hands-on facilities. Users are trained by the staff to become self sufficient. A selection of reproducible and specialized processes and process sequences, essential to a variety of tasks (thin low stress membranes, selective etchings, deep etches, coatings, fine-line lithography, etc.) can be performed remotely by a NNIN staff member, and the user need not travel to a site. NNIN, however, does not operate as a foundry of complex integration. The execution of a complex multi-step process sequence is itself a research project and performed by the user. 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 5200 different users taking advantage of NNIN laboratory 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.

2.2 Activities Overview for 2009

2009, as the first year of renewal, was a very active year for NNIN as three new sites were integrated into the network. This occurred together with the start of number of new programs and initiatives. American Recovery and Reinvestment Act (ARRA) funds also made possible a significant expansion and renewal of the equipment infrastructure of NNIN.

2.2.1 New Facilities

Significant facility expansion and construction occurred at University of Colorado and Washington University at St. Louis, two of the new sites in the network, in support of the technical focus areas of the sites, and at University of Michigan which expanded its footprint. These are just three of the nine major facilities built or under construction at NNIN sites since 2004. In total, eight entirely new facilities (Cornell, UCSB, Harvard, prior; Michigan, Washington University at St. Louis, and University of Colorado, Georgia Tech 2009; PSU, under construction) represent an investment by the universities and state governments of a fair fraction of a 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 and their successes and contributions enabled by NNIN, is a key factor in the business model that makes these facilities affordable. While these expenditures are made to enhance the local university's capabilities and stature, NNIN and its users receive enormous benefit from this significant investment in infrastructure.

2.2.2 New Equipment-ARRA

Just prior to the start of five year renewal, NNIN conducted an internal assessment of the state of its instrumentation and needs to identify and prioritize those critical to continuing effectiveness as national resource in support of nanotechnology research. Equipment sustainability and acquisition of new capabilities has traditionally been a major challenge to facilities of NNIN. Nearly all of the funds that NNIN receives from NSF and the user fees are employed for staff who train and help users and maintain equipment, and towards consumables. Traditionally, NNIN relies on equipment competitions such as Major Research Instrumentation (MRI), gifts and other opportunities local to universities to acquire equipment. As part of ARRA sponsored funds, NSF provided a one time opportunity for utilizing $10M for

NNIN instrumentation during 2009. NNIN's self-assessment provided a foundation for the network's thinking and awareness in what needed to be stressed in response to this opportunity.

Discussions with site directors, and the Executive Committee of the network, resulted in the following order of priority for emphasis in the equipment acquisition under a common expectation of maximum external user impact.

1. ***Workhorse Tools:*** Tools that are used by a large and diverse set of users – tools that have become standard in fabrication/synthesis work – are hard to replace through federal equipment competitions such as Major Research Instrumentation (MRI) that emphasize novel and new area impact. Yet they are critical and their breakdown and failures has a large impact. They are amongst the oldest and most prone to **failures.**
2. ***Larger Relative Support to New Sites and Smaller Sites of Network:*** Three new sites entered the network during this year – Arizona State University, University of Colorado and Washington University in St. Louis – with technical leadership responsibility in the areas of hard-soft interfaces and flexible materials technology (ASU), energy and precision sciences and engineering (UC) and support of nanotechnology-related health and environment studies (WUStL). The emphasis for newer sites is founded on importance placed on these areas within NNIN coupled to increased geographically convenient reach for the broader technical community. Equipment acquisition is also a relatively more difficult task for small sites. Larger sites with their large usage and stronger university support system have relatively more opportunities and freedom in acquisition and longer term support.
3. ***Technical Emphasis of Sites:*** NNIN has used the approach of using precious resources to make sure that sites place emphasis in capabilities and resources for specific technical directions, their technical leadership area, and provide world leading capabilities in technology, i.e. tools and processes and staff support, for them.
4. ***New Capabilities Tools:*** While strongest emphasis should go to workhorse tools, tools that provide new capabilities but are smaller in scale of acquisition costs, were also considered as potential targets for acquisition.

A network-wide call for new submissions, modifiable from the earlier network self-assessment, was made describing the opportunity and outlining the selection process based on (a) independent review of the submission from outside the network (submissions from sites included a one page each of description of rationale for each equipment including its estimated cost), (b) input from advisory board on selections and key questions that the selections raised, and (c) discussions with sites and the input from the network's executive committee. Excluded from the selection process were instruments whose cost exceeded a million dollar. These were considered major instruments that needed to be subjected to an open national competition for a thorough independent review, rather than to be considered in an internal competition. Also excluded were characterization instruments that are an end in themselves rather than necessary for in-process characterization in support of fabrication tasks.

The submissions were reviewed by four external reviewers not affiliated with NNIN universities – faculty members in different technical areas who are also very knowledgeable in the operation of facilities. Based on this feedback, written and oral, the first selection list proceeded to step (b) for feedback including questions related to the specific list that arose from the granularity of costs of equipment and issues arising related to the goals of emphasis above and fund distributions among the sites. The network's advisory board consists of senior and accomplished people in industry and academe outside of the network who have faced complex decisions before together with having expertise in different disciplines. It includes Deans, past Senior Vice Presidents of technology companies, and distinguished scientists including a Nobelist. The advisory board also includes one faculty, Dr. Vivian Weil, representing ethics perspective. The executive committee consists of five members (during 2009, Cornell site director, Stanford site director, and three elected site directors who from Penn State University, University of Washington and Georgia Institute of Technology). Following the input from the advisory board, an expanded list was arrived following: (a) a study of the realistic cost of equipment with its selected options that a site should be able to achieve on its own, and (b) cost benefits that can be derived by the network collectively bargaining from the same manufacturer. A number of tools – etching tools, sputtering tools, evaporators, electron microscopes, etc., common on the list allow this latter efficiency. The result of the expanded process was a list that is nearly 30% more in value than the first draft of selection.

The selection submitted here represent the optimal combination achieved consistent with criteria (1) through (4) described above. The larger sites of the network have equipment funding in the 40-51% range of their yearly NNIN funds, while for smaller sites the equipment funding reaches up to 160% for University of Colorado.

Table 1 – List of Tools acquired and being acquired through ARRA Funding

#	Site	Item	Request	Site Total
1	Cornell	Advanced High Resolution Pattern Generator	$850,000	
2	Cornell	Contact Mask and Bond Aligner	$270,000	
3	Cornell	Expanded Range Film Thickness Measurement	$44,000	
4	Cornell	Ion implanter Computer Upgrade	$85,000	
5	Cornell	Atomic Force Microscope	$127,000	$1,376,000
6	Stanford	Plasma Enhanced CVD System	$550,000	
7	Stanford	Electron Beam Evaporator System	$250,000	
8	Stanford	Flexible RF/DC Research Sputtering System	$210,000	
9	Stanford	Versatile Atomic Layer Deposition Tool	$225,000	$1,235,000
10	Michigan	Inspection SEM-	$460,000	
11	Michigan	Image Reversal Oven	$55,000	$515,000
12	Georgia Tech	Monochromated small-spot X-ray Photoelectron Spectrometer (XPS) System.	$420,000	
13	Georgia Tech	Plasma Enhanced Atomic Layer Dep. System	$225,000	
14	GeorgiaTech	Confocal Microscope	$150,000	$795,000
15	Penn State	Advanced Optical Microscope	$36,000	
16	Penn State	Electroplating System with full wafer capability	$32,000	
17	Penn State	Stylus Profilometer	$85,000	
18	Penn State	Ion Beam Assisted and Conventional Sputter Deposition chamber for existing sputter tool	$220,000	
19	Penn State	One Atmospheric and Two LPCVD Stack	$275,000	$648,000
20	U. Minnesota	Sputtering System	$250,000	
21	U. Minnesota	High Throughput RIE	$180,000	
22	U. Minnesota	High Resolution FE-SEM (refurbished)	$200,000	$630,000
23	UCSB	Field Emission SEM for Insulators	$450,000	
24	UCSB	Spectroscopic Ellipsometer	$135,000	
25	UCSB	Xenon Difluoride Etching System	$100,000	$685,000
26	U. Washington	Sputtering System	$170,000	
27	U. Washington	Reactive Ion Etch System	$225,000	
28	U. Washington	Maskless Photolithography Tool	$150,000	
29	U. Washington	Rapid Thermal Annealer	$100,000	$645,000

30	Harvard	Sputtering System	$116,990	
31	Harvard	Microfluidic Lithography Station	$24,000	
32	Harvard	Plasma Enhanced CVD of Diamond	$183,010	$324,000
33	Howard	Surface Profiler	$34,000	
34	Howard	Spin Coaters (x4)	$30,000	
35	Howard	Contact Mask Aligner	$200,000	
36	Howard	Field Emission SEM	$450,000	$714,000
37	Arizona State	Optical Contact Aligner (photolithography)	$225,000	
38	Arizona State	Plasma CVD	$325,000	$550,000
39	U. Colorado	ICP Deep Silicon RIE Tool	$375,000	
40	U. Colorado	Photomask Pattern Generator	$275,000	
41	U. Colorado	Maskless lithography Tool	$150,000	$800,000
42	Wash. U. St.L.	Particle Image Velocimetry (PIV)	$150,000	
43	Wash. U. St.L.	Particle Characterization incl. zetapotential	$80,000	
44	Wash. U. St L	ICP-MS	$160,000	$390,000
45	U. Texas	Deep Silicon Etch	$525,000	$525,000
46	NNIN	Mobile SEMs for Education (2) + 1 EDX detector	$168,000	$168,000
		Total Request	**$10,000,000**	**$10,000,000**

The following is the status of these purchases as of January 2010.

Cornell University

1) Advanced High Resolution Pattern Generator: Mask fabrication is an essential part of CNF's user program; thousands of masks are fabricated each year. This tool will replace an older version at CNF to allow high speed fabrication of mask features down to 0.5 um. This is particularly critical due to CNF's recent acquisition of a 248 nm (4:1 reduction) deep ultraviolet stepper. Full usage of the stepper requires masks with the resolution afforded by this pattern generator. CNF chose a Heidelberg DWL2000. **This tool will be delivered in March 2010.**

2) Contact Mask and Bond Aligner: This instrument expands and improves on CNF's contact lithography ability. CNF chose a Suss Microtech MA6/BA6 with backside alignment. This tool complements an existing Suss SB8e wafer bonder to allow aligned wafer bonding. **This instrument as been installed and is fully operational.**

3) Expanded Range Film Thickness Measurement: This instrument is for measuring the thickness of transparent films using wavelength variation of the optical reflectivity. All thin film deposition processes require frequent measurement and calibration of deposition rates, film quality, etc. CNF's older Filmetrics system was heavily used for a number of years but could only measure thin films. The F50 EXR model contains an additional infrared (IR) light source and software to perform measurements on films up to 250 µm thick. Materials such as SU8 and KMPR are often used in thick layers for many life sciences applications as well as for electroplating molds. **This instrument is installed and operational.**

4) Ion implanter Computer Upgrade: CNF operates a Nova ion implanter, one of the few available in university laboratories. This instrument is over 20 years old and suffered badly from an outdated and obsolete control system. This item provided for a modern PC control system with new software and hardware interfaces, purchased as an upgrade from the OEM. **It has been installed and the entire instrument is working.**

5) Atomic Force Microscope: This state of the art atomic force microscope expands CNF's capability in this area, supplementing CNF's current 10 year old DI3100 AFM. CNF selected a Veeco Icon AFM. This newest generation of AFM has a significantly lower noise floor than prior instruments. This instrument includes the Nanoman option for direct lithography and manipulation of nanostructures. **This instrument will be delivered in March 2010.**

Stanford University

6) Versatile Atomic Layer Deposition System: This instrument enables the deposition of conformal, extremely thin high quality films ranging from dielectrics to high conductivity metals. A Cambridge Nanotechnology Fiji 202 system was selected to meet this need because of its versatile two chamber design and plasma capabilities. This will enable low temperature deposition on sensitive substrates such as carbon nanotubes. **T*he purchase has been finalized and delivery is expected in 6-8 weeks.***

7) Load-locked Capacitive Coupled Plasma Enhanced Chemical Vapor Deposition System: This instrument enables users of the lab to deposit doped amorphous silicon and silicon carbide. A Plasma-Therm model SLR-730 PECVD system was selected to meet this need. This system met all performance requirements at an affordable price. ***The purchase request in currently in Stanford procurement. Delivery should be 8 weeks after the order is placed***.

7a) Load-locked Inductively Coupled Plasma Enhanced Chemical Vapor Deposition System: This instrument enables deposition of silicon dioxide and low stress silicon nitride at low temperatures (<100 C). This capability is needed by the MEMs/NEMs lab users. A Plasma-Therm model VLN-LL-HDPCVD PECVD system was selected to meet this need. This system met all performance requirements at an affordable price. ***The purchase request in currently in Stanford procurement. Delivery should be 8 weeks after the order is placed.***

8) Flexible Sputtering System: This system adds new metal deposition capability in SNF and increases the capacity for sputter deposition. An Intlvac Nanochrom I system was selected to meet this need as it provided the most capability for the lowest price. ***The purchase request in currently in Stanford procurement. Delivery should be 12-14 weeks after the order is placed***.

9) E-beam Evaporator: This system will add much needed capacity for electron beam evaporation. An Intlvac Nanochrom I system was selected to meet this need as it provided the most capability for the lowest price. ***The purchase request in currently in Stanford procurement. Delivery should be 22-24 weeks after the order is placed.***

University of Michigan

10) Inspection Scanning Electron Microscope (SEM): There is currently no SEM inside the LNF cleanroom and this instrument provides a much needed capability for all lab users, more efficient than having to go to a separate building, especially for external users who are not onsite all the time. A Hitachi HTA SU-8000 was selected because of its high resolution imaging capabilities and stability. ***It has been ordered and will be delivered in May 2010.***

11) Image reversal oven: The LNF currently only supplies one main negative photoresist (AZ 5214) and an image reversal oven will allow our user community to access a much broader set of negative photoresists. The Yield Engineering System YES-310TA Vacuum Bake/Vapor Prime and Image Reversal System is the only system currently available for such unique technology. ***It has been delivered and is currently being installed.***

Georgia Institute of Technology

12) X-Ray Photoelectron Spectroscopy Instrument: This system provides surface science capabilities to the broad user community of the Georgia Tech Nanotechnology Research Center. This instrument was selected mainly due to its ease of use. ***The XPS system has been installed in the Marcus Nanotechnology Building at Georgia Tech and was put into service in February, 2010.***

13) Atomic Layer Deposition (ALD) System: This instrument enhances the ability of NNIN users at the Georgia Tech Nanotechnology Research Center (NRC) to grow thin films of a wide variety of materials (metals and oxides) with monolayer precision and conformal coating of high aspect ratio (> 200:1) nanoscale features. ***A system has been ordered and delivery is expected in the April-May timeframe.***

14) Confocal Laser Scanning Microscope: This instrument enables Georgia Tech NRC users one to characterize the surface features and topology of materials in a broad range of areas research from semiconductor, photonic, and MEMS devices, biomaterials, and corrosion analysis. The microscope selected will allow sub-micron imaging with outstanding 120 nm lateral resolution, 10 nm Z resolution and accurate three-dimensional measurement capabilities without any sample preparation. ***No tool has been selected for purchase,*** but Olympus has agreed to loan a LEXT OLS-3100 system to NRC for evaluation during the February-April time period.

Pennsylvania State University

15) Optical Inspection Microscope

The instrument provides transmission capability and a possible route to high resolution UV imaging in order to implement both a fast turn-around photomask and imprint mask service for our customers. ***We are currently evaluating*** three microscope models: a KLA-Tencor INM100, a Nikon L200D and an Olympus MX61. On site demonstrations of the three instruments will be complete by the end of February 2010.

16) Stylus Profilometer

This instrument replaces the current dated stylus profilometer that is used extensively for in-line film thickness measurements and process control. In addition to programmable multipoint thickness measurements it offers new capabilities for soft material surface characterization and film stress measurement capability. ***We are currently evaluating two models***, the KLA-Tencor P-16+ and the Nanometrics Dektak 8. On site demonstrations will be held in February or March 2010.

17) Plating System

The system provides reliable submicron metal hardmask plating resolution, an important upgrade that will enhance Penn State's focus area and strength in complex oxide device integration. In addition, it will be capable of electroforming metal nanowires directly into nanmolds or creating anodized aluminum nanomolds for nanowire formation. ***We are currently in discussion*** with ElectroChemical Systems, Inc. to redesign their system to provide additional small volume plating capability for added low cost flexibility.

18) Oxidation / LPCVD System

The new compact system provides our customers with the same oxide growth and polysilicon and nitride deposition processes offered today but will provide a more efficient use of clean room space, decreased downtime, lower defect density and lower operating costs. ***We are currently evaluating systems*** from ATV-Technologie (PEO-604), Steed Technology(Colt 150 model), Thermco Systems (Model 2604), and MRL Industries (HT/LT Series).

19) Combined ion beam and sputter deposition chamber

The new chamber provides critical sputtering processes for emerging applications that require ultra-smooth films or for devices that are extremely sensitive to high energy ion bombardment, electron flux, and high temperatures. ***We are currently in discussion*** with Kurt Lesker, Inc. concerning the design of the chamber and its integration into our existing Lesker evaporation system.

University of Minnesota

20) Reactive Ion Etch system

This instrument enhances dielectric etching capability for standard silicon processing. An Advanced Vacuum Vision 320 Mk II was selected as it is compatible with an etcher we currently have in operation, easing training and maintenance tasks. ***The tool has been ordered and is scheduled to be delivered in May.***

21) Sputter Deposition system

This instrument enhances sputter deposition capability for both metals and insulators. An AJA International ATC 2200 was selected since Minnesota currently already has a similar system from AJA. We are in the process of final negotiations with the AJA on system configuration. ***We expect a purchase order to be issued in March, with delivery in fall 2010.***

22) Scanning Electron Microscope

This instrument enables NFC users to image and analyze the devices they fabricate at the micron and nanometer scales. A JEOL 6610-LV was selected to meet this need because of its ease of use, allowing a wide range of users to operate the system with only basic training, and its ability to operate at low vacuum to accommodate out-gassing samples. ***The system has been ordered and will be delivered in about four months.***

UCSB

23) Field Emission Scanning Electron Microscope: This instrument enables imaging of insulating materials at the nanoscale without the need for conductive layer coatings, a critical need for measuring samples in the middle of process sequences, and will increase the facility's strained FESEM imaging capacity. A JEOL 7600F system was selected to meet this need because of the demonstrated imaging capabilities using the Gentle Beam mode of the instrument at voltages less than 500V. ***It was installed in January 2010 and is undergoing acceptance testing.***

24) Spectroscopic Ellipsometer: This instrument enables complete characterization of the optical properties of the wide variety of optical films produced in the facility and allows for in-situ characterization of films grown in the facility's new Atomic Layer Deposition (ALD) system. A Woolam M-2000D system with Infrared extended wavelength and automatic angle options was selected to meet this need because of the ability for the tool to integrate with the ALD and the unique rotating compensator design for fast, accurate, repeatable measurements over the full spectral range. ***It was delivered in February 2010***.

25) Xenon Difluoride Etcher: This instrument enables the MEMS community at UCSB to do chemical release etching of free-standing structures without the need for plasma or wet chemistry. A Xactix Xetch X3 system was selected to meet this need because of the unique pulsing capabilities of the machine compared to other models that use XeF_2 for dry gas etching. ***It was delivered in January 2010 and will be installed in early March 2010.***

25a) Plasma Enhanced Chemical Vapor Deposition System: This instrument alleviates major process throughput issues in the facility as this process is used by a large number of researchers. An Advanced Vacuum Vision 310 system was selected due to price and ease of maintenance compared to competitors with similar processes including dual frequency low-stress nitrides and large platen area for wafer throughput. ***The system has been ordered and was partially paid for by the facility.***

University of Washington

26) Sputtering System: This instrument enables the sputtering capability at Washington by improving deposition uniformity and adding capabilities such as cosputtering and elevated substrate temperature deposition. A Kurt J Lesker Lab 18 was selected to meet this need based on the fact that it was able to provide standard RF/DC sputtering for at least 4 targets, plus had the added capabilities of cosputtering, deposition on substrate temperatures up to 550 C, as well as options for pulsed DC deposition. ***The system will be ordered shortly and is expected to be received in June/July 2010.***

27) Reactive Ion Etcher: This instrument replaces an aging parallel plate system at the site. The system allows improvements in etch rate and uniformity that were degrading on the old system; it also adds two gases not previously available to further enhance the etch capabilities in the lab (specifically more selective oxide etch and physical sputter etching). An Advanced Vacuum Vision 320Mk system was selected in collaboration with the University of Minnesota based on the capacity for different etch gases, the use of highly regarded STS technology (Advanced Vacuum is a spin-off of STS to create small research and development etchers). ***The system has been order and is expected to be received in May 2010.***

28) Tabletop Laser Pattern Generator: This instrument can be used for applications like MEMS, BioMEMS, Integrated Optics, Micro Fluidics or any other application that requires high precision, high resolution microstructures. A Heidelberg µPG 101 system was selected specifically to bridge existing micro/nano fabrication capabilities for production of chrome photomasks and direct write patterns. In addition to producing 3 micron features at 30 square mm per min the internal camera facilitates alignment for multiple layer devices. ***The µPG 101 system was fully functional and available to users in February 2010.***

29) Rapid Thermal Annealer: This instrument enables rapid thermal annealing at the NNIN site, something previously unavailable. It allows users to perform implant activations, contact anneals, and even oxidation of very thin films. Two Modular Process RTP-600S systems were purchased to fill the need, based on systems sold and the positive response from those users. ***The system is expected to be received in April 2010.***

Harvard University

30) Sputter Deposition System: One of the most heavily used capabilities in the CNS is sputter deposition of materials, and this second system will provide a significant and much-welcomed increase in deposition capacity. An Orion 3 system by local Massachusetts company AJA was selected after a competitive process which resulted in additional warranty, pricing discounts, and additional options. A purchase order is currently being readied for release to the vendor. ***The system is expected to be delivered by early August.***

31) Microfluidic Lithography Station: In support of a very active microfluidic fabrication and characterization user base we are obtaining a new flood exposure system which will be used in the . production of master molds. After a competitive procurement process, an LS 30/5 Near UV Lightsource System by OAI Company was selected. A purchase order is currently being readied for release to the vendor. ***The system is expected to arrive April 2010.***

32) Diamond Deposition System: Deposited single crystal and polycrystalline diamond films have remarkably exceptional properties and are of acute current interest across a range of diverse research disciplines. In order to provide research-oriented deposition capability, A Model AX5010-INT Microwave Plasma CVD System by Seki Technotron USA was selected after competitive analysis because of its flexibility and proven ability to produce quality films in a university environment. Purchase negotiations have resulted in the addition of valuable options, and a purchase order is currently being readied for release to the vendor. ***The system is expected to be delivered in early August.***

Howard University

33) KLA-Tencor-Alpha-Step IQ Stylus-based Surface Profiler: The Alpha-Step IQ stylus-based surface profiler combines high measurement precision with versatility and economy. Ideal for semiconductor pilot lines and materials research, this advanced surface profiler enables faster process learning and higher yields. With guaranteed 8Ã… (1 sigma) or 0.1% step height repeatability and sub-angstrom resolution. A basic tool like this will clearly have many users and is a good investment. ***This profiler is ordered and the deliver date is early April.***

34) OAI: Model 804MBA Mask Aligner: The OAI Model 804MBA is a mask aligner with optical front side and optical backside alignment capabilities. The system has outputs of 365nm, 405nm and 436nm. Both optical and infrared transmission viewing are available for front to backside alignment. This system is designed to operate for extended periods (years) with minimum maintenance. This is a tool that will be used by a number of groups. ***The mask aligner is ordered and the deliver date is late April.***

35) JEOL- JSM-7600F Scanning Electron Microscope: The JSM-7600F is a state-of- the-art thermal FE-SEM that successfully combines ultrahigh resolution imaging with optimized analytical functionality. SEI resolution is 1.5 nm (1 KV) in GB mode, 1.0 nm (15 KV). The system employs gentle beam mode for top-surface imaging reduced beam damage and charge suppression. The facility is missing a high quality tool like this and it will double as an e-beam writer. ***The system is ordered and deliveyr will be sometime in May or June.***

36) Specialty Coating Systems (2) SCS 6800 Spin Coaters: The SCS 6800 Spin coating Series enables R&D and university laboratories to efficiently and accurately develop and refine coating applications. Its user-friendly operation allows for uniform coatings of photoresist, metal-organics, dopants, and aqueous solutions to planar substrates. A basic set of tools like this will clearly have many users and is a good investment. ***The spin coaters are ordered and delivery is early April.***

Arizona State University

37) Optical Mask Aligner: This instrument enables optical patterning of samples up to 8" diameter wafers with feature sizes of approximately 1 micrometer. A model 800MBA from Optical Associates Inc. was chosen because of the enhanced flexibility and ease of use allowing for full front and back side optical alignment. ***The instrument has been fully commissioned and is available for use in the ASU NanoFab cleanroom***.

38) Plasma Enhanced Chemical Vapor Deposition: This tool replaces an existing PECVD system that is >25 years old and is close to failing permanently. An Oxford PlasmaLab 100 was chosen to provide our users with additional capabilities including doped oxide deposition. ***The tool is being manufactured and will be delivered to ASU in April 2010.***

38a) Laser Diode Equipment Upgrade to Optical Mask Maker: Our existing DWL66 Heidelberg Instruments mask aligner uses gas lasers that can take > 24 hours to expose a single mask plate. This equipment upgrade will make use of higher power solid state laser diode and a new optical imaging system to allow much faster write times. ***The order has been placed with the manufacturer and they are scheduled to install the equipment in April 2010***.

University of Colorado

39) Inductively coupled plasma (ICP) reactive ion etcher (RIE): This tool provides users the ability to perform deep dry etches with high aspect ratio. A SPTS LPX ICP SR was selected. ***It has been ordered and is expected to be delivered in May 2010.***

40) Laser Pattern Generator: This instrument provides users with low cost, fast turn-around, quality lithography masks. A Heidelberg DWL 66FS was selected because of the balance between cost, quality and reliability. ***It has been delivered and is in use***.

41) Maskless Exposure System: This system offers direct on-wafer exposure, for fast-turn, flexible optical lithography. An Intelligent Micro Patterning SF-100 Xpress was selected because of the flexibility and high speed. ***It has been ordered and is expected to be delivered in May 2010.***

41a) Atomic Force Microscope (AFM) upgrade: This upgrade for Nanosurf EasyScan 2 expands the capabilities of our AFM to include pen-dip lithography, STM measurements, and larger range scanning. ***It has been ordered and is expected to be delivered in February 2010***.

Washington University in St. Louis

42) Particle Image Velocimetry: This instrument enables fluid visualization that obtains instantaneous velocity measurements and related properties in fluids. A Model TSI-2D & 3D PIV was selected to meet this need because of its generic functionality of handling different cases – micro flow, macro flow, air flow and liquid flow. ***It has been purchased and will be delivered in March 2010.***

43) Dynamic Light Scattering: This instrument enables the measurement of particle size distribution, zeta potential and molecular weight. A Model Malvern Nano ZS was selected to meet this need because of this unique technology backscattering that improves sensitivity of measurement and prevents multiple scattering. ***It was delivered in November 2009.***

43a) Inductively Coupled Plasma Mass Spectrometry: This instrument enables the ultra-trace level detection of elements (ppt-ppb). A Model Elan DRCII from Perkin Elmer was selected to meet this need because of this unique technology Dynamic Reaction Cell (DRC) that can eliminate the interference of elements with plasma based polyatomic species. ***It was delivered in November 2009.***

44) Inductively Coupled Plasma Optical Emission Spectroscopy: This instrument enables the trace level detection of elements (ppb-ppm). A Model Optima 7300 DV from Perkin Elmer was selected to meet this need because of the capability of analyzing large sample loads quickly and the function of automatic dual viewing that ensures the lowest detection limits and widest working ranges. ***It was delivered in November 2009.***

University of Texas at Austin

45) Deep Silicon Etch (Bosch): This instrument enables etching of high aspect ratio features into silicon, with smooth side wall profiles. A Plasma Therm Versaline DSE was selected. The Versaline DSE will be essential for the groups who develop Biological MEMS with Porous Silicon vehicles and imaging agents at the University of Texas at Austin. ***This system has been ordered and will be delivered in March 2010.***

NNIN Education Program

46) Portable SEMS(2): Demonstrations are an important part of the NNIN Education Program. Table top Scanning Electron Microscopes provide an opportunity to expose students to a “real” piece of nanotechnology instrumentation. On behalf of NNIN, the NNIN Education Coordinator at Georgia Tech has been evaluating the available instruments which include instruments from Phenom (FEI) and Hitachi. ***A decision will be made in March***. Two instruments will be purchased for loan around the network, one located at Georgia Tech and the other on the west coast.

46a) EDX detector for portable SEM: A small solid state EDX detector (SwiftED-tm) has been purchased for use on the NNIN table top SEM located at Cornell. It will be used to demonstrate simple materials analysis to high school students. ***It has been delivered and installed.***

2.2.3 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. As part of the renewal, the following 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 National Institute of Materials Science (NIMS) in Japan and Forschungszentrum (Helmholtz Insitute, Jülich) in Germany, building upon the NNIN REU program. Ten 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 as globally aware researchers.
- **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. Ten students, selected through a national competition open to US national graduate students, and five faculty traveled to IIT Bombay, India for a course on Nanoelectronics. The US faculty taught the course and nearly 150 students from India attended the course. 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.

Each of these three programs had the additional effect of establishing important relations between NNIN and major research international research institutions. A fourth major program initiated by NNIN is:

- **LEF:** NNIN Laboratory Experience for Faculty Program; a summer REU-like program for under-represented faculty or faculty at under-represented 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 under-represented 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.

2.2.4 Expanded Continuing Programs

As part of the renewal, the following existing NNIN programs were expanded significantly:

Symposia and Advanced Topics Workshops: The Symposia and Advanced Workshops are four major events during the year, organized by different NNIN sites, to explore advanced topics – new research direction areas and their needs that NNIN could contribute to, bringing together senior thinkers and practitioners to explore questions at interdisciplinary interfaces, or to deliberate how NNIN can seed and catalyze important research and development activities. During the 2009 year, these included:

- **Nanotechnology as an Enabler for Neuroscience, Neuroengineering and Neural Prostheses (Nano for N3)**: Organized at Stanford University
- **Synergies in Nanoscale Manufacturing and Research**: Organized at Cornell University
- **Nano-enabled Sensing Microsystems for Geo Sciences:** Organized at University of Michigan
- **Symposium on Nanotechnology for Public Health**: Organized at Washington University at St. Louis

Summaries of learning from these symposia are summarized later in this report.

In addition, NNIN organizes a variety of workshops and conferences as outreach activity to both its user community and the broader nanotechnology community. These are detailed in Education and Outreach section of this report.

Nanotechnology Showcase for Students: The NNIN Nanotechnology Showcase is a pipeline event to increase awareness of nanotechnology opportunities among under-represented undergraduates. An introduction to nanotechnology, together with table-top demonstrations, is provided at prominent undergraduate engineering conferences. In March 2009, the Showcase was presented at the Annual Conference of the National Society of Black Engineers in Las Vegas. Technical Staff and Education Staff from most NNIN sites participated in this event.

Nanooze, the Web Site, the Magazine and the Exhibit: Nanooze is one of the few nanotechnology resources available at a level appropriate for use in elementary and middle school classes. As the approach has been well accepted by kids and educators, we have expanded the scope and reach of the "Nanooze" brand over the last several years. The original web site at **Nanooze.org** contains science features related to nanotechnology and items in the news in an interactive format accessible to children. In print, **Nanooze** magazine is distributed to classrooms by direct mail as well as distribution at education conferences and workshops. Two to three issues of **Nanooze** are produced each year, under the editorial direction of Prof. Carl Batt at Cornell; we are currently distributing the sixth issue. Issues in 2009 covered "W*hat's nano about* "Self Assembly and Food. Fifty thousand copies of each issue are printed; for one issue, we are on the second 50,000 print run. **Nanooze** has also been expanded as an exhibit for hands-on experience that can be located at important places with a high flow of young people. Developed under another program and "repositioned" to NNIN use, "**Nanooze-the Exhibit"**, a 1500 sq ft. museum quality interactive exhibit, has been at the new nanotechnology facility at Georgia Tech for most of 2009. Again, with separate funding, a copy of **"Nanooze-the Exhibit**" opened in February 2010 at the Innovations Center at Epcot Center at Disney World(Fig. 3). where it will be seen by hundreds of thousands of visitors each year.

Fig. 3:: Nanooze the Exhibit at Epcot Disney World

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

Computation and Modeling: NNIN has chosen to tackle the truly challenging science and engineering problems of nanoscale where software and hardware by themselves are insufficient. These problems are interdisciplinary or cross between theory and experiment. In such cases, a domain expert staff member helps with extracting information that is useful beyond the discipline for which a software was originally written, or where academic software becomes useful for community at large. NNIN focuses on computation and modeling tools in support of problems that are interdisciplinary, that bring theory and experiment together, that require advanced knowledge between disciplines, and that address previously unsolvable problems that could benefit from availability and technical support of open codes. NNIN expert staff support mechanics-fluidics-electronics-optics-atomic-molecular dynamic- and related areas. Domain experts are in residence at Harvard and Cornell for science and engineering of condensed matter, at Stanford for interfaces, molecular dynamics and materials science, and at Michigan for fluidics and mechanics and sensors. These efforts are supported through advanced computation clusters where simulations can be performed. In addition, NNIN has also undertaken an initiative to be a repository and archival source for the research community by putting together, testing, and making available trusted pseudo-potentials, interatomic potentials, input file banks, etc. that are of use in a variety of scientific problems. Over 5000 users scientific research users, most of whom are graduate students, employ these resources, with publications results appearing regularly in Nature, Science, Applied Physics-Physical Review-Nano Letters, and other leading journals on problems ranging from chaos, *ab initio* thermal transport, fluid dynamics, multi-phase phenomena, interface and molecular chemical dynamics, Casimir forces, etc.

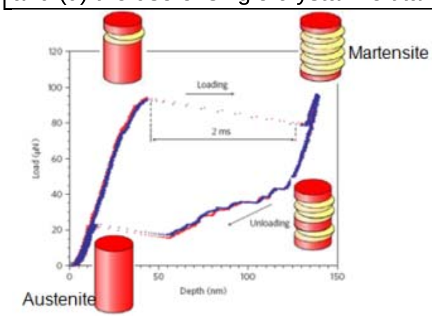
Societal and Ethical Implications (SEI) of Nanotechnology: NNIN seeks the integration and development of a social and ethical consciousness throughout the breadth of network activities while becoming the nation's leading open-access research facility for the study of science. SEI efforts within NNIN therefore embody both the network's research and educational pursuits. NNIN has organized its efforts to take advantage of the network's unique strengths as a national resource with geographic diversity, technical breadth and community interests. Within its user community, NNIN provides training and educational opportunities through SEI modules and supporting teaching materials employed in training and ongoing educational programs, selective incorporation of these in the network educational activities (REU, RET, workshops, symposia, etc.), and in broader outreach activities. NNIN stimulates and facilitates SEI research on the NNIN's unique world leading strength – the largest collection of nanotechnology users (students and professionals), communities (academe and industry) and technologies across the breadth of subjects. NNIN provides opportunities for national researchers via competitive travel and seed grants to support related SEI investigations. NNIN's research efforts also include examination and development of (a) understanding of interdisciplinary collaborations and their impact on research, (b) the impact on competitiveness and the process of technology transfer and industrial innovation and innovation by industry through NNIN, (c) impact of government-funded faculty research and the faculty's interaction with industry in technology transfer, (d) impact of intellectual exchange, openness and sharing such as in a network in conduct and impact of research, and (e) the ethical issues related to nanotechnology and fostering of ethical conduct.

2.3 Examples of Scientific Impact from 2009:

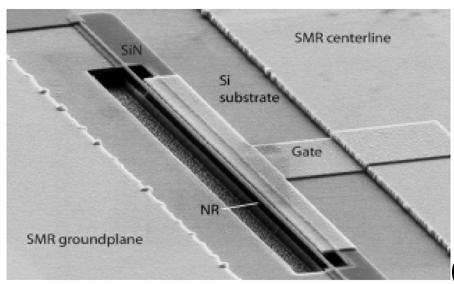
The nearly 3200 publications resulting from work made possible by NNIN encompasses the breadth of engineering, and physical and life sciences where small scale brings exquisite disciplinary and interdisciplinary problems of materials, structures, devices, systems. A publication list over the period July 2008-June 2009 is available as supplementary material to this annual report. These are all available from NNIN's website and they range from fundamental measurements, to molecular and supra-molecular scale structures where technology and devices are practiced, and applications where significant integration is brought together in physical and life science and engineering disciplines.

As examples of recent work, Figure 4 shows a few of the examples from 2009. In Figure 4(a), work by Prof. C. Schuh et al. from MIT, shows the shape memory recovery characteristics at nanoscale dimensions demonstrating the large strain that crystalline phase change can withstand at extremely small dimensions and the complete shape recovery in nanoscale Cu-Al-Ni alloys – a property that could be use in many applications requiring mechanical strength and bistability at small dimensions. In Figure 4(b), Prof. K. Schwab et al. from CalTech have looked at the vibrational/phonon characteristics and come close to the lowest mode limits for this Bosonic system. They have achieved positional sensitivity of 4 times the zero point motion, and using back-action cooling reached 12 quanta through capacitive coupling between mechanical and electrical resonances using superconducting resonators. In the results that are summarized in Figure 4(c), in a joint work between groups of Prof. S. Cronin (USC) and Prof. M. Bockrath (CalTech), Born-Oppenhimer approximation, the approach used to separate electronic and nuclear contributions in condensed matter and molecular calculations, is shown to break down in metallic

Figure 4: (a) shows shape recovery in shape memory alloys at nanoscale exhibiting the high strain possible (Schuh et al. from MIT), (b) shows a resonator (mechanical and electrical) that allowed positional sensitivity of 4 times the zero point motion and back action cooling to 12 quanta by Schwab et al. from CalTech, (c) breakdown of Born Oppenheimer approximation in a carbon nanotube structure by Cronin of USC and Bockrath of CalTech, and (d) the use of single crystalline titanium dioxide nanorods in dye sensitized solar cells.



(a)



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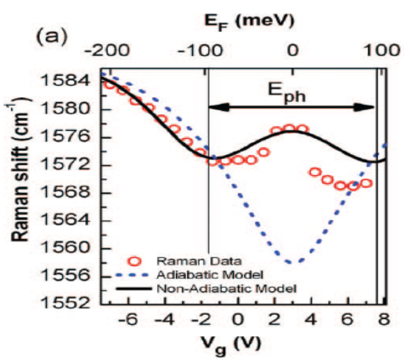
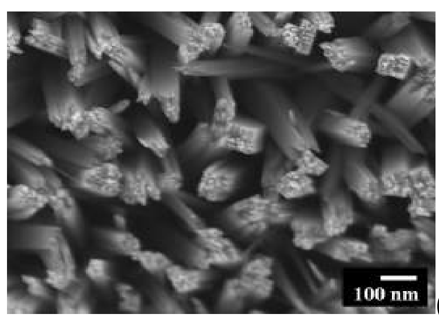


(c)



(d)

nanotubes. Figure 4(d) shows an example of application of nanotechnologies to energy generation. Prof. E. Aydil et al. (U. Minnesota) achieve a 3% efficient dye-sensitized solar cell using short titanium dioxide nanorods and a potentially low cost approach.

2.4 Network Management

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 5: Network Management Structure

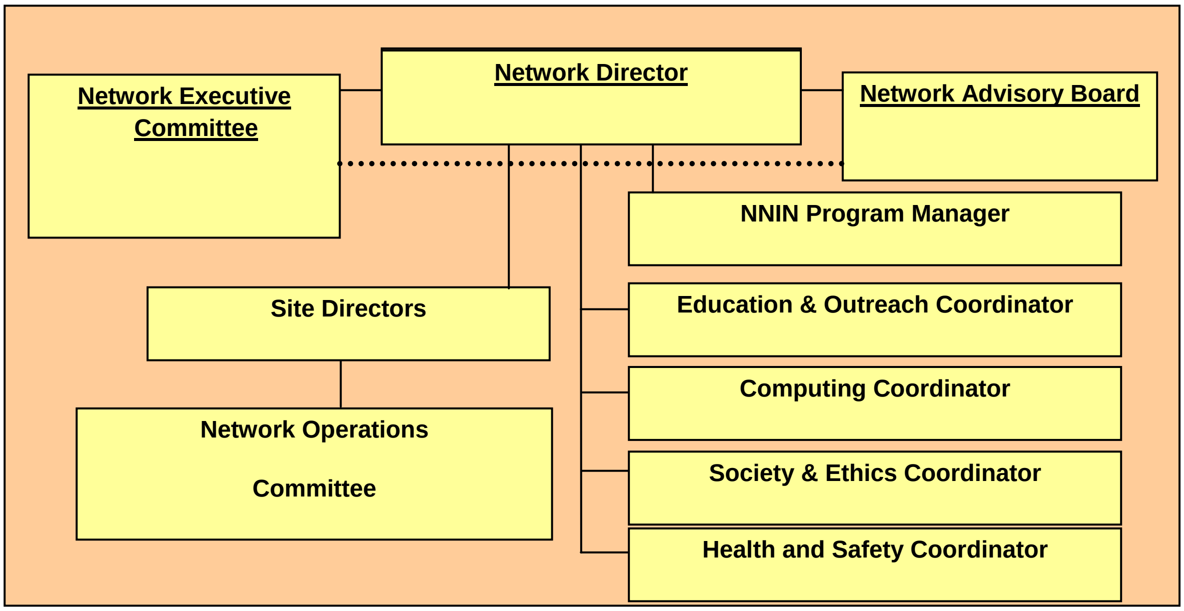


Figure 5 shows the broad outline of the organizational structure. Currently, Prof. Sandip Tiwari, Cornell University, the NNIN Network Director, is the point of contact with NSF, and is responsible for implementing the network policies and program. Dr. Lynn Rathbun, Cornell University, serves as the NNIN Program Manager coordinating the daily activities and communication with network sites.

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

- **Education & Outreach:** Dr. Nancy Healy, Georgia Tech,
- **Society & Ethical Implications in Nanotechnology:** Prof. Katherine McComas, Cornell,
- **Computation and Modeling:** Dr. Mike Stopa, Harvard, and
- **Environment, Health and Safety:** Dr. Dong Qin, Washington University at St. Louis

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 Network Coordinators also participate in the Network Executive Committee discussions. The NEC meets monthly by conference call, or more often, if necessary.

For 2009, the Network Executive Committee consisted of

- **Dr. Sandip Tiwari**
- **Prof. Dan Ralph (Cornell University)**
- **Prof. Yoshio Nishi (Stanford University)**
- **Prof. Theresa Mayer (Penn State University, term expires 2010)**
- **Prof. Francois Baneyx (University of Washington, term expires 2010)**
- **Prof. James Meindl (Georgia Tech, term expires 2011)**

The NEC receives 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 members of the Network Advisory Board are:

Dr. Samuel Bader; Assoc. Div. Director, Materials Science Division, Argonne Natl. Lab

Prof. Harold Kroto; Department of Chemistry, Florida State University

Dr. Carl Kukkonen; CEO, ViaSpace Technologies

Prof. George Langford; Dean of College of Arts and Sciences, Syracuse University

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; Entrepreneur and consultant

Dr. Tom Theis; Director of Physical Sciences, IBM Research

Prof. Vivian Weil; Director, Center for the Study of Ethics in the Professions, Illinois Institute of Technology, Chicago

The advisory board meets, in person, at least once a year, by conference calls, and is consulted by phone and group email by the NNIN Director at critical times.

2.5 Network and Site Funding-Year 6 (2009)

NNIN has been funded by a primary cooperative agreement between NSF and Cornell University. 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. 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. The budget is outlined in Table 2.

Table 2 NNIN Annual Funding by Site-year 6 – March 1, 2009-Feb. 28,2010	Year 6 baseline budget
Cornell	$2,675,000
Stanford	$2,675,000
Georgia Tech	$1,590,000
Michigan	$1,275,000
UCSB	$875,000
Harvard	$825,000
U. Minnesota	$775,000
Penn State	$750,000
U.Washington	$725,000
U. Texas	$700,000
Howard Univ.	$550,000
Arizona State	$500,000
U. Colorado	$500,000
Wash. Univ. in St. Louis	$500,000
Network Coordination	$372,855
Network Activities	$1,712,145
Total	$17,000,000

The NNIN Activities budget is for network-scale activities, including participant support for various programs (REU, iREU, LEF, iWSG, Showcases), network booths at outreach activities and professional meetings, support of Symposia and Workshops, Advisory Board and Annual Meeting, etc. Much of this budget is sub-awarded to sites annually with the activities expected to change based on feedback and in support of new initiatives.

Note, the special ARRA supplement (10M$) is not included in these figures.

A more complete explanation of funding and program allocation is given in the Budget Justificaiton for year 7 funding supplied to NSF.

2.6 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 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, the needs of different types of usage, 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 experimental R&D 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 facilities, gets trained and uses resources to accomplish their own technical tasks, is a research user.

We also collect statistics related to Scientific Computation and Modeling activities separately because of the different nature and needs of this activity.

Evaluating performance in this context is a complex task since it must balance between the nature, character, and the requirements of the activity and an appropriate evaluation of the contribution.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, the impact of the scientific research, 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:

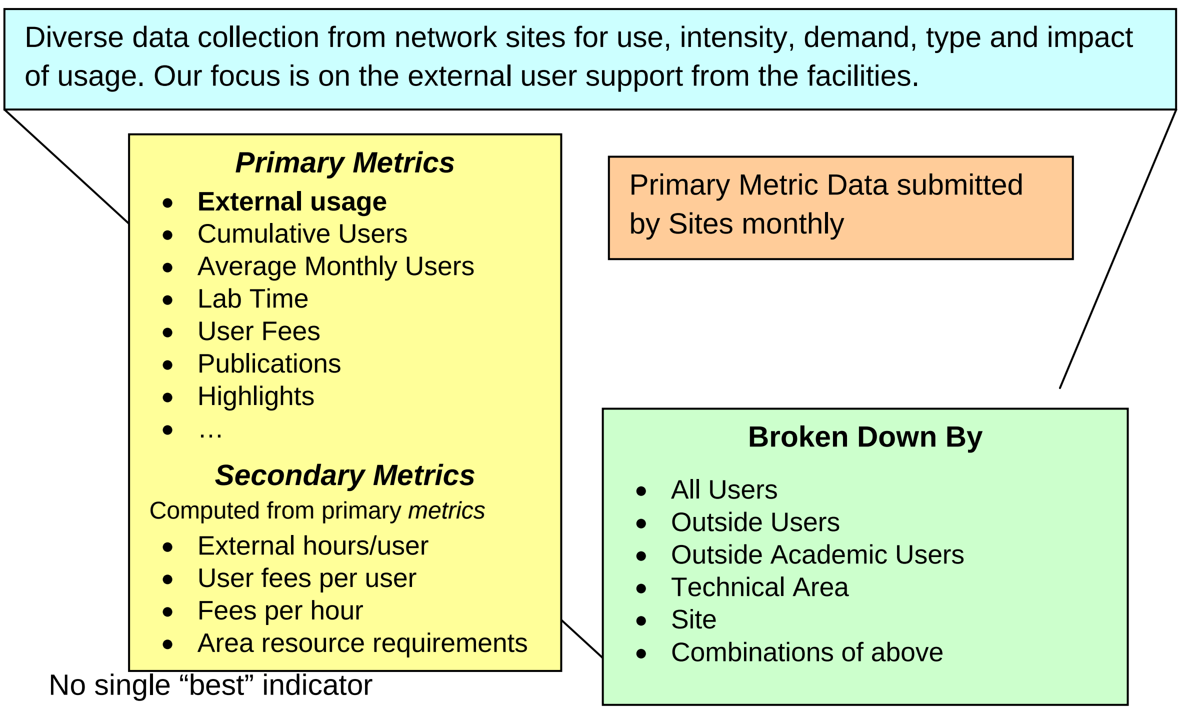
- The range and volume of service that each site can, now and in the near future, provide to outside research users in specific technical areas assigned to it;
- The infrastructure needs of the technical focus areas that are supported by each site;
- The infrastructure needs for the educational efforts 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.

Figure 6 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 experimental research lab usage only. These are related to the projects where a user 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 do not include Computation and Modeling 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 four sites currently.

Figure 6: Network information collection.



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 11 month period March 2009-Jan 2010. Data will be updated after Feb. 28, 2010 to reflect the full 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.

2.6.1 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 7 shows the distribution of users by field (11 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. GeoSciences is an area with least activity, and NNIN has placed special emphasis for expansion here. Our focus is on leveraging sensors and microsystems knowledge to help the scientists and engineers in Ocean Sciences community. A Symposium was held at University of Michigan in 2010 resulting in collection of a number of ideas jointly developed by geoscientists and NNIN users that will be catalysts seeds for this expansion.

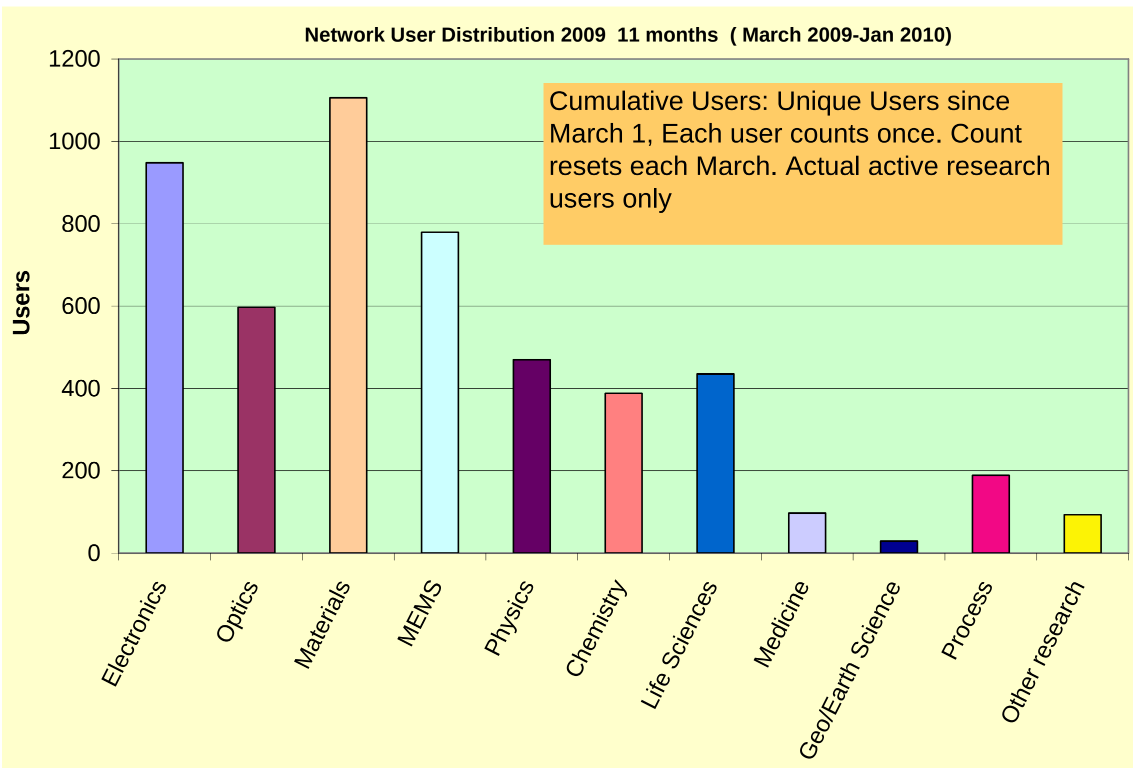
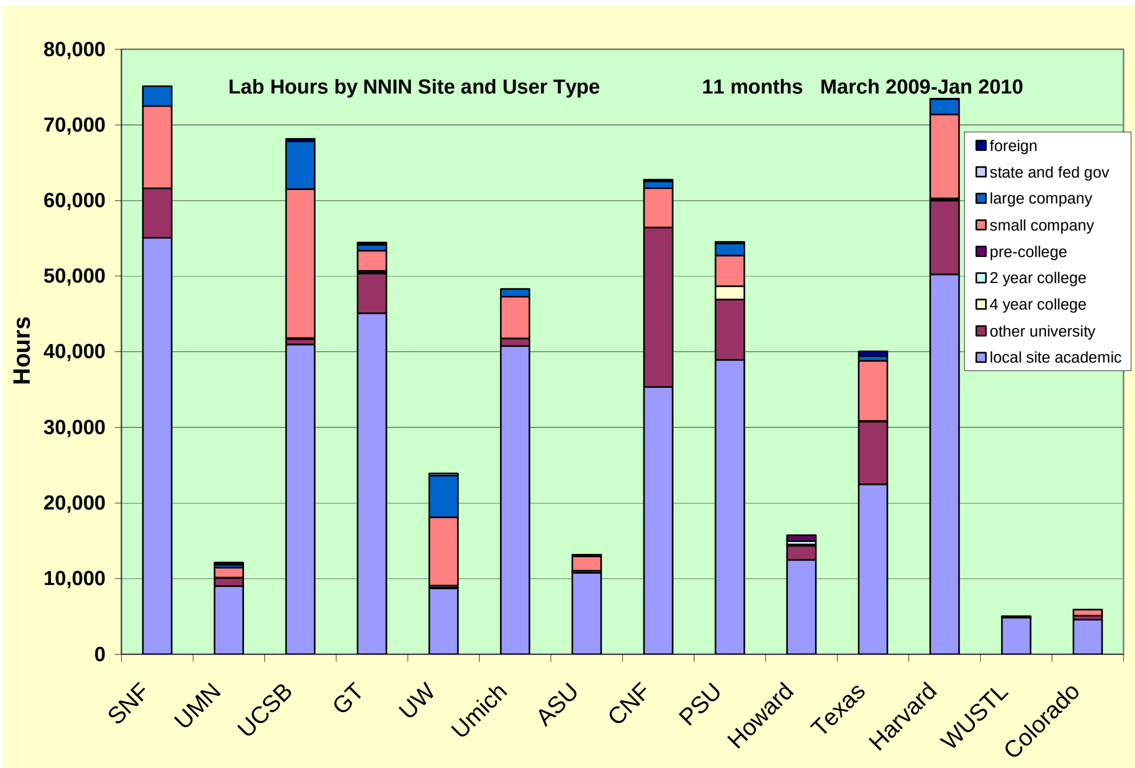


Figure 7: Network User Distribution by Technical Area.

2.6.2 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 8: User Lab Hours by NNIN Site.



The chart in Figure 8 represents total lab hours during the 11 month period (March 2009-Jan. 2010). 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.

2.6.3 Cumulative Annual Users

***Cumulative Annual Users* is a primary user counting metric employed by NNIN; this is often just referred to as "users"**. This is each unique experimental research 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 9 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.8.) Cornell and Harvard reflect a large and good balance between internal and external users, with Stanford, U. Minnesota, UCSB, Texas, and Georgia Tech also 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, such as intensity of usage, as a supplement to this.

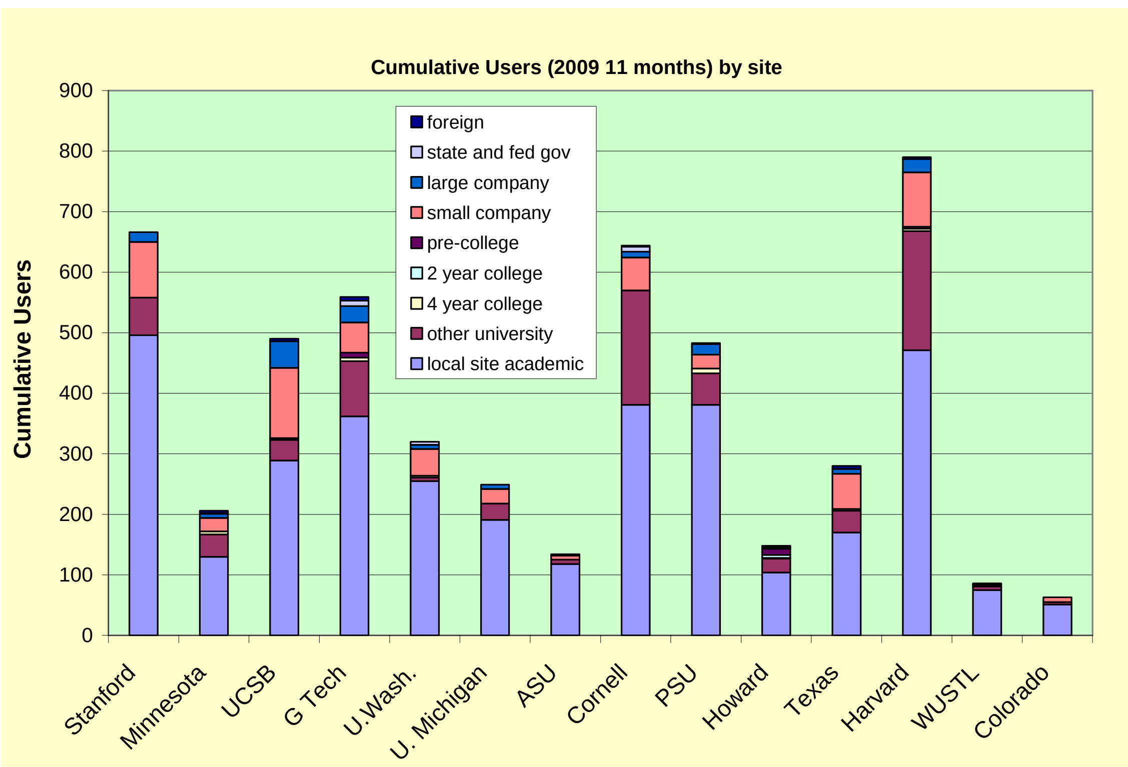
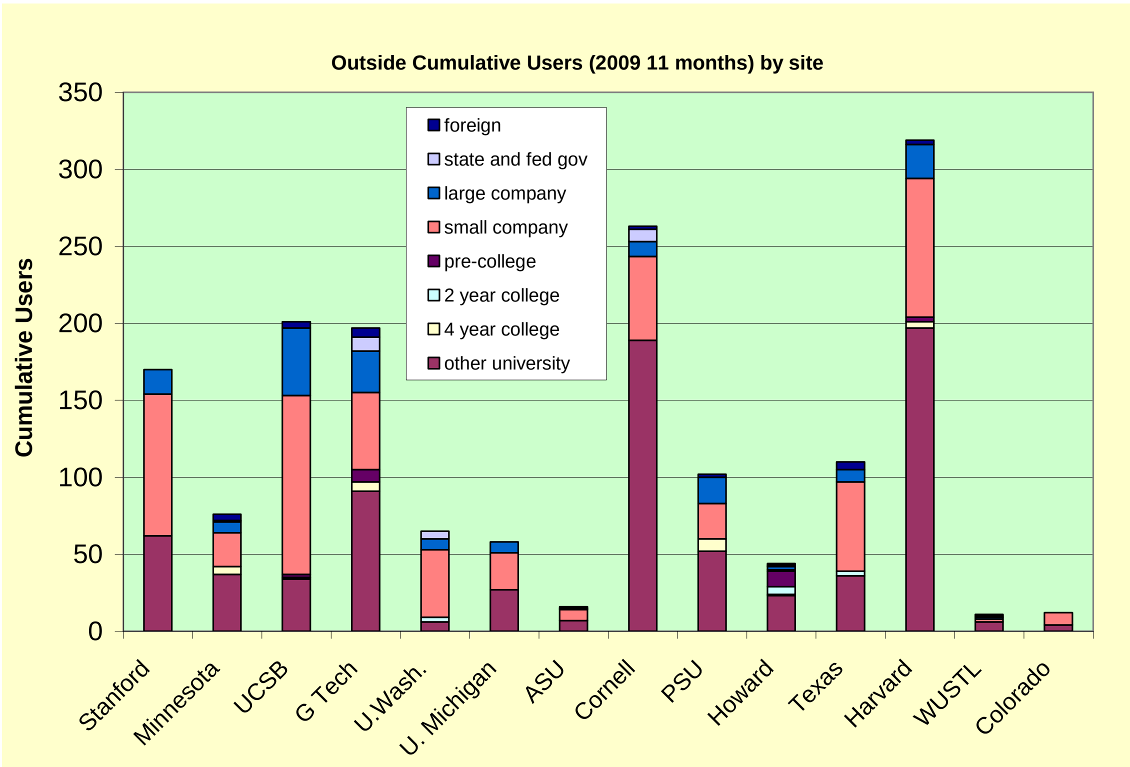


Figure 9: Cumulative Users at each site. (March-Dec)

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 10 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 11 month period, with both academic and industrial users benefiting from the network.

Figure 10: 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 11 shows the trends in usage of the network at the sites. Note that 2009 data is for 11 months only (March 2009-Jan 20108), and is thus approximately 10% less than it would be for the full 2008 NNIN year (March 2009-Feb 2010). While comparison of the 11 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.

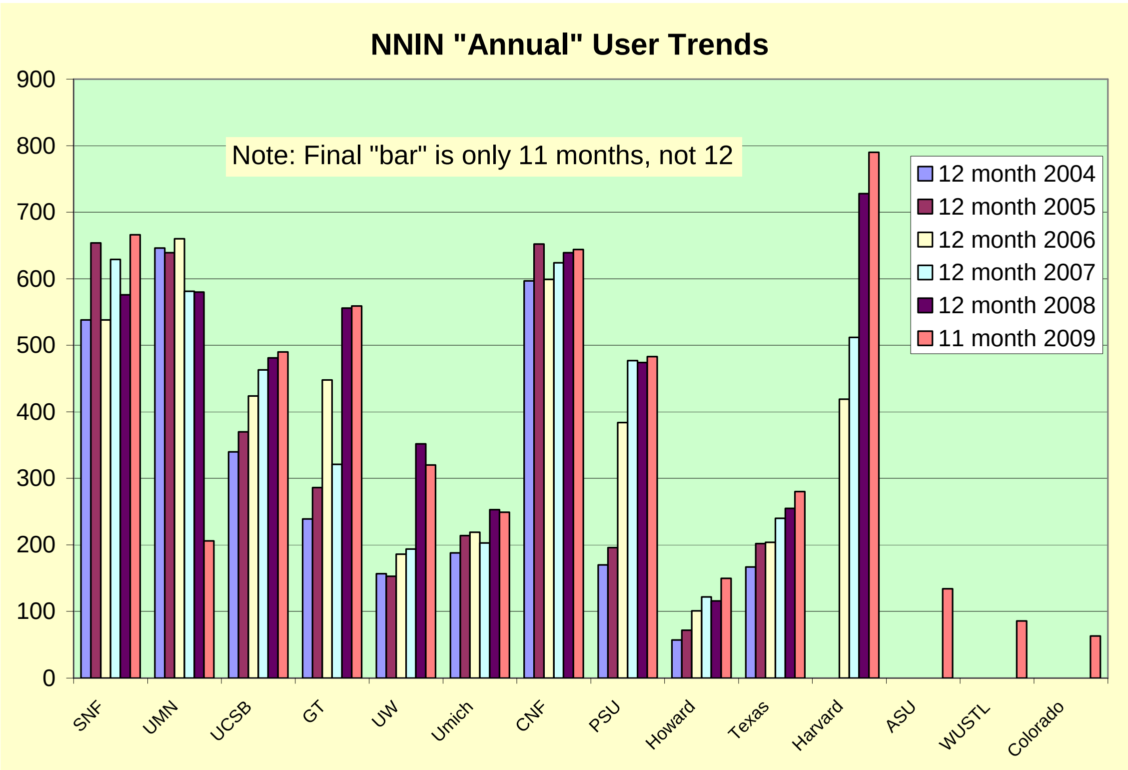
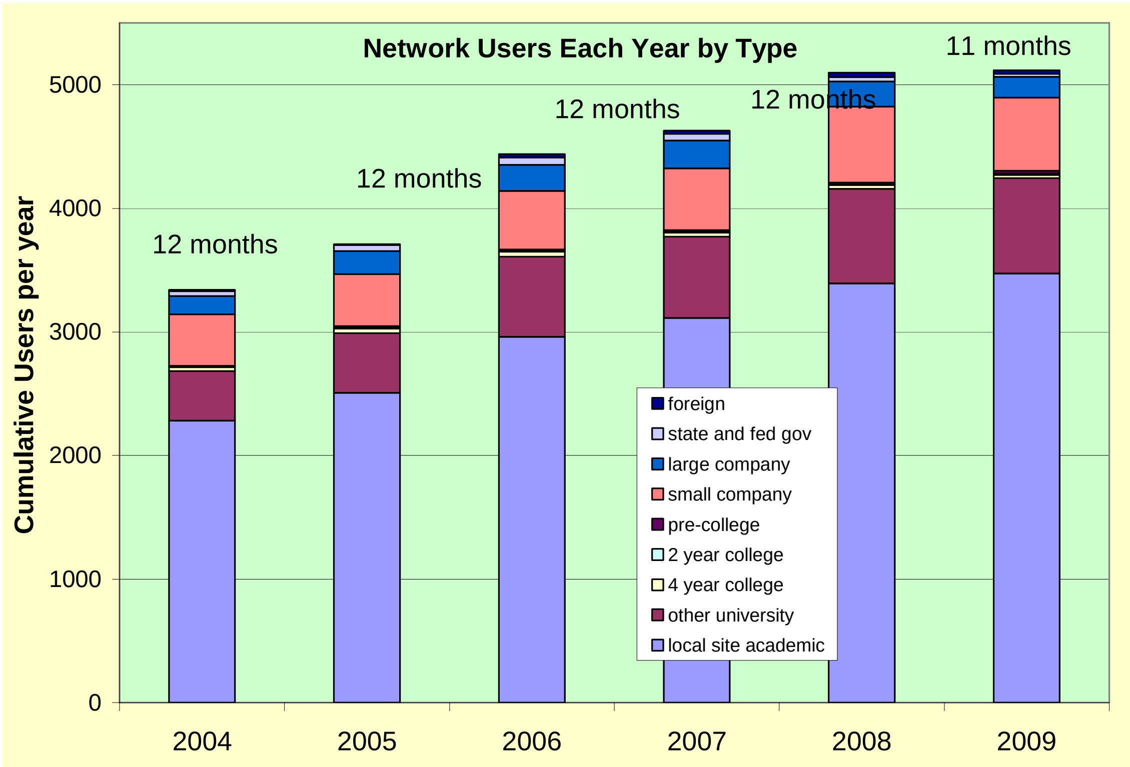


Figure 11: NNIN users by site in a multi year comparison.

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

Figure 12: Network wide research usage



When an adjustment is made for the shorter reporting period of 2009 (i.e. adding approximately 10%), Figure 12 shows a general increase in network usage across all institution types, summed across the network (2009 data for 11 months March 2009-Jan 2010).

2.6.4 Average Monthly Users

An alternative way to look at usage is to look at Average Monthly Users—simply the number of unique uses each month. This is a metric of "how busy" a site is. (Fig. 13). The larger NNIN sites clearly also show a larger number of average monthly users.

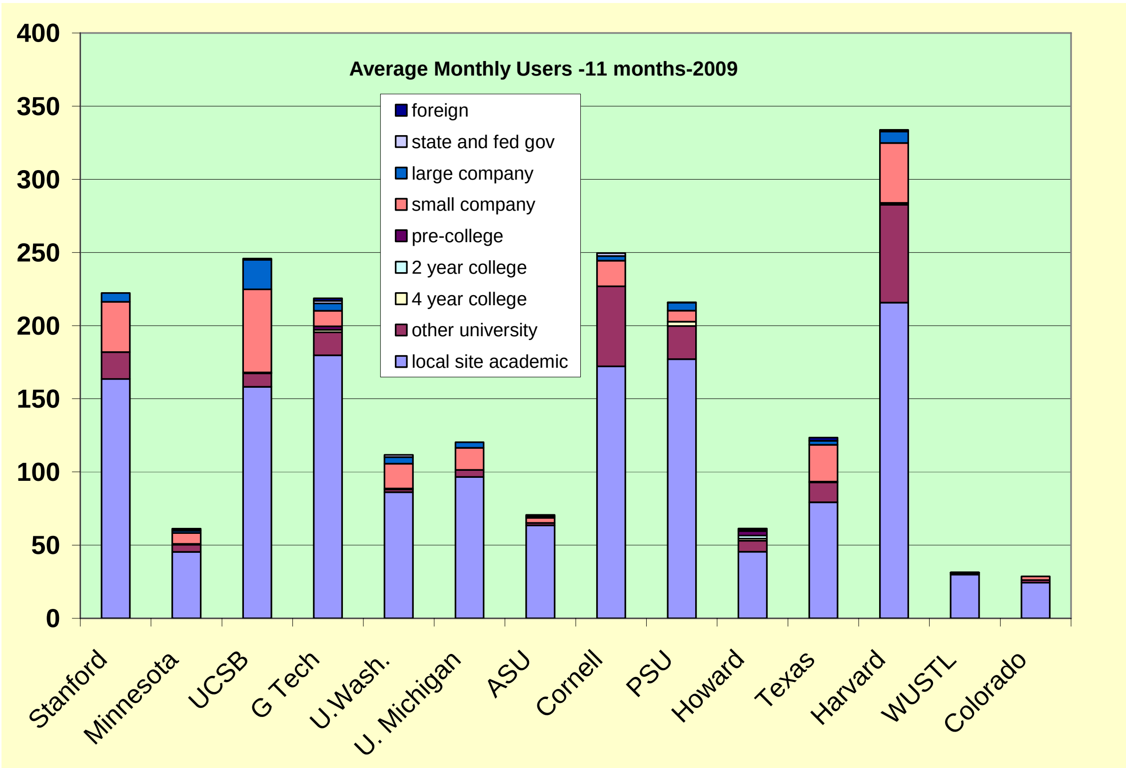


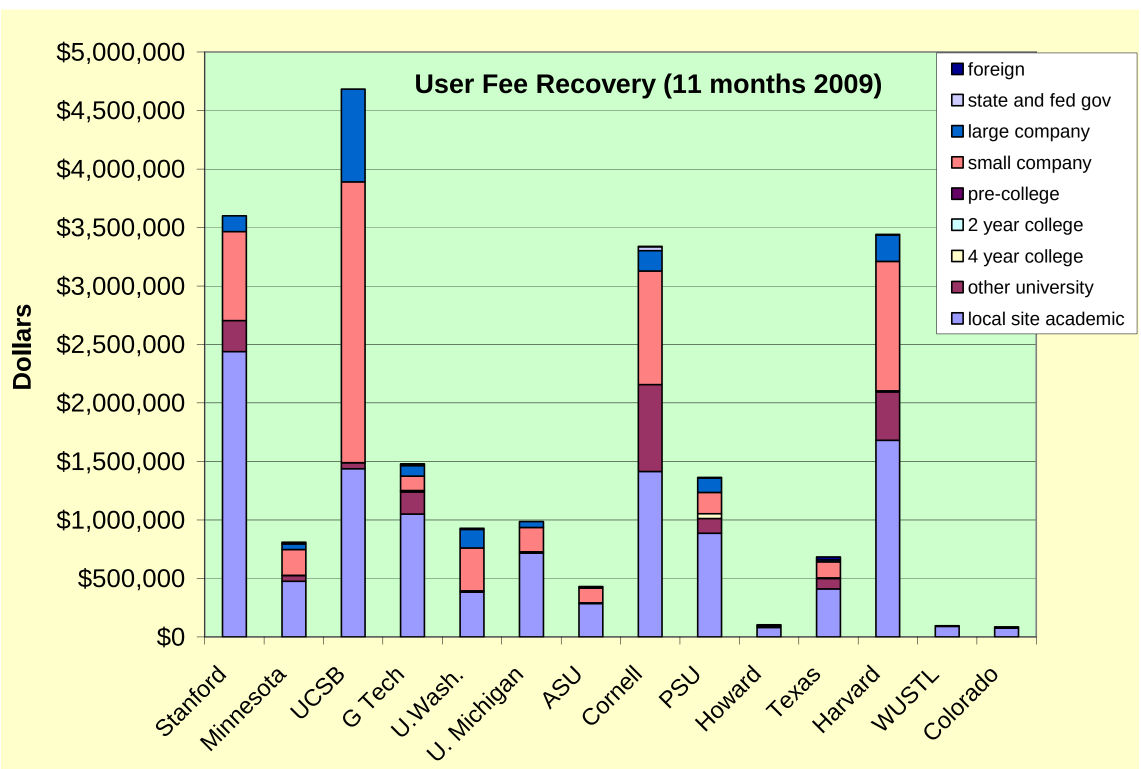
Fig. 13—Average Monthly Users

2.6.5 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 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 to existing, 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. 14 (11 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.

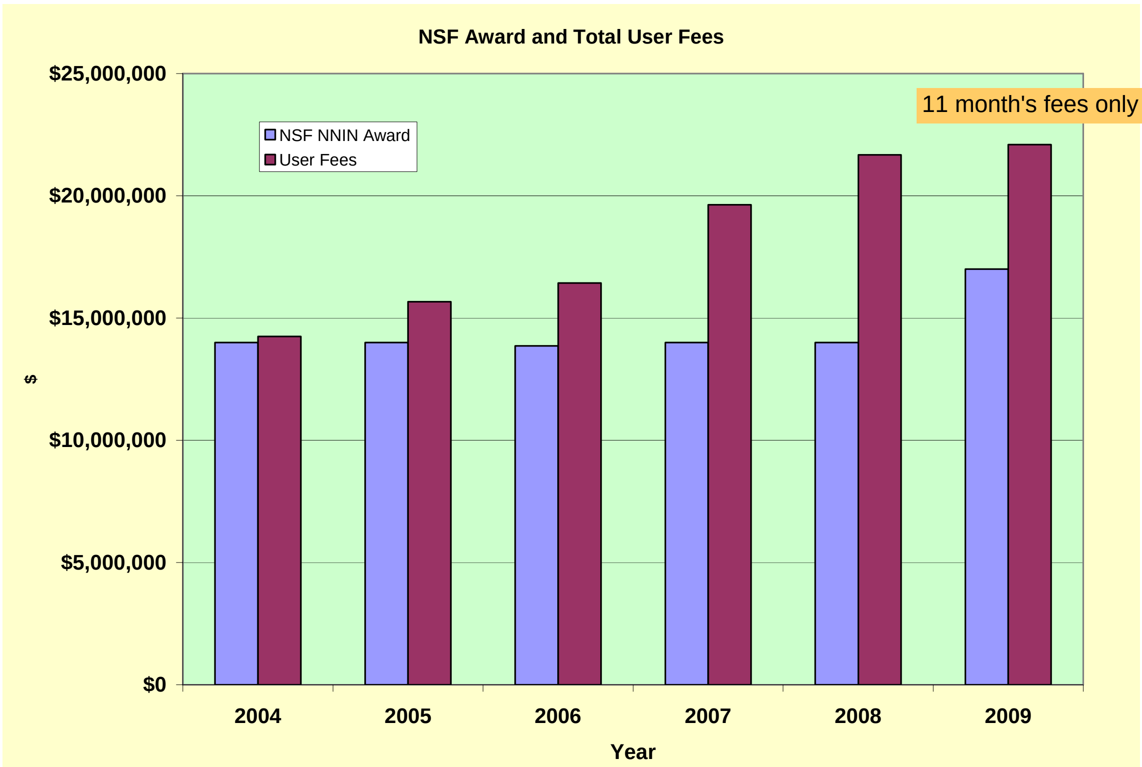
Figure 14: User fee recovery in 2009.



This figure shows the dominance of user fees from small company users to UCSB site, relatively smaller recoveries for most of the other sites, and a balance at Stanford, Cornell and Harvard.

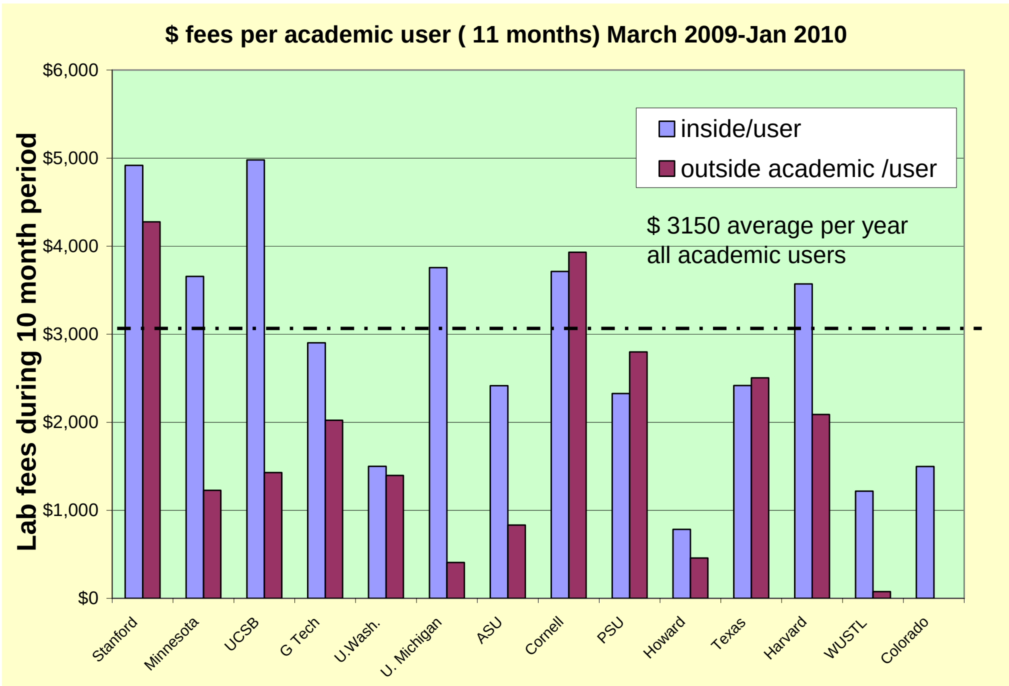
Figure 15 shows the overall high leverage of the NSF investment. Each dollar of the NSF cooperative agreement is more than matched by user fees. Both user fees and the NSF support are critical to operation of NNIN.

Figure 15: Two of network's major sources of funding: NSF and user fees. (NNIN Main Cooperative agreement only)



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 16 compares the local academic (NNIN institution) and outside academic average user fees per user over the 11 month period (total academic fees/ total # of academic users). Fig. 17 shows the average user fees per user for **outside** academic users By NNIN mandate, local users and outside users pay the same rates for use; the variation from the total for all academic users reflects different levels and types of usage. While there is some variation between sites, the most striking part is that the average users paid just over $3000 during the 11 month reporting period. This is an average; many heavy users paid significantly more, and many users paid significantly less.

Figure 16: Average academic user fees.



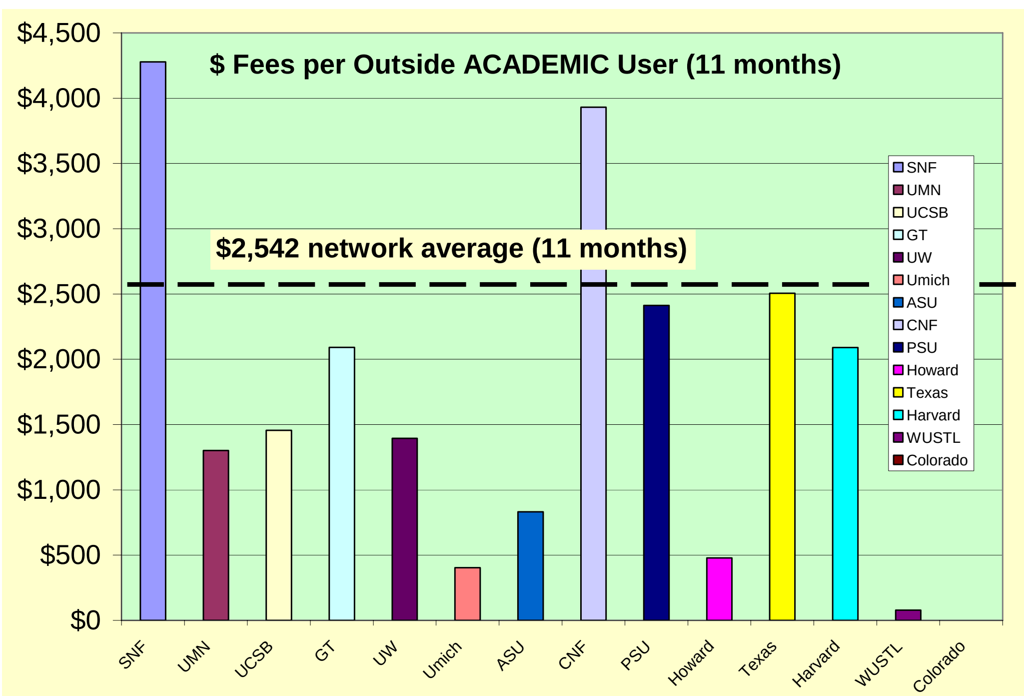
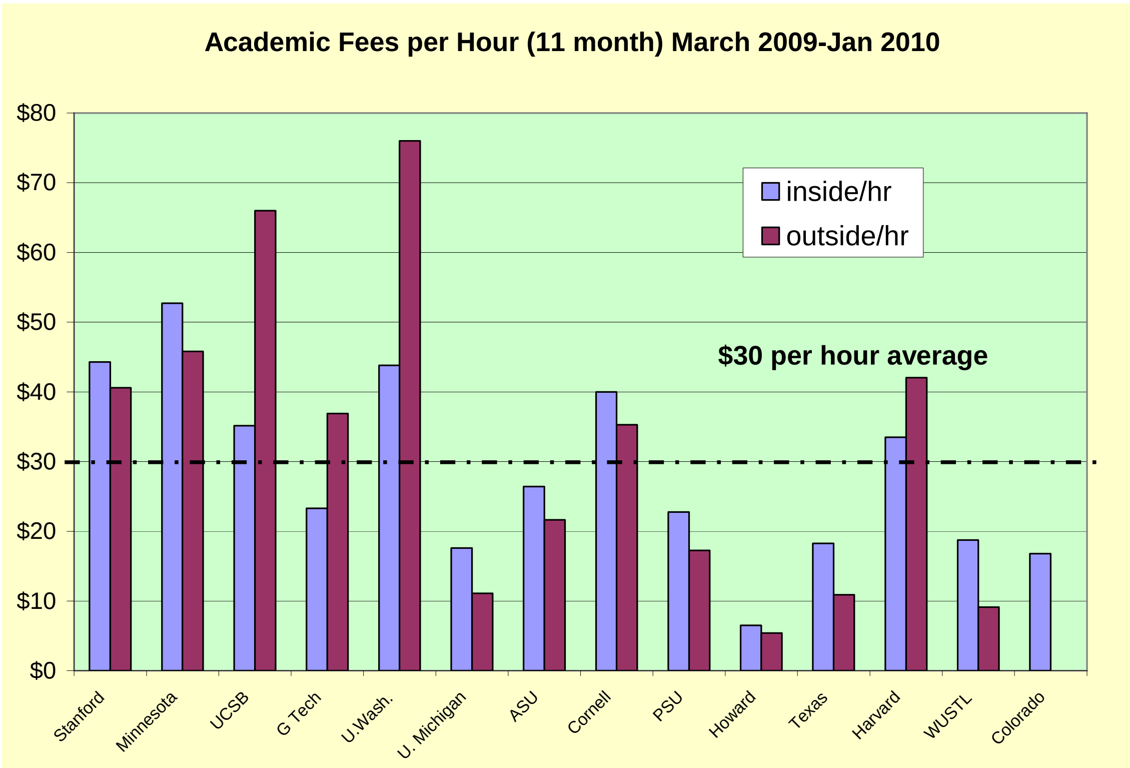


Fig. 17 Average fees for Outside academic users

Similarly, average fees per hour (Figure 18) are clustered fairly tightly around $30 per hour, a quite reasonable fee for access to high technology equipment.

Figure 18: Academic fees per hour in NNIN facilities.



The point of these figures 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 $3150 for 11 months, quite within the budget of most research grants. In contrast, the average cost for an industrial users (small and large company) is $1111 (Fig. 19), again with a broad distribution both within sites and across sites, but extremely manageable for the complex resources that the NNIN sites provide.

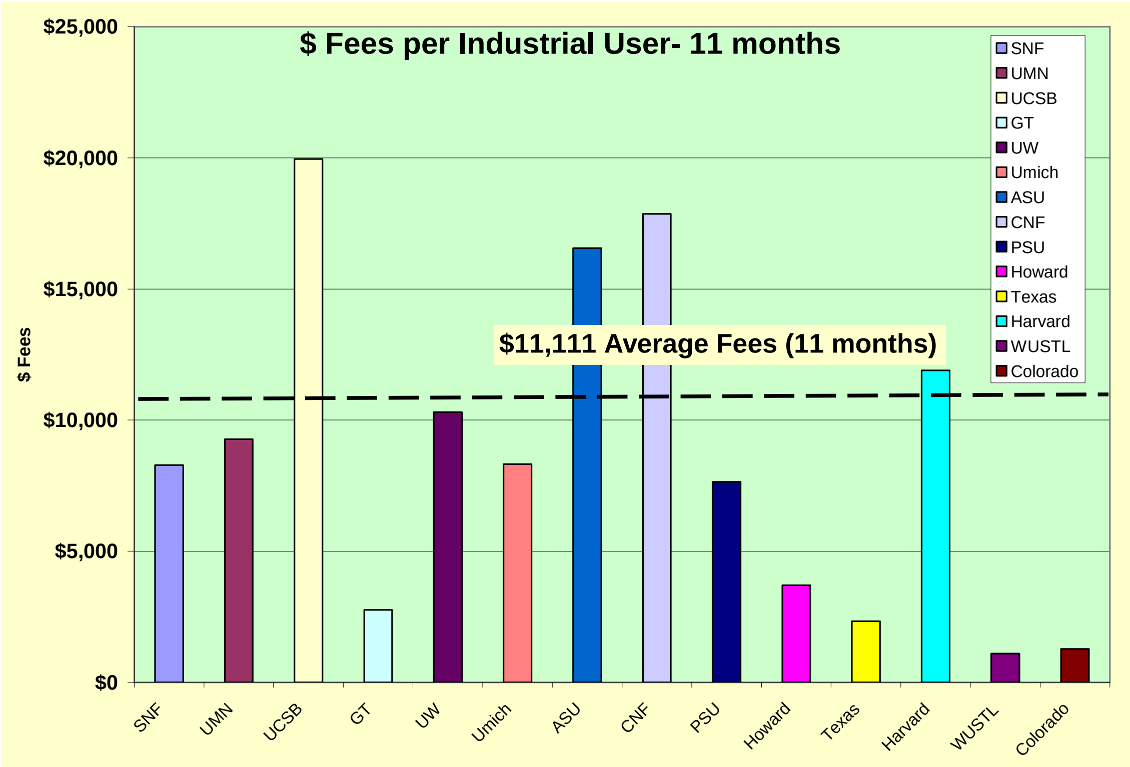


Figure 19: Average Industrial User Fees by Site

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.

2.6.6 Hours per user

Hours per user is a particularly enlightening metric as it, in some sense, shows intensity of use. A site can more easily sustain a large number of users doing small processes than a similar number of users doing complex processing. Hours per user 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 academic users, are shown in Figure 20. 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.

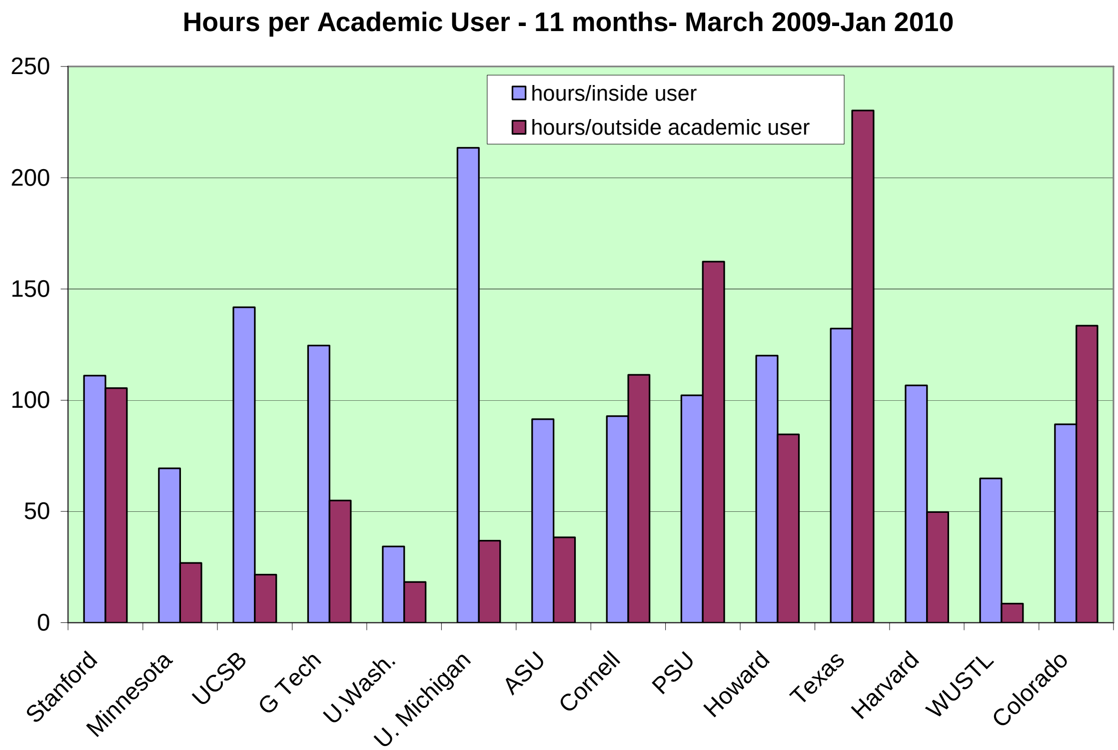


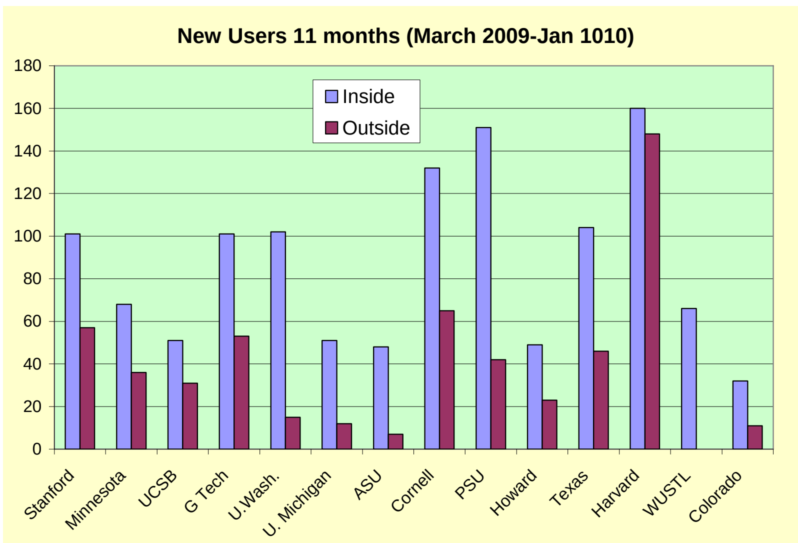
Figure 20: Laboratory hours per user (local and external).

2.6.7 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 21) we show the number of new users trained in FY2009 by site. Note that at some sites (e.g. Stanford, Cornell, Harvard, Georgia Tech, Penn State, Texas)) average 3-6 new users (inside + outside) per week.

In addition, there needs to be a balance between new users and total users. Figure 22 shows the ratio of new users to total users in FY2009 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 21: Training load for new users (internal and external)



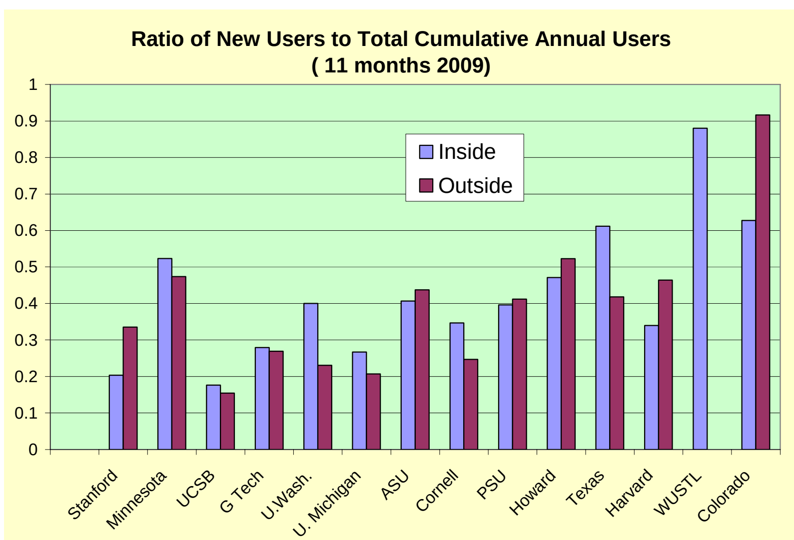


Fig. 22 Ratio of New Users to Cumulative Annual users by site.

3.0 NNIN Education and Human Resources Programs

3.1 Objectives and Program Challenges

In completing its sixth 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 23 shows that we have reached our capacity in the number of events offered across the network sites. A dip in the number of participants in 2009 is largely the result of the University of New Mexico no longer being a member of NNIN with several large scale events at state fairs. The new NNIN sites have not yet filled this gap.

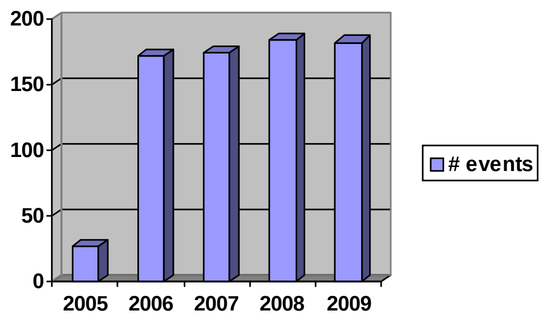


Fig. 23A

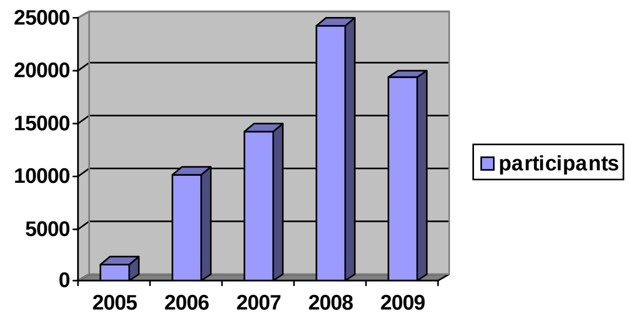


Fig. 23B

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 human resource development:

- Educate a dynamic workforce
- Spread the benefits of nanotechnology to new disciplines
- Be a resource for all ages and educational background
    - K-12
    - Undergraduates
    - Graduate students
    - Post-docs, faculty, government/industry
    - General population

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. Our programs directly reached approximately 20,000 individuals during the past twelve months. This does not include those receiving print editions of *Nanooze* or accessing our education portal.

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 3 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 3. Local and National NNIN education activities and program

	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*

3.2 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 Dr. Nancy Healy serves as the NNIN Education Program coordinator. Communication methods include phone, e-mail, wiki, and face-to-face meetings.

The education site coordinators meet once a 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 the University of California Santa Barbara September 22-23, 2009. Minutes of all meetings are available. 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). 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.

3.3 NNIN Major National Programs: REU, iREU and RET

3.3.1 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 coordinated network activity which has 70-80 students participating each summer across 14 NNIN sites. In 2009, 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 14 sites.

Our program offers a well-supervised independent research project for a 10 week summer period. While individual sites are responsible for daily project supervision, there is strong network coordination to assure a uniform program with high expectations. Our program features a central on-line application process for the entire network program 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 625 applications received in 2009. We have been committed to providing research opportunities to students who have the most to gain from the NNIN REU experience 75% of the 2007, 69% of the 2008, and 65% of the 2009 participants had no prior summer research experience. Table 4 shows the demographic make-up of applicants, participants, and their type of home institution for 2007, 2008, and 2009.

Table 4. Demographics of NNIN applicants and participants 2007-2009.

2007-2009 NNIN REU Program Demographics															
	# of applicants			**Applicant Pool**			**# Participants**			**Appl. Success Rate**			**Participation (%)**		
	‘07	**‘08**	**‘09**	**‘07**	**‘08**	**‘09**	**‘07**	**‘08**	**‘09**	**‘07**	**‘08**	**‘09**	**‘07**	**‘08**	**‘09**
Overall	403	553	625				70	73	74	17%	13%	12%			
Gender															
Women	134	194	213	33%	35%	34%	24	36	40	18%	19%	19%	34%	49%	54%
Men	269	359	412	77%	65%	66%	46	37	34	17%	10%	9%	66%	51%	46%
Race/Ethnicity															
Minorities	57	93	103	14%	17%	19%	21	26	14	37%	28%	13%	33%	37%	19%
Non-	346	399	446	86%	72%	81%	43	45	59	12%	11%	13%	67%	63%	81%

Minorities															
Inst. Type															
Ph.D. Level	258	376	406	64%	68%	65%	43	50	52	17%	13%	13%	61%	68%	70%
Master's Level	72	81	114	18%	15%	18%	13	12	10	18%	15%	9%	19%	16%	14%
Bacc. Level	60	94	85	15%	17%	14%	11	11	11	18%	12%	13%	16%	15%	15%
Assoc. Level	13	2	18	3%	0%	3%	3	0	1	23%	0%	5%	4%	0%	1%

* 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.

Of particular interest is the high number of female participants in the last two years.

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 2009 convocation was held August 9-12, 2009 at the University of Michigan. 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. These presentations are archived on the web (http://www.lnf.umich.edu/Events.aspx?id=108). To complete the program, all students write a research report that is published as the *NNIN REU Research Accomplishment*s. The archived webcasts and the *Accomplishments* are online at http://www.nnin.org/nnin_reu.html

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 for 2009 indicate high learning gains of participants in: 1. demonstrating confidence in self; 2. creating and following a timeline when managing projects; 3. conveying ideas verbally and in formal presentations; 4.recognizing knowledge transfer between real-world engineering/scientific problems and coursework; 5. recognizing contemporary scientific, engineering, and technology issues; 6. designing a product, process, or system; 7. operating in the unknown, and 8. conducting or simulating an experiment (among others). "*Overall, summarizing the learning outcomes, students had many learning gains.* ***In fact, it is important to note that 31% of the learning outcomes were rated highly in the pre-survey in comparison to 70% of the learning outcomes being rated high in the post-survey. This is over a two-fold increase and illustrates how valuable the research experience was for students***."

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

"Thank you SO much for the experience -- I had an amazing time, and value it greatly. I just wanted to express my gratitude for everything I learned and all the people I met during my summer." Julia Sokol, Georgia Tech REU

"This was one of the most memorable and important experiences I have had. Not only did I learn a lot from my mentors, research, and future career, but I think I made friends and connections that will last for a long time! If I had the chance, I would do it again! Thanks for this chance." Sweta Sengupta, Stanford REU

"A few weeks after the program is done, I am very glad I did it. It was a good learning experience as to what research, grad school, giving a technical presentation, writing a technical paper, and making a poster are like. I learned a lot." Rachel Hoffman, U. Minnesota REU

faculty and graduate student mentors, and technical training and support (among others). Table 5 highlights the technical components of our 2009 program (Likert scale of 1-5 with 5 being the highest rating):

Table 5. NNIN Participant post-program survey

NNIN Post Survey 2009				
Question	**Avg**		**Question**	**Avg.**
Did the program offer you a substantial independent research project with a strong intellectual focus?	4.27		How well did the program provide you with an understanding of the graduate research life?	4.12
Were you able to execute the research project using the available equipment and facilities?	4.36		How well did the program provide you with an understanding of careers in nanotechnology?	3.68
Did you consider your project a "good" project- interesting, right scale, right complexity, etc.	4.11		Did the program assist you in making future educational & career choices?	4.14
Were you reasonably able to complete the project?	3.95		How likely is it that you will choose a career in nanotechnology?	3.56
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?	4.56
Did you receive significant scientific interaction with the faculty member/ senior staff in charge of your project?	3.90		Did the program assist you in developing presentation and writing skills?	4.16
Were you included in group meetings and seminars?	4.31		Was the Convocation a worthwhile experience?	4.30
Did the program provide you with experience that allowed you to see the breadth of nanotechnology applications?	4.29		Would you recommend the program to a friend?	4.78
How well did the program assist you in learning to use advanced equipment and processes in nanotechnology?	4.13		How likely is it that when you return to your home campus that you will share your experiences with fellow students and faculty?	4.59
How well did the program assist you in understanding the scientific basis of nanotechnology equipment & processes?	4.12		How do you rate the overall quality of the program?	4.58
			Did you think that your experience with the program was positive? Would you do it again?	4.54

Since its inception in 1997, the NNIN REU program has had over 730 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. In 2006, we began a longitudinal study to determine the educational and career path of interns who participated in the 1997-2005 period of the program. This is an ongoing, labor-intensive study which has significance for not only the NNIN REU program but other undergraduate research programs.

We have chosen this 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. Of the 450 participants from 1997-2005, 262 (58%) have completed the online survey. Academic and career results are shown in Table 4. Ninety-five percent of the respondents are in science and engineering and approximately in nanotechnology (Broadly defined). The results presented in Table 6 have remained consistent as the number of responses has increased.

Table 6 Academic/Career paths

NNIN REU Longitudinal Study	
Degree/Career	1997-2003
Doctorate	53%
Master's	26%
Baccalaureate	12%
M.D./J.D./MBA	9%

3.3.2 iREU Program

Each summer, NNIN provides and introductory research experience for approximately 70 students. The training and experience these students receive is excellent and are highly sought by employers, graduate schools, and other internship programs. While they almost all perform well, from observations over the summer, it is clear that 15-25% are exceptional students and have an exceptionally commitment and love for research and development.

In 2007, we established the NNIN International REU (iREU) to further the nanotechnology experience of these exceptional individuals. 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. In 2009, we had two partners for this international program: the National Institute of Materials Science (NIMS) in Japan and the Forshungsentrum Julich (FZJ) (a Helmholz Research Institute) in Germany who hosted 6 and 4 students, respectively in summer 2009 (Fig. 24, 25). We have supplemental funding from the NSF International Research Experience for Students program (IRES) for five Japan participants.

Fig. 24 : Japan Participants 2009

Participants in 2009 included

Japan

- David Christle, University of Minnesota
- Sarah Grice, U. Maryland
- Jillian Kiser, Olin College
- Arun Swain, Cornell University
- Justine Yoon, RPI
- Julie Stiver, U. Mass. Amherst

Germany

- Jose Gurevarra, UCSB
- Kishore Padmaraju, U. Rochester
- Jennifer Hou, Johns Hopkkins
- Adam Scofield, RPI

Fig. 25: Germany Participants 2009

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 several weeks at Pennsylvania State University (2), University of California Santa Barbara, University of Texas, and Harvard University.

3.3.3 iREG-International Research Experience for Graduates

As an integral part of our relationship with NIMS Japan for hosting our iREU program, NNIN hosts a number of graduate students from Nanonet, the Japanese equivalent of NNIN, which is managed by NIMS. In 2009, 3 graduate students from Japan came to NNIN sites, two to Cornell University and one to University of Texas.

- Tatsuro Morimoto, Kyushu University; Morimoto-san worked at Cornell University with Prof. Ulrch Weisener on the project **"Nanostructured metals from block copolymer self-assembly "**
- Chiaki Kobayashi, Waseda University; Kobayashi-san worked at Cornell University with Prof. Edwin Kan on the project **"Non-Faradic FET-based sensor integration"**
- Kenta Aoyagi, Tohoku University:; Aoyagi-san worked at the University of Texas with Prof. Brian Korgel on the project **"Semiconductor Nanocrystal Inksfor Printed Photovoltaics"**

Each of these students was at NNIN for 8-10 weeks during which time they were treated much like our REU students. In particular, they were integrated both socially and technically with the REU students, which added greatly to their experience. Unlike undergraduate REU students, these graduate students come with a significant prior skill set and focused interest. During this time they integrated into the appropriate research group, were trained in equipment and techniques, and contributed to both their own research project and the overall goals of the research group. Morimoto-san was included as a co-author on a presentation at the Fall MRS meeting. Towards the end of the summer, Kazuo Furuya, the scientist at NIMS in charge of the Nanonet and this exchange program, visited Cornell to see the progress of the students and to meet with the project faculty directors.

In the prior year, 5 students were hosted at Penn State(2), University of Texas, Harvard, and UCSB. The goal of this program is much the same as iREU, that is, to increase awareness of the global nature of research. In this it has been very successful. These students interact strongly with our resident REU students, and there thus results a considerable synergy between the REU, iREU , and iREG programs.

3.3.4 RET Program

Five sites participate in an NSF-funded Research Experience for Teachers (RET) Program which began in March 2006. A second three-year NSF award was received in May 2009. Georgia Tech (lead), Harvard, Howard, Penn State, and UCSB host the teachers. In 2009, we had 19 diverse participants: 11 females (58%), 8 males (42%) and 53% from underrepresented populations. This is consistent with the prior program which had 60 participants: 33 females (55%), 27 males (45%) and 42% from underrepresented populations. Some sites leveraged the RET award (15 participants) with NNIN funds to support additional participants in 2009 (4 participants) 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—75% of the schools have a high percentage of underrepresented populations (race, ethnicity, and socioeconomic status).

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 7. 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 7. Examples of NNIN RET Post Survey Results 2009	
Program was responsive to professional development needs	**3.9**
Program provided opportunities to engage in inquiry/research activities that I will adapt for classroom use	**3.9**
I designed/implemented my own research/ investigation under supervision of a mentor	**2.8**
I collaborated in ongoing research with site staff	**3.4**
I operated instruments, equipment, & other technologies	**3.5**
Program increased interest in research & ways that STEM can be applied.	**3.9**
I gained greater understanding of the applications of STEM to everyday life.	**3.6**
I acquired greater understanding of fundamental concepts in STEM	**3.6**
I became familiar with new materials & equipment that I can use in my teaching.	**3.7**
I learned innovative ways to use standard materials and equipment in my field.	**3.5**
I increased my knowledge of current issues in STEM research	**3.7**
Mentor's knowledge of roles & responsibilities of teachers in STEM	**3.6**
Mentor's interest in helping you develop a plan to improve education in STEM	**4.0**
As a professional development program, how do you rate the NNIN RET program?	**4.6***
Would you recommend the NNIN RET program to your colleagues?	**3.9**

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 that they can adapt for their classrooms, a main goal of the program. The project mentors showed that they had an understanding of teacher roles and responsibilities and wanted to help the teachers in improving education. Teachers also indicated that they increased their knowledge of current issues in STEM research. Overall, the program received very high ratings.

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 participants of the REU 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 an instructional unit for his/her classroom, which are then reviewed and field tested before placement on the NNIN education portal (http://www.education.nnin.org).

3.3.5 iWSG

The international Winter Schools for Graduate Students (iWSG) are organized jointly by NNIN and institutions in third world countries with the goal of promoting international bridge building and understanding by bringing together students and faculty in an intense teaching and societal experience. Each year, 10 graduate students and faculty participate in a rigorous course in an emerging and research-intensive interdisciplinary direction that is not part of US graduate curriculums. This lasts six days and includes laboratory sections. This is followed by travel to a rural part of the country where students spend time observing, experiencing and discussing the societal challenges and the part science and technology can play. A large group of students from the host country participate in the teaching part and a smaller group joins in the rural experience.

The second edition of iWSG took place at IIT Mumbai (Bombay) starting on Nov. 30, 2009 with the societal experience in Khargone a district of Madhya Pradesh in central India. The subject of the teaching was "Nanoelectronics (with an emphasis on Silicon)". The rural experience focused on early education and rural needs.

Participating students were selected from a nationwide solicitation. Student participants for 2009 included

- Brandon Aguirre, U. Texas, El Paso
- Ken Everaerts, Northwestern
- John Ferguson. U. Minnesota
- Andrea Giordoni, Penn State
- Johnathan Hennek, U. Minnesota
- Scott Lee, Stanford
- Ryan Shea, U. Minnesota
- Angela Shum, U. Washington
- Jeff Sididqui, U. Michigan
- Abbie Tippie, U. Rochester

Participating US faculty included

- Sandip Tiwari , Cornell University
- Jason Woo, UCLA
- Jean Pierre Leburton, U. Illinois
- Paul Hasler, Georgia Tech
- David Frank. IBM
- Ira Bennett. ASU

Profs. Tiwari, Bennet, and Hasler went with the students on the rural experience part of the program.

Fig. 26: Scenes for iWSG India 2009

Students (US and Indian) completed an evaluation instrument for the event and the results are presented in Table 8. Overall, the course received very good ratings including providing a broad perspective to the field and its challenges as well as allowing participants to interact across international boundaries and see the other world perspectives. This latter was an important goal of the program in that we are seeking to develop globally aware scientist through this experience. (an important focus of the program).

Table 8. Evaluation results for iWSG 2009	
To what extent did this event: n=64	**Average**
Give you a broad perspective of the field and its challenges	4.33
Introduce/discuss nanoscale MOSFET and current research	4.40
Provide introductory theoretical understanding of high k and metal gates	4.17
Introduce variability issues/sources for devices and SRAMs	4.03
Provide understanding of major fabrication technologies	4.12
Discuss issues of interconnections and reliability	3.72
Provide and understanding of non-volatile memories	3.93
Provide understanding of device transport & nanoscale modeling	4.08
Introduce circuit techniques for digital and analog	3.65

Provide effective forum to discuss critical technical issues	3.93
Provide a systems constraint perspective to design	3.96
Allow you to interact across international boundaries and see the other world perspective	4.31
How do you rate the course in its effectiveness as an approach to teaching/learning and bridge building	4.47

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

Participants on the field trip portion of the trip completed an essay on their thoughts and observations. These essays indicated that students were extremely positive about the workshop and the field trip. The visits to rural villages in India were "eye-opening" events for all participants and helped them to see how technology can help the poorest people in the world. Sample comments are in the boxes below.

"I feel that I had a great opportunity to see the contrasts of Indian life and technology. The trip was very informative, absolutely amazing, and was an excellent compliment to my technical training back home at Northwestern and during the IIT conference. I will remember this trip for many, many years and hope to kept the ramifications of technology in the world throughout my career."

"From the trip to the rural area in India, I learned that we, as engineers and scientists, must share the responsibility of increasing people's quality of life in rural areas. The reason is that we do have the infrastructure and knowledge needed to investigate solutions to daily problems (and people from villages do not….. The iWSG provided an excellent experience in understanding people's lives in rural areas and in making us aware of our role in the quality of life of society in general."

"To visit the communities, to see the conditions in these rural parts of India, to speak and interact with the different members of the community, to see the use of technology (or lack thereof) was quite eye opening for me personally…. Even with just a brief exposure to the conditions and everyday realities of many, many people living in rural communities throughout the world, it is quite evident that science and technology can make a difference in the quality of life of these people.

3.4 Other Education Programs

3.4.1 Teacher 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.

Georgia Tech offers a variety of workshops ranging from half to week long workshops on including nanotechnology in science classrooms. All of the instructional materials are tied to Georgia Performance Standards and National Science Education Content 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, the South Carolina Science Council, the Wyoming Math and Science Teachers Conference, and national and regional NSTAs. In Georgia, we have reached at least one teacher from 63 of Georgia's 159 counties. NNIN sites are now encouraged to either exhibit or present at their state science teachers' association meeting to inform teachers about nanotechnology and its inclusion in the science curriculum.

Stanford provides hands-on activities, lectures, and facility tours to teachers attending the weeklong Summer Institute for Middle School Teachers.

3.4.2 NanoTeach

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 two week professional development workshop which will occur in July 2010. NanoTeach is developing a combination of face-to-face and online professional development experiences for high school science teachers who teach physical science topics. The primary goal of NanoTeach is to prepare teachers to use an instructional design framework to integrate nanoscale science and technology content into their curriculum in significant ways.

3.4.3 Other K-12 outreach

Numerous outreach activities have occurred in 2009 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. We also adopt and adapt activities developed by other centers and programs such as University of Wisconsin-Madison MRSEC & NSEC, Nanosense (SRI), NISE Net, among others. The Georgia Tech site developed the *NNIN Outreach Demonstration Guide* which is a resource on how to adapt larger lessons developed by NNIN and other nanoeducation groups into demonstrations. This guide has been posted on the NNIN education portal - http://www.nnin.org/doc/NNIN_Outreach_Demo_Guide.pdf

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, and University of Michigan. 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
- Penn State's *NanoCamps* hosted 2 groups during summer 2009
- U. of Minnesota and Dakota Technical College offer NanoScience Class for High School Students.
- University of Michigan offers a one day program for middle and high school students in introduce them to nanoscale science and technology
- Stanford provides support for the High School Summer College program by providing a presentation on nanotechnology and a tour of the cleanroom facilities.

In addition, most sites provide on-site activities for visiting school groups as well as the general public. These typically involve lectures, 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, science fairs, and community days. 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 LNF. Cornell, Howard University, Georgia Tech, Harvard, University of Minnesota, and University of Washington St. Louis hosted NanoDays using materials supplied by NISE Net. At the September 2009 coordinators meeting it was agreed that all sites would seek materials from NISE Net to host a NanoDay in 2010.

3.4.4 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. 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.

3.4.5 NNIN Education Portal

The NNIN education portal (http://www.education.nnin.org) serves as another avenue in reaching a variety of audiences by offering information for children and adults.

3.4.6 Nanooze

Cornell has developed a children's science magazine related to physical sciences and particularly nanotechnology. *Nanooze* is a web based magazine (http://www.nanooze.org/), with kid-friendly text, topics, and games. It is designed for grades 5-8 but we have found that even high school students enjoy the magazine. *Nanooze* is available in English, Spanish, and Portuguese on the web. We now offer special topic issues of *Nanooze* in hard copy with the most recent issues focusing on self assembly and nano and food. A total of 6 issues are available. Teachers may request classroom packs of any or all of these issues. Through a variety of distribution mechanisms, including NNIN's exhibit booth at NSTA, Over 70,000 copies were distributed to upper elementary through high school students in 2009. (A total of almost 400,000 copies have been printed). Additional details are available in the Cornell site report.

3.5 Technical Workshops-Laboratory Oriented

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.

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 May 2009 forum was on Cancer and Nanotechnology and the November 2009 event focused on Nanotechnology in Medical Imaging (http://www.mirc.gatech.edu/nanofans.php).

3.6 Symposia and Advanced Topics Workshops

NNIN has over recent years held a number of special focused advanced topic workshops or symposia which bring together significant contributors in fields covered by NNIN. In general, the purpose of these special workshops is to explore emerging areas in which NNIN may be able to make significant contributions. They aim to foster interactions with NNIN and interactions between the participants, and are one source of information to guide NNIN management in new initiatives. With the recent renewal, NNIN recommitted to these special symposia with a goal of 4 major events per year. Recent workshops are highlighted below.

3.6.1 NNIN Advanced Topic Workshop: Nanotechnology as an Enabler for Neuroscience, Neuroengineering and Neural Prostheses (Nano for N3)

An NNIN Special workshop was held at Stanford University, Dec, 11-12, 2008 to explore the impact of Nanotechnology on Neuroscience. Neural prostheses aim to help improve the quality of life for patients suffering from neurological disease and injury. They function by translating electrical signals from the brain (e.g., action potentials, local field potentials, ECoGs,EEGs) into control signals for guiding assistive devices. Despite considerable progress in recent years, the field actively continues to pursue

- increased sensor lifetime and

- increased system performance so that the anticipated quality-of-life improvements will clearly outweigh potential surgical risks.

Despite ongoing efforts in recent years, neither sensor lifetime nor system performance have grown at a rate necessary to dramatically enable the widespread clinical translation of these systems. MEMS-based electrode arrays have had functional lifetimes of approximately one year without substantial improvement. While flexible substrate and pharmacological agent delivery through micro-fluidic channels appears promising, there is considerable interest in understanding what nano-structured electrical and/or optical sensors which reside at the size scale of neurons (< 1 um) may enable. Similarly, system performance relies on massively parallel measurement of neural signals and MEMS based measurement has remained at roughly 100-200 neurons for the past decade. There is considerable interest in understanding what massively parallel, nano-structured electrical and/or optical sensors which could provide both the high-density measurements within one brain/neural area, and measurement from multiple brain areas separated by many centimeters may provide. Advances in both of these areas are crucial for the sustained advancement of both basic systems neuroscience which aims to provide fundamental scientific understanding of complex nervous systems, and may generate biologically-inspired computational principles for next generation electronic computational architectures - as well as more applied neuroengineering, which aims to build core technology.

The major goals of the workshop were:

- To build bridges and promote collaborations between the neuroscience, neuroengineering, neural prosthesis and nanotechnology/sensor communities.
- To identify limitations in current neural-measurement technologies and critical needs for basic neuroscience, neuroengineering, and clinical neural prostheses.
- To identify potential solutions to these needs based on recent progress in nano- and micro-technology.
- To identify how NNIN can best leverage its tools, user base and staff expertise to enable these goals.

3.6.2 NNIN Symposium: Symposium on Nanotechnology for Public Health

The 1st Symposium on Nanotechnology for Public Health was held Thursday and Friday, Sept. 24 and 25, 2009 in the Whitaker Hall auditorium at Washington University at St. Louis. The symposium, which highlighted the opening of Washington University's nano research facility, included over 200 participants. Chancellor Mark S. Wrighton and Lawrence S. Goldberg, Ph.D., a WUSTL alumnus and a senior engineering adviser at the National Science Foundation welcomed participants to the 1st Symposium on Nanotechnology for Public Health, Environment, and Energy. George M. Whitesides, Ph.D., the Woodford L. and Ann A. Flowers University Professor at Harvard University, delivered the keynote address, "Nanotechnology in Adolescence," which provided an overview of the historical significance of nanotechnology and its future implications. Speakers Sandip Tiwari, the director of the National

Fig. 27: Poster session at the Nanotechnology for Public Health Symposium

Nanotechnology Infrastructure Network (NNIN), and Larry Nagahara, the Nanotechnology Project Manager at the National Cancer Institute, addressed the implications of nanotechnology for the technical session, “Environment, Health, and Safety,” while Cindy Buhse of the Food and Drug Administration (FDA) discussed the related regulatory considerations for nanomaterial-containing therapeutics and Laura Stole of the Air Force Research Laboratory (AFRL) discussed the implications of nanotoxicity in immunity. Industry leader Gary Wiederrecht of Argonne National Lab provided an overview of preeminent research in hybrid plasmonics, while Chancellor Thomas S. George (University of Missouri at St. Louis, UMSL) and Guoping Zhang presented a two-part session on “Light Energy Relaxation and High-Harmonic Generation in C60” for the technical session “Nanomaterials for Energy and Environment.”

The symposium focused on the practical issues of incorporating nanomaterials in consumer products, and an initial session addressed the consistency and cost-effectiveness of nanoparticle synthesis. Afterwards, a poster session (Fig. 27) and open house were held on the lower level of the Earth & Planetary Sciences Building. Nanotech research in the St. Louis region was showcased in the poster session, which included 44 posters from Washington University, Saint Louis University, University of Missouri-Columbia, and University of Missouri-St. Louis. The open house featured the facility’s four new labs — a micro and nano-fabrication lab, including the Class 100, Class 1,000 and Class 10,000 clean rooms, a surface characterization lab, a particle technology lab and a bioimaging lab — located in the Earth & Planetary Sciences Building and Whitaker Hall. Also included in tours were live demonstrations of gold nanocage synthesis by lab manager Yujie Xiong and live video streaming of the scanning electron microscope (SEM)’s remote access feature, a unique capability of the surface characterization laboratory’s transmission and scanning electron microscopes. Research engineer Brent Riggs provided a brief informational session on the NRF’s latest equipment acquisition: the Nanoman- an advanced scanning probe microscope precise enough to move atoms around one by one.

Sponsors providing financial support for the 1st Symposium on Nanotechnology for Public Health included: National Science Foundation, National Nanotechnology Infrastructure Network, ClassOne Equipment, FEI, Veeco, Zeiss, PerkinElmer, and Washington University.

3.6.3 NNIN Advanced Topic Workshop: Synergies in NanoScale Manufacturing and Research

Overview

NNIN hosted a two day workshop, **“Synergies in NanoScale Manufacturing and Research,”** held on the Cornell University campus **January 28-29, 2010**. This was a by-invitation-only working group intended to generate active discussion in the issues related to bringing emergent tools, processes, and materials into commercialization. The speakers, moderators, and attendees were selected from across the country and from industry, academia, and government labs to bring a broad range of expertise and experience to the group discussions. The workshop was sponsored jointly by the NSF’s *National Nanomanufacturing Network* (centered at U Mass Amherst), and the *National Nanotechnology Infrastructure Network*. The program effort was led by Don Tennant, Sandip Tiwari, and Lynn Rathbun from Cornell University and Mark Tuominen and Jeff Morse from U. Mass.

Speaker Presentations:

Speaker topics ranged from roll to roll production of flexible electronics, mass methods of producing bit patterned magnetic media, ways to manufacture in silicon with atomic precision to groundbreaking methods of making measurements of structural properties in complex materials. We also heard reports on several new means of highly specialized drug delivery, the possibility of mass production of carbon substrates for electronics, a new class of photochemicals compatible with organic materials, and more. Each day's presentations were followed by group and breakout discussions centered on questions and topics stimulated by the various speakers. The main themes dealt with issues such as infrastructure investment, standardization, development of metrology and quality monitoring methods, and scalability of many of the emergent technologies.

Fig. 28: Nanomanufacturing Workshop

Discussion Points:

Key initial application areas/first-to-market opportunities: data storage/bit patterned media; flexible lighting and displays; solar cells; fuel cell catalysts; transparent electrodes; batteries and ultracapacitors; life sciences, including drug delivery with nanoparticles, and biosensors.

Costs and economic factors that may affect development of nanomanufacturing: include qualification of materials in the supply chain, and complying with environmental health and safety regulations regarding worker exposure and environmental release; production of material safety data. A nanofoundry for producing masters for nanoimprint may be helpful for the nanoimprint roll to roll industry.

Standards: There is a need for standards for roll to roll nanoimprint; the state of the industry now is like the early days of the semiconductor industry, when many small companies were creating their own processes, which were all different.

Process modeling: There is a need for predictive modeling of hybrid materials, taking into account the properties of solvents vs. temperature and other characteristics. Modeling process kinetics would be helpful to predict process windows. Web-based software for analyzing critical dimensions of ordered patterns would be useful. Block copolymer models exist but there is a need for structure databases and instruments to quickly test new block copolymers.

Metrology needs: for roll to roll production, there is a need for real-time inspection and characterization during production, instead of offline. Specific needs are for defect inspection and pattern fidelity. Existing tools for semiconductors need to be adapted for use in roll to roll systems. For self-assembled materials, there is a need to examine the long-range order of self-assembled materials, which is more difficult than verifying short-range order. Materials can be qualified at nanoscale before use to make products, which can be inspected at larger scale. Companies do not have all the characterization equipment they need and are looking for university partners to do characterization.

Intellectual property issues: conflicts over IP have prevented some funding of university research in the U.S. In Asia, it's common for research groups to be funded by companies and not by government.

Funding: In the U.S., NSF and universities want to fund novel research and not work to scale up processes for production. It is more common for DARPA and venture capital firms to provide funding for more applied research in the U.S. The 3-year MRI grants don't work for long-haul instrumentation development that used to be done by large corporate research labs. This may be work that the national labs could do now.

Group Composition:

Approximately 40 Participants came from the following institutions: (Table 9)

Table 9		
Participating Institutions		
Carnegie Mellon Univ.	**Integrated Surface Technologies**	**U Houston**
Cornell Univ.	**Kionix**	**U Michigan**
EV Group	**Liquidia Technologies**	**U Texas**
GE	**NIST**	**UCLA**
Hitachi Global Systems	**Northeastern Univ.**	**Univ. of Illinois-Urbana**
HP Labs	**RPI**	**Yale University**
Industrial Collaboration Commercial Partnerships	**SWeNT**	**Zyvex Labs**

Academic **Industrial** **Government**

The program committee will be presenting a summary of the in depth discussions to the National Science Foundation.

Goals Met:

1) The assembled group identified issues common to a number of emergent technologies that are potentials impediments to commercialization.
2) It is clear that there are instruments in labs that are not being standardized or whose infrastructure is not progressing at the same rate as the prototype systems.
3) Researchers gained insight into the complexities of scaling up and industry participants heard of possible new fields emerging from academic labs for scalable materials (such as graphene).
4) In the area of mass production of imprinted structures, a likely high impact industry will be in the bit patterned magnetic storage sector. Approaches including combining electron beam lithography and block copolymers may be employed to create extremely high density island material. The business model for such a shift in product lines was discussed.
5) Attention was drawn to NNIN laboratories as enabling facilities for pre commercialization work to be done.
6) Important new instrumentation suitable to support metrology needs was discussed.
7) IP concerns and viewpoints were compared.
8) In all, a diverse group with often competing technology pursuits were brought together to look forward and look back over the continuum of lab to startup-mature to industry

3.6.4 NNIN Advanced Topic Workshop: Nano-enabled Sensing Microsystems for Geo Sciences

NNIN organized a two-day workshop on "**Nano-enabled Sensing Microsystems for Geo Sciences**" at the University of Michigan, Ann Arbor campus on Feb 4-5 2010. The objectives of the workshop were to: (i) raise awareness and highlight opportunities for research to both nanotechnologists and geo/environmental communities, (ii) promote collaborations between the nano/microsystems community and geo/environmental community, (iii) identify short-term and long-term joint projects, and (iv) leverage on the NNIN infrastructure, tools, user base and staff expertise to enable advancement of the state of the art in geo and environment sciences. A similar workshop was held at the University of Washington in April 2008 on "Nanotechnology as an Enabler for Ocean Observatories" to identify priority areas in geo sciences.

Fig. 29 : NNIN Geosciences Workshop

The existing micro/nano-enabled sensors typically detect, monitor and respond to physico-chemical parameters of interest to DoD, DARPA, Homeland Security and the NIH. Although the same technologies hold enormous potential for studying the ecosystem at the local, national and global scales, they have not transitioned to this field, chiefly because the geoscientists and nanotechnologists are unaware of each others' needs. The mission of this workshop was to bridge this gap between two disjoint communities up till now, with enormous opportunity and potential for each other. To this end, the workshop brought together more than 30 participants with expertise in integrated microsystems, nano-enabled sensor design, nanotechnology, physical, chemical and biological oceanography, climate monitoring and environmental sciences.

On the first day, the micro/nanotechnologists and geo/environmental researchers presented a total of ten talks on the latest developments in their respective field. Next, breakout discussion groups based on common interests were established with the specific aim to identify and define short-term and long-term joint projects. Five breakout groups were established: (i) Harsh Environment Sensors, (ii) Biological Toxin Detection and Analysis, (iii) Microfluidic Systems (sampling, pre-concentration), (Iv) Trace Metal Sensors, and (v) Other Sensors – Measuring Water Content in Snow/Ice. The project ideas presented by the groups were discussed thoroughly and drafts for 6 joint projects were prepared. These drafts include the possible project title, collaborators, possible funding source, short project description, motivation and specific aims, timeline for research, and timeline for proposal submission to funding agency.

Participant List

Table 10

Participant	Institution
Ana Barros	Duke University
Carl Batt	Cornell University
Paul Bishop	NSF
Clara Chan	University of Delaware
Thomas Dichristina	Georgia Institute of Technology
Kang Ding	University of Minnesota
Yogesh Gianchandani	University of Michigan

Kimberly Gray	Northwestern University
Peter Hesketh	Georgia Institute of Technology
Nancy Love	University of Michigan
Karen Orcutt	University of Souther Mississippi
Becky Peterson	University of Michigan
Barbara Ransom	NSF
William(Bill) Seyfried	University of Minnesota
Martial Taillefert	Georgia Institute of Technology
Jeanne VanBriesen	Carnegie Mellon University
Mark Wells	Universiy of Maine
Ken Wise	University of Michigan
Qiuming Yu	University of Washington
Ted Zellers	University of Michigan
Sandip Tiwari	NNIN
Francois Baneyx	NNIN
Khalil Najafi	NNIN
Sandrine Martin	NNIN
Shyam Aravamudhan	NNIN

3.7 Diversity Related Efforts and Programs

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.

3.7.1 REU

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 typically have a higher participation rate in our program in comparison to the applicant pool and in 2009 we exceeded our goal of 50% female participation in the REU program (52% in 2009).

3.7.2 RET

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 79 RETs - 44 females (57%), 35 males (43%), and 44% from underrepresented populations. Our RET program has been very successful in including teachers who teach at schools with high-minority populations—75% 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. The University of Michigan exhibited at the regional NSBE conference and represented the NNIN at our exhibit booth at the October 2009 HBCU-Up meeting in Washington, DC. The University of Minnesota participates in the National American Indian Science and Engineering Science Fair. This event is for students in grades 5-12 and the University of Minnesota had an exhibit booth on nanotechnology where they demonstrated cantilevers. They also assisted the organization with registration and other logistical support.

3.7.3 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. This event features a series of talks in the morning about the career and education opportunities in Nanotechnology. The afternoon session consist of a variety of high-tech and low-tech demonstrations of nanotechnology instrumentation and concepts. NNIN has an array of portable nanotechnology instrumentation, including AFM, STM, SEM, and a variety of optical microscopes. These are set up for live demonstrations to the student. In addition, staff from different NNIN sites bring smaller items that can be used to demonstrate nanotechnology concepts. These include shape memory alloys, nanotechnology products, quantum dots, and hydrophobic and hydrophilic materials. The focus is on undergraduate students who attend conferences sponsored by underrepresented professional science and engineering organizations. NNIN held one workshop in 2009 at the National Society for Black Engineers. We reached approximately 200 students at the event. 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.

Fig. 30 Table top SEM at NNIN Nanotechnology Showcase for Students

3.7.4 LEF

In fall 2007, 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. Four awards of $12,000 each were made to Georgia Tech, Cornell (x2), and Stanford. Faculty spent 8-10 weeks in the summer of 2009 undertaking their own research project in nanotechnology. Table 11 summarizes the faculty and their projects.

Table 11. NNIN 2009 LEF participants

Faculty Participant	**Home Institution**	**NNIN Site**	**Project**
Prof. Frances R. Williams	Norfolk State Univ.	Georgia Tech	Acoustic MEMS Sensors for Bio/Chemical Sensing
Prof. Julie Zhili Hao	Old Dominion Univ.	Cornell	Analytical and Experimental Investigation of Interfacial Loss in AIN Resonators

Prof. Ruben Diaz-Rivera	University of Puerto Rico at Mayaguez	Cornell	Hydrodynamically Induced Whole-Cell Manipulation in Microfluidic Devices
Prof. Lili He	San Jose State University	Stanford	Study of Switching Mechanism of Resistance Change Memory

3.8 Evaluation

NNIN has developed a variety of evaluation instruments for its major programs which include: REU RET, iREU, LEF, past REUs, iWSG, teacher workshops (pre and post), camps (pre and post), and school visits (pre and post). Instruments have been shared among all of the sites which can adopt and adapt them for their particular programs.

In 2008, NNIN developed a logic model and evaluation plan with the assistance of an external consultant (Tom McKlin, The Findings Group). The model and plan were presented in the 2008 annual report. We use the plan to ensure that we are collecting the correct data to assess the impact and quality of our outreach endeavors. Data presented in this report represent some of our findings using our instruments and other data collection methods. At the Fall MRS meeting, Nancy Healy and Joyce Palmer (Georgia Tech) presented a talk on survey findings from Georgia Tech's teacher workshops. The presentation demonstrated how the evaluation results (pre and post surveys) have been used to refine the workshops.

3.9 Program Summary

NNIN's education program Is widely recognized as a leader within the nanotechnology and academic research center community. NNIN has and will continue to offer a variety of education and outreach activities at the local and national level. Table 12 below summarizes the major network wide programs.

Table 12. Summary of NNIN Network-wide Programs

Program	Participants	Purpose	Status
REU	Undergraduates	Research experience for a diverse population of undergraduates; introduction to nanotechnology research & careers	Upcoming 14th summer in 2009
iREU	Undergraduates – former NNIN REU participants	Develop globally aware scientists and engineers from the most successful REU participants	Upcoming 3nd summer in 2010
iREG	Graduate students from Japan (NIMS)	International outreach; reciprocity for iREU Japan; No cost to NNIN	Upcoming 3nd summer in 2010
RET	Middle and high school science teachers	Introduce teachers to nanotechnology and experimental design; develop nanotechnology classroom activities	Refunded by NSF in May 2009; upcoming 5th year in summer 2010
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 3nd summer in 2010
SFS – Nanotechnology Showcase for Students	Undergraduates	Expose diverse population of undergraduates to education and career opportunities in nanotechnology	Plan to offer 1-2 times per year
Nanooze	Upper elementary	Stimulate and maintain interest in STEM at a	Classroom packs

	and middle school students	young age	distributed in 2010 on special topics.
iWSG	Graduate students	Develop globally aware scientists and engineers; Provide technical workshops in nano to US and foreign students; Encourage international collaboration	Second two week workshop held in Mumbai, India in December 2009.

4.0 NNIN Computation Program

The computation project of the National Nanotechnology Infrastructure Network has undertaken ambitious plans to upgrade and expand our service to the computational and experimental nanoscience communities. The expansion was both geographical and programmatic. Stanford University and University of Michigan are now contributing at full strength. Thus, with Harvard and Cornell there are now four nodes fully participating in the NNIN nanoscale computation effort. The programmatic expansions include (1) our initiative, called the "virtual vault for nanoscience," that would contain databases for pseudopotentials for electronic structure calculations and inter-atomic potentials for molecular dynamics calculations, and (2) the installation of a GPU cluster and related workshops on massively parallel programming with CUDA. We have made considerable progress on both of these fronts.

4.1 Codes at the Sites

Nanoscale science pertains to the regime where the number of atoms or molecules under study are too numerous and arranged in too complex a manner for a single-atom/molecule treatment, on the one hand, and the number and arrangement of atoms is neither regular (periodic) nor sufficiently large so as to make statistical (thermodynamic) treatments meaningful, on the other hand. Nevertheless, the foundations of nanoscale computation consist of **electronic structure codes**, which are initially appropriate for small atom number or periodic systems, and **molecular dynamics codes**, which are statistical insofar as they typically require ensembles of initial conditions and treat systems interacting with heat baths. Additionally, **photonics and phononics** codes address the primary bosonic degrees of freedom of nanoscale matter, **processing or fabrication** codes treat the physics of ion implantation (among other areas), and **multiscale or finite element** tools treat micro-fluidics, which while larger than the nanoscale often interfaces with nanoscale structures and is important in its own right.

Table 13 illustrates the matrix of computational codes available at the various NNIN/C sites. Some codes require that users register or purchase their own copy before using them on the cluster. Note that the Michigan effort has only begun and so they do not as yet have any codes up and running.

Table 13 List of computational codes available at the various NNIN/C sites.

	Harvard	**Cornell**	**Stanford**	**Michigan**
Electronic Structure				
Quantum Espresso		x	x	
Abinit		x	x	
CPMD		x	x	
WIEN2K		x		
SETE	x			
LM Suite		x		
NWChem		x	x	
Siesta		x		
PARSEC		x		
Akai KKR		x		
FDMNES		x		

QuantumWise		x	x	
Socorro	x			
VASP	x		x	
HARES	x			
CHAMP			x	
Gaussian		x	x	
GAMESS			x	
Octopus	x		x	
TurboMol	x			
Molecular Dynamics				
LAMMPS		x		
DL_POLY	x	x		
Gromacs		x	x	
MOSAICS			x	
Desmond			x	
CP2K			x	
SDTrimSP	x			
GULP		x		
Photonics & Phononics				
MIT Photonic Bands (MPB)		x		
MIT FDTD code (MEEP)		x		
FDTD (Lumerical Licenses)	x			
MULTEL		x		
Nanoscale Electrostatics				
UT-MARLOWE		x		
UT_Quant		x		
Nanoscale Fabrication				
Patacon		x		
Multiphysics & Finite Element Tools				
Elmer		x		

Nippon Control Systems has provided the Cornell Nanoscale Facility with a license for the parallel cluster version of their Patacon software. This software package can convert semiconductor mask design data into proximity-corrected exposure data for Electron beam lithography and it has specialized capabilities for proximity effects issues, stitching, complementary division, and sub-field division. Access to a cluster version of this software provides the capability to handle large scale patterns efficiently.

4.2 Computation Users

The counting algorithm for users includes only users who are doing calculations currently in NNIN/C. This is distinct from the previously used algorithm where users who, annually, had applied for and been given a computational account were included. These numbers reflect users of NNIN/C computer clusters who have performed computation in the current year.

Table 14: Computation Users 2009 (11 months)

	Internal	External
Harvard	47	18
Cornell	17	9
Stanford	10	8

Additionally, NNIN/C does extensive consultation with computational scientists as well as experimentalists who do not use computational hardware and so are not included in the above count.

4.3 Research Highlights

4.3.1 Surface Enhanced Raman Scattering

Semion K. Saikin, Roberto Olivares-Amaya, Dmitrij Rappoport,Michael Stopa and Alan Aspuru-Guzik

A recent work appearing in *Physical Chemistry Chemical Physics*, **11**, 9401 (2009), and performed with the computation facilities of NNIN/C described the calculation, using time-dependent density functional theory (TDDFT), of the Raman scattering of benzenethiol molecules adsorbed on nano-crystals of a few (~10) silver atoms. Raman scattering cross sections were computed using a formalism that employs analytical derivatives of frequency-dependent electronic polarizabilities, which treats both off-resonant and resonant enhancement within the same scheme. The Raman enhancement was analyzed using Raman excitation profiles (REPs) for the range of excitation energies 1.6–3.0 eV, in which isolated benzenethiol does not have electronic transitions. The work demonstrated the importance of excited states concentrated at the binding point between the nanoparticle and the molecule, in this study consisting of the sulfur atom, in enhancing the vibrational response of the molecule. This enhancement, one form of the so-called "chemical enhancement," goes beyond the electromagnetic enhancement resulting from the excitation of the plasmon in the metal particle. However the new method, which featured extensions to the "Turbomole" DFT code, suggested a paradigm in which the chemical and electromagnetic effects could be combined into a single formalism which treats fully the excitations of the metal-molecule system all on an equal footing.

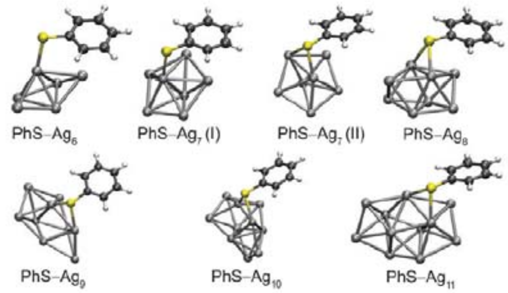


Fig. 1 Optimized geometries of PhS–Ag_n, n = 6–11 complexes that were utilized in the study. For n = 7 two isomers with different types of binding for the molecule were considered.

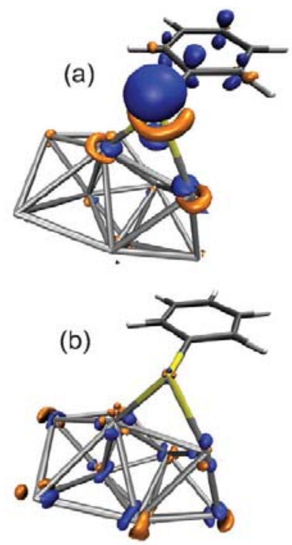


Fig. 6 The transition electron densities for (a) the 2.17 eV electronic excitation and (b) the 1.84 eV electronic excitation in the PhS–Ag_{10} complex. The former transition results in the strong resonant features in the REP, whereas the latter one has much weaker effect. The orange color corresponds to the transition density of −0.002 a.u., the blue corresponds to the transition density of 0.002 a.u.

4.3.2 Research Highlight: Lumerical-NNIN partnership accelerates nanophotonics research

A donation has been made to NNIN-Harvard by the Lumerical Corporation of licenses for the FDTD Solutions Engine for the study of nanophotonics. Each of the ten FDTD Solutions Engine licenses enable a current FDTD Solutions customer to run, at no additional cost, large-scale electromagnetic simulations on any number of the 224 cores that are part of the Harvard University facility. The company issued a press release on February 22, 2010 describing the donation. Note, users must already own their own TDTD license to use the licenses on the Harvard cluster. Nonetheless, they gain access to considerably more computation power through the shared NNIN licenses.

FDTD Solutions can model the electromagnetic response of nanoscale optical devices, systems and materials including silicon photonics components, photonic crystals, metamaterials, solid-state emitters, thin-film solar cells and components that make use of surface plasmons. Surface plasmon devices, which involve localized confinement of light at metallic interfaces, are of increasing interest for activities such as designing ultra-compact waveguides, generating large local field enhancements in metallic nanohole arrays, and engineering decay rates for fluorescence enhancement in bio-sensing applications.

4.3.3 Research Highlight: Using Electrons to Probe Optical Modes in Nanowires

Nanowires hold great promise as potential photodetectors, nanoscale lasers, and solar cells. However, due to the small size of these structures, it is often very difficult to couple light into these systems to properly characterize the different optical modes. In a recent paper (Nano Letters, 9, 4073 (2009)), I. Arslan et al., have shown that transition radiation from a 1 nm diameter electron beam can be used to excite optical modes in a GaN nanowire. This study represents an important new diagnostic tool for characterizing nanoscale optoelectronics. Calculations were done on the CNF cluster using the MIT Photonics Band code to determine the optical modes of the GaN nanowire (Fig 31 a) and show good agreement with the modes measured with this new technique Fig (31 b).

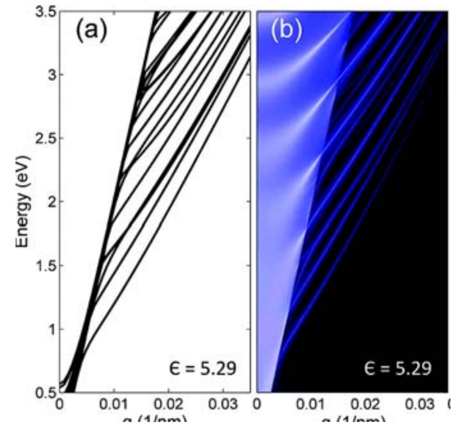


Fig.31

4.3.4 Characterizing Graphene Oxide

Graphene, a single honeycomb layer of carbon, could provide the ultimate limit in device miniaturization. However, critical questions remain on the practical design of devices and how chemical bonding affects graphene sheets. Graphene oxide could also provide a complimentary insulating material, however the exact atomic structure of this system is still a matter of debate. In a recent Nano Letters article (K. A. Mkhoyan *et al.* Nano Letters, **9**, 1058 (2009)), researchers have combined experimental measurement techniques (EELS and STEM) with density functional calculations to determine the atomic and electronic properties of graphene oxide. For the work, density functional calculations using the Quantum Espresso code were performed on the CNF cluster to determine the stable atomic structure of graphene oxide. Several oxygen bonding sites were considered and the case where the oxygen atom sits above a C-C bond was found to be the most stable. These structural relaxation calculations show clear evidence that oxygen distorts graphene, pulls neighboring carbon atoms above the plane, and transforms sp^2 bonds to sp^3 (Figure 32) These distortion have a significant effect on the local density of states, removing the p_z states near the Fermi energy, and resulting in a metal to insulator transition.

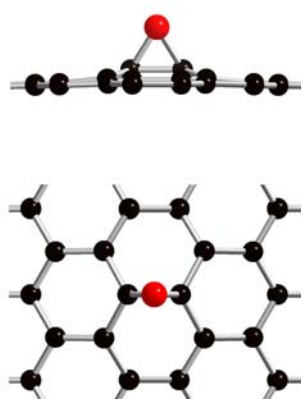


Figure 32 Side and top view of oxygen atom (red) bonded to graphene. Oxygen distorts graphene and pulls carbon atoms above the graphene plane. (*Mhkoyan et al, Nano Letter,* 9**, 1058 (2009)**)

4.4 Progress on New Computation Initiatives

4.4.1 Virtual Vault for Interatomic Potentials

In September of 2009, the National Science foundation awarded a grant to the "Knowledge-Base for Interatomic Models," or KIM for short. KIM is a program to test, validate and store interatomic model potentials for use in molecular dynamics calculations, which are at the heart of many biological and chemical simulation approaches. The principal investigators, Ellad Tadmoor, University of Minnesota, James Sethna, Cornell University and Ryan Elliott, University of Minnesota, plan to work with NNIN/C to make the database, which is a major output of their research, available to the nanoscience computing community. KIM is currently hiring a postdoctoral research assistant to work on the project. Discussions between the KIM P.I.s and NNIN/C envision a mirror site for the database on NNIN/C hosts as well as workshops on the database and its usage in molecular dynamics calculations. Finally, the new “Orgoglio” cluster of General Purpose Graphical Processing Unit computers that has a theoretical speed of 9 TFlops is particularly suited to molecular dynamics calculations and coulc play an important part of the applications which the database will enable.

4.4.2 Virtual Vault for Pseudopotentials

The development of the Virtual Vault for Pseudopotentials is headed by the Cornell NNIN node. While electron scattering from atoms can be describe using a full potential, this process is be computationally expensive and dramatically limits the number of atoms that can be considered. Pseudopotentials can efficiently capture the relevant scattering information and allow for large scale calculations. The NNIN database provides the global scientific community with access and statistics on pseudopotentials used in a wide range of electronic structure codes. Since pseudopotentials are often described using different formats, it is also important to provide resources to convert between different codes.

One of the key problems in pseudopotential development is that work is often focused around a particular electronic structure code and there is little communication between different research communities. During 2009, the CNF developed a general clearinghouse for information related to pseudopotentials to serve as a cyberinfrastructure resource for the community. Version 1 of this resource is available at http://www.nnin.org/nnin_comp_psp_vault.html This website includes links to over 10 different pseudopotential collections on the web, 12 pseudopotential generators, 4 pseudopotential translators, and links to key references on pseudopotentials. The site currently ranks as 2nd on a Google search for pseudopotential, behind the general Wikipedia entry for pseudopotentials.

Building on this initial step, the computation node at the CNF has developed a PHP-SQL database of pseudopotentials that can be accessed online. This database contains nearly 600 pseudopotential files drawn from several different pseudopotential codes. Users can interface this data through an online periodic table to find information related to a particular atom. Users can also search the database based on a given element and compare available pseudopotentials based on criteria such as exchange-correlation functional, pseudopotential class (i.e. ultra-soft, norm-conserving), parent electronic structure code, and more. This database provides the first centralized resource for pseudopotentials that spans multiple electronic codes.

A key concern for researchers in the electronic structure community is pseudopotential accuracy. The validity of a pseudopotential can be tested by running calculations for standard crystal structures and comparing the results for physical properties such as lattice constant, bulk modulus, magnetic moment with experimental data and previous calculations. The Cornell site is currently developing automated scripts that will allow researchers to upload a pseudopotential file and run through a series of calculations to score the pseudopotential accuracy. These “scores” will be stored with the pseudopotential in the database.This feature will help build a strong database of trusted pseudopotentials and help prevent new researchers from wasting time running calculations with poor pseudopotentials. To insure that this trusted set of pseudopotentials can have the most impact in the community, the NNIN is planning a workshop later in 2010 that will bring together experts in pseudopotential development and formatting to help establish a common format that can be used across several different electronic structure codes.

4.4.3 GPU Initiative

The Graphical Processing Unit, highly parallel computing initiative of NNIN/C got underway in 2009 with the installation of the Orgoglio cluster. The cluster specifications are as follows: