National Nanotechnology Coordinated Infrastructure

NNCI Coordinating Office Annual Report (Year 4)

April 1, 2019 – March 31, 2020

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NNCI Coordinating Office Annual Report 2020

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1. NNCI Overview

1.1. Introduction

The National Nanotechnology Coordinated Infrastructure (NNCI) is an NSF-funded network of academic nanofabrication and characterization sites and their partners, formed to advance research in nanoscale science, engineering and technology. The NNCI site awards were the culmination of a competition conducted by NSF, under Program Solicitation NSF 15-519, which was generated as a result of input from the science and engineering community following the completion of the National Nanotechnology Infrastructure Network (NNIN, 2004-2015). Over 50 proposals from potential NNCI sites were submitted, resulting in 16 awards. The NNCI network is funded by the NSF through cooperative agreements with the individual sites, with the initial site awards being made around September 15, 2015 with an initial award period of 5 years. The Coordinating Office for the network was awarded to the Georgia Institute of Technology on April 1st, 2016. The total NSF funding for the initial 5 years of the NNCI network is $81 million.

The NNCI sites are located in 17 states and involve 29 universities and other partner organizations (see Figure 1) that provide researchers from academia, small and large companies, and government with access to university user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology.

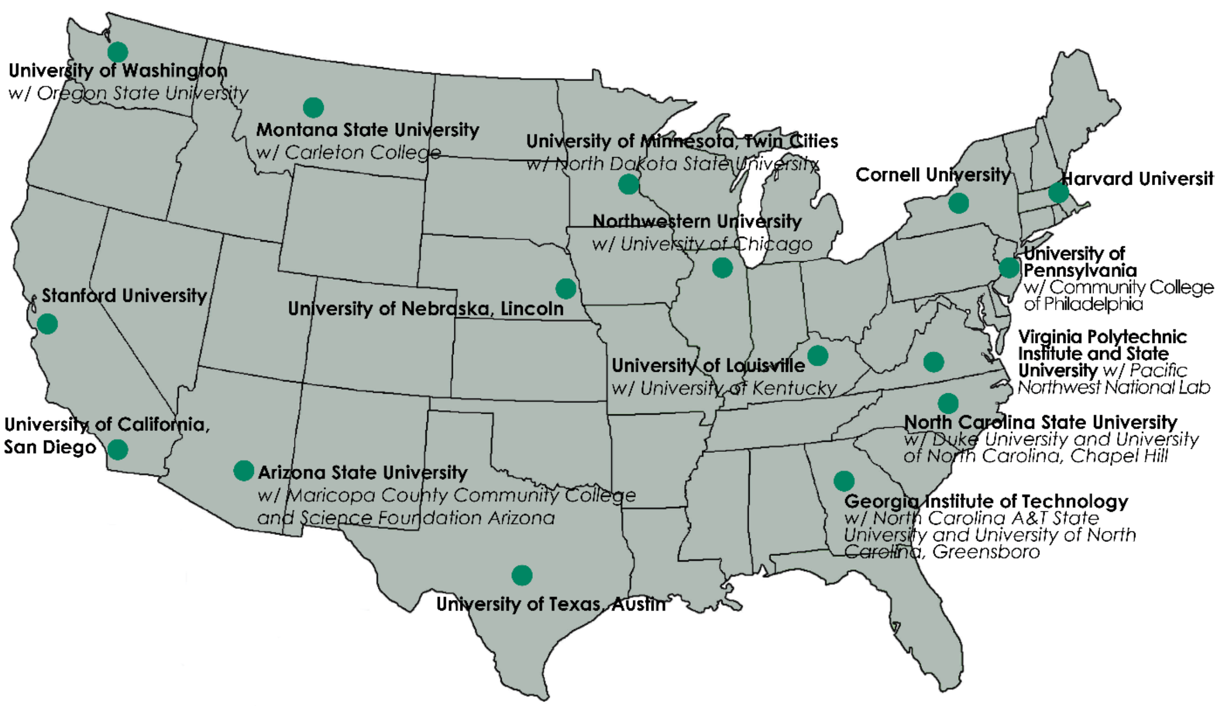

Figure 1: US Map with Locations of the 16 NNCI Sites

The goal of the NNCI network is (1) to provide open access to **state-of-the-art nano-fabrication & characterization facilities**, their tools and staff expertise across US, and (2) to use these resources to support **education & outreach (E&O)** as well as **societal & ethical implications (SEI) programs** in/of nanotechnology.

The 16 NNCI sites and their 13 partners (university, college, national lab, and non-profit foundation) provide access to more than 2,000 tools located in 69 distinct facilities. As will be detailed later in this report, these tools have been accessed by more than 13,000 users including more than 3,800 external users, representing nearly 250 US academic institutions, >900 small and large companies, ~60 government and non-profit institutions, as well as ~70 foreign entities. Overall, these users have amassed more than 1,000,000 tool hours, surpassing this milestone for the second year in a row. During the fourth year, the network has trained more than 5,000 new users.

This report summarizes the activities and progress for Year 4 of the Georgia Tech Coordinating Office of the NNCI, from April 1, 2019 - March 31, 2020. NNCI sites are funded via separate cooperative agreements between NSF and each site, with reporting of site specific data and activities corresponding to Year 4 (October 1, 2018 – September 30, 2019).

1.2. NNCI Organization

All of the NNCI facilities, most of which have partners and multiple locations, are available for use by students and professionals from around the country and globally. The sites and facilities within NNCI (Table 1) support research and development for academic education and research purposes, as well as product and process development for commercial purposes. Each site operates under its own procedures for user recruitment, user access, training, rates, billing, and other logistical details. However, each has agreed to provide open access, with as minimal a burden as possible, to their state-of-the-art nanofabrication and characterization facilities, their tools, and staff expertise. All sites use the resources provided by NSF to support a variety of education and outreach activities (Section 4.1), and many also offer programs or research in societal and ethical implications (SEI) of nanotechnology (Section 4.2).

Table 1: NNCI Sites, Locations and Facilities

NNCI Sites and Locations	NNCI Facilities
Cornell Nanoscale Science and Technology Facility (CNF) Cornell University	Cornell Nanoscale Science and Technology Facility
Center for Nanoscale Systems (CNS) Harvard University	Center for Nanoscale Systems
Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY MMNIN) University of Louisville University of Kentucky	Micro/Nano Technology Center Center for Nanoscale Science and Engineering Huson Nanotechnology Core Facility Electron Microscopy Center Conn Center for Renewable Energy Research Center for Applied Energy Research Center for Advanced Materials Rapid Prototyping Center

Mid-Atlantic Nanotechnology Hub (MANTH) University of Pennsylvania Community College of Philadelphia	Singh Center for Nanotechnology Quattrone Nanofabrication Facility Singh Center for Nanotechnology Nanoscale Characterization Facility Singh Center for Nanotechnology Scanning Probe Facility
Midwest Nanotechnology Infrastructure Corridor (MINIC) University of Minnesota North Dakota State University	Minnesota Nano Center NDSU Packaging Center
Montana Nanotechnology Facility (MONT) Montana State University Carleton College	Montana Microfabrication Facility Imaging and Chemical Analysis Laboratory Center for Biofilm Engineering Proteomics, Metabolomics and Mass Spectroscopy Facility Center for Bioinspired Nanomaterials
Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth) Virginia Tech Pacific Northwest National Laboratory	Virginia Tech Center for Sustainable Nanotechnology Virginia Tech Nanoscale Characterization and Fabrication Laboratory PNNL Environmental Molecular Sciences Laboratory
Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) Arizona State University Maricopa County Community College District Science Foundation Arizona	ASU NanoFab LeRoy Eyring Center for Solid State Science Solar Power Lab Peptide Array Core Facility Nano in Society User Facility Center for the Life Cycle of Nanomaterials
Nebraska Nanoscale Facility (NNF) University of Nebraska-Lincoln	Nebraska Center for Materials and Nanoscience Nano-Engineering Research Core Facility
Northwest Nanotechnology Infrastructure (NNI) University of Washington Oregon State University	Washington Nanofabrication Facility Molecular Analysis Facility Advanced Technology and Manufacturing Institute Materials Synthesis & Characterization Facility Ambient Pressure Surface Characterization Lab Oregon Process Innovation Center
Research Triangle Nanotechnology Network (RTNN) North Carolina State University Duke University University of North Carolina at Chapel Hill	Analytical Instrumentation Facility NCSU Nanofabrication Facility Shared Materials Instrumentation Facility Chapel Hill Analytical and Nanofabrication Laboratory Zeis Textiles Extension for Economic Development Nuclear Reactor Program Public Communication of Science & Technology Project

	Center for the Environmental Implications of Nanotechnology Duke Magnetic Resonance Spectroscopy Center Chemical Analysis and Spectroscopy Laboratory
San Diego Nanotechnology Infrastructure (SDNI) University of California - San Diego	Nano3 Cleanroom Microfluidic Medical Device Facility Chip-Scaled Photonics Testing Facility NanoMagnetic Material Processing Facility
Southeastern Nanotechnology Infrastructure Corridor (SENIC) Georgia Institute of Technology Joint School of Nanoscience and Nanoengineering	Institute for Electronics and Nanotechnology-Micro/Nano Fabrication Facility Materials Characterization Facility JSNN Cleanroom and Labs
Soft and Hybrid Nanotechnology Experimental (SHyNE)Resource Northwestern University University of Chicago	Northwestern University Atomic and Nanoscale Characterization Experimental Center Integrated Molecular Structure Education and Research Center Northwestern University Center for Atom Probe Tomography J.B. Cohen X-ray Diffraction Facility Northwestern University Micro/Nano Fabrication Facility Simpson Querrey Institute Pritzker Nanofabrication Facility
NNCI Site @ Stanford (nano@stanford) Stanford University	Stanford Nano Shared Facilities Stanford Nanofabrication Facility Stanford Microchemical Analysis Facility Stanford ICPMS/TIMS Facility
Texas Nanofabrication Facility (TNF) University of Texas -Austin	Microelectronics Research Center Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies The Center for Nano and Molecular Sciences Texas Material Institute

Sites have identified approximately 250 staff that support the NNCI program (Table 2), although some individuals fulfill multiple roles within a site's operations. In general, Site Leadership includes Site Directors, Deputy Directors, and Associate/Assistant Directors. Some of these individuals also serve as project co-PIs. New User Contacts are those site staff responsible for coordinating access to facilities for external users. Program Managers are identified as those staff who most interact with the Coordinating Office, providing data as requested and communicating information to appropriate site staff. Facility Managers are responsible for the operations of site facilities, often assisted by Technical Staff when identified. Education/Outreach Coordinators handle the K-12 activities and sometimes the university student and professional education as well. SEI and Computation Coordinators are responsible for those aspects of site operations.

Table 2: NNCI Site Staff

NNCI Site Staff	
Site Directors	16
Other Site Leadership	38
New User Contacts	32
Program Managers	18
Facility Managers	59
Education/Outreach Coordinators	33
SEI Coordinators	8
Computation Coordinators	5
Safety/Facility Director/Technical Staff	30
Facility Administrative Staff	12

2. NNCI Coordinating Office

The NNCI Coordinating Office is led by Prof. Oliver Brand (Executive Director, Georgia Tech Institute for Electronics and Nanotechnology (IEN) and Director, SENIC) who serves as **Director**. Dr. David Gottfried (Senior Assistant Director, Georgia Tech IEN and Deputy Director, SENIC) serves as **Deputy Director** and oversees the Coordinating Office day-to-day operations, assisted by a **Program Manager** (Amy Duke). Three **Associate Directors** manage the network activities in specific areas. Dr. Quinn Spadola (Georgia Tech) coordinates the NNCI education and outreach programs. Dr. Spadola previously was with the National Nanotechnology Coordination Office (NNCO) focusing on education and outreach on behalf of the National Nanotechnology Initiative (NNI). Prof. Jameson Wetmore (Arizona State University) coordinates the Societal and Ethical Implications (SEI) activities. Prof. Wetmore is an Associate Director within Nanotechnology Collaborative Infrastructure-Southwest at ASU and has been coordinating SEI activities on a national level as Co-Director of the Center for Engagement and Training in Science & Society. Prof. Azad Naeemi (Georgia Tech) coordinates the computational activities and facilitates interactions with nanoHUB/NCN at Purdue University. This Coordinating Office staff meets monthly by conference call.

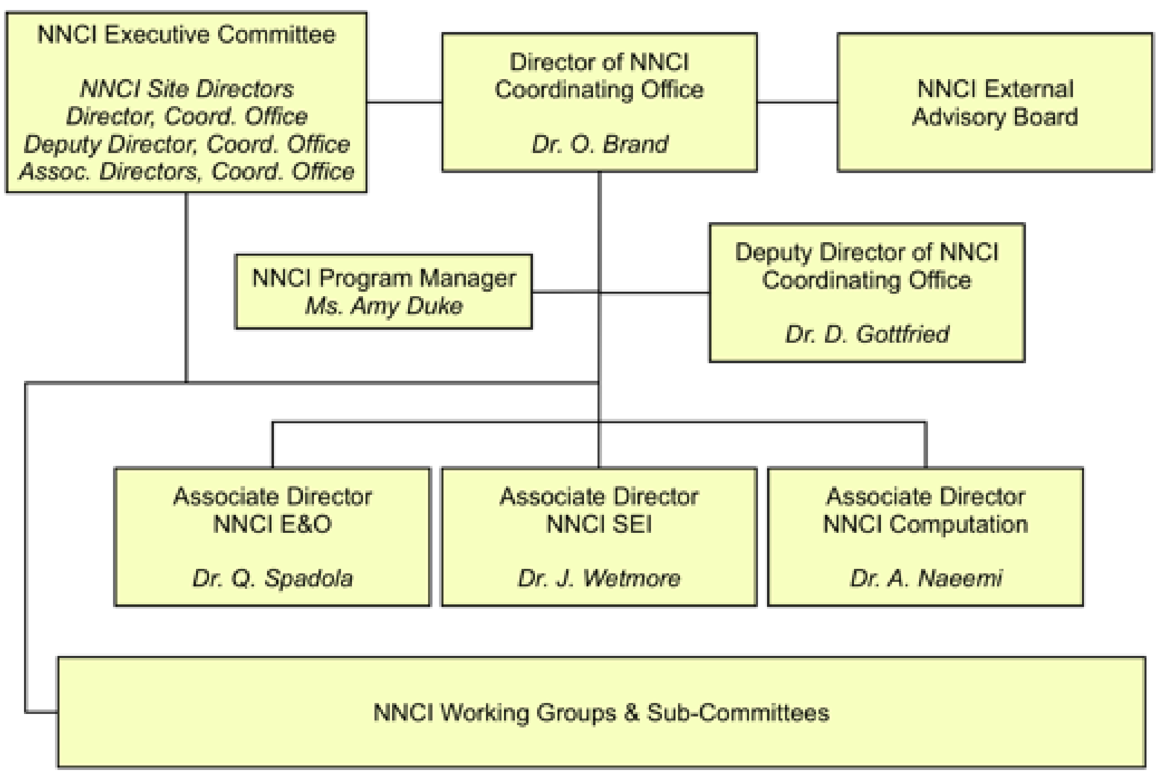

Figure 2: NNCI Coordinating Office Organizational Chart

The Coordinating Office staff is guided by an **Executive Committee** which includes the 16 NNCI site directors. The Executive Committee meets monthly via teleconference and annually in person at the NNCI Conference. The Executive Committee and Coordinating Office are advised by an **External Advisory Board** (EAB, see Section 3) comprised of members representing industry, academia, government, education and outreach, SEI, computation and non-traditional disciplines in nanoscience and nanoengineering. The EAB meets in person as part of the NNCI Conference, with additional conference calls as necessary.

In addition to the work of the Associate Directors, several **subcommittees** of the Executive Committee have been formed to tackle high-level issues related to the NNCI network as a whole (see Section 5). Finally, leveraging the distributed expertise at the network level, several **working groups**, composed of staff members from the NNCI sites, have been formed to share and develop best practices for site and network operations, technical areas, research areas, and education and outreach (see Section 6).

Other tasks of the Coordinating Office include:

- creation and maintenance of the NNCI website
- organization of the NNCI Annual Conference
- interfacing with NSF and the External Advisory Board
- facilitating interactions among the sites via an email listserve
- incentivizing sites to collaborate via support of workshops
- marketing the NNCI at conferences and trade shows and through printed and electronic materials
- organization of an annual REU Convocation
- development of an annual user satisfaction survey
- management of the Outstanding NNCI Staff Member awards
- providing unified outlines and templates for site annual reports and reverse site reviews
- collection of site usage statistics
- collection of annual user highlights
- preparation of this annual report

More details on these activities are shared in the sections below, and plans for future activities are provided in Section 12.

3. External Advisory Board

During the first year of the NNCI, the Coordinating Office established an NNCI External Advisory Board. To this end, names for potential advisory board members were solicited from the 16 NNCI sites. The Coordinating Office then assembled the Advisory Board from the solicited list, ensuring a diverse board in terms of gender, ethnicity and disciplinary background. Since its inception, there have been some changes in the EAB membership and Table 3 shows the Advisory Board members and their affiliations as of January 2020.

Table 3: NNCI External Advisory Board

Name	Affiliation
Prof. Reggie Farrow	Department of Physics New Jersey Institute of Technology
Dr. Andrew Greenberg	Associate Director, Institute for Chemical Education University of Wisconsin
Dr. Elaine Cohen Hubal	Acting Director, Computational Exposure Division US Environmental Protection Agency
Dr. Angelique Johnson	MEMSTIM Louisville, KY
Mr. Joe Magno	Executive Director The North Carolina Center of Innovation Network
Prof. Richard Osgood	Department of Electrical Engineering & Department of Applied Physics Columbia University
Dr. Kurt Petersen	Band of Angels Palo Alto, CA
Prof. Ken Wise	Department of Electrical Engineering and Computer Science University of Michigan

The Advisory Board meets in person during the annual NNCI Conference and virtually via teleconference call as needed. Ahead of the first NNCI Conference in January 2017, the Coordinating Office asked the Advisory Board to take a critical look at what NNCI is doing well and areas where it can improve. In particular, the Advisory Board considered the following questions:

1. What activities can/should NNCI support to achieve the goal of the network surpassing the sum of the parts? This should involve not only research facilities aspects, but also consider

support of education/outreach, computational tools, and societal and ethical implications activities.

2. The NSF considers increasing usage by external users as well as usage by "non-traditional" users of prime importance. Considering the current activities of the sites and the network, what can be improved to achieve this aim?
3. Since NNCI serves to support cutting-edge research in both academia and industry, what capabilities should sites begin to acquire to anticipate 5-10-year research trends?

From the feedback of the Advisory Board at the January 2017 NNCI Conference it became clear that a more detailed "Charter Letter" with input from the NSF on what would constitute a successful network was needed. This document was created during 2017 and communicated to the Advisory Board with a copy provided in the 2017 annual report. The report of the Advisory Board following the most recent NNCI Conference (October 2019) is provided in Appendix 13.1.

4. Associate Director Reports

4.1. Education and Outreach

The mission of the NNCI's Education and Outreach (E&O) efforts is to offer education and training to address the growing need for a skilled workforce and informed public; provide resources, programs, and materials to enhance knowledge of nanotechnology and its application to real-world issues; and support the US economy by enabling a STEM-literate workforce ready to meet the technological challenges of a nano-enabled economy as well as an informed citizenry that supports continued and safe growth of nanotechnologies.

The 16 sites of the NNCI each have separate E&O programs in order to address these goals. Throughout the NNCI Year 4, E&O coordinators and staff reached more than 66,000 people. These are personal interactions through classroom visits, teacher workshops, remote sessions, short courses, seminars, symposia, community events, booths at conferences, tours, internships, REUs, and RETs. Of those interactions, 56% are with K-12 students, 2% with educators (K-12 teachers and community/technical college faculty), 27% with the general public, and 15% with professionals (REUs and other student interns, short course and workshop participants, seminar attendees, etc.). That number does not include NanoEarth's Pulse of the Planet programs (25,512 listeners) or Nebraska Nanoscale Facility's traveling museum exhibit (20,100 visitors) or the Nanooze magazines distributed through CNF. Also not included are the number of people enrolled in the online courses offered through RTNN and nano@Stanford; these are discussed in the Technical Content Development working group report (Section 6.12).

In celebration of National Nanotechnology Day, the NNCI hosted an image contest, *Plenty of Beauty at the Bottom*. Sites submitted images created at one of their facilities during the past year to three categories: Most Stunning, Most Unique Capability, and Most Whimsical. Public voting took place during the week of National Nanotechnology Day (Oct. 7-11) with sites promoting the contest through their various communication channels. Over 5,000 votes were cast to determine the winner in each category. In addition to the image contest, individual sites hosted a number of events including tours, activities at schools, celebrations in collaboration with local science centers, and posting social media content. Many also participated in the Nanotechnology Applications and Career Knowledge (NACK) Network's Remotely Accessible Instruments for Nanotechnology (RAIN) event, operating remote access sessions across the NNCI network.

To facilitate the sharing of information across the network, coordinators participate in monthly calls and post information to a Slack workspace. The purpose of the calls is to share information about upcoming events, partnerships, conferences of interest, and for working group leads to update the entire group on relevant information. This is also an opportunity for coordinators to connect over common interests and plan follow-up conversations. Some examples of cross site interactions include:

- SENIC implemented nano@Stanford's teacher workshop, Nano Summer Institute for Middle School Teachers, during the summer 2019 and SDNI plans to do the same for summer 2020.
- After asking about mentor training resources during a monthly call, RTNN was provided with information by SENIC.
- TNF has started using video training for tools modeled on those produced by nano@Stanford.
- NanoEarth and MONT collaborated on publication of a review article in *Science* and the related teaching companion that encourages the inclusion of nanoscience in earth and environmental sciences.

Across the network, E&O coordinators make an effort to reach groups historically underrepresented in STEM fields. Coordinators attend conferences and programs such as those hosted by the American Indian Science and Engineering Society, the Annual Biomedical Research Conference for Minority Students, and the Society for the Advancement of Chicanos/Hispanics and Native Americans to promote REU opportunities to students from URM serving institutions.

Additionally, coordinators have been encouraged to include information on all of the other NNCI REU opportunities (the Coordinating Office has provided a flier with all NNCI REU sites listed) when they attend events to promote their own program. Coordinators work to create relationships with and provide information on teacher workshops and student programs particularly to Title 1 schools (schools where at least 40% of students come from low-income families) in their respective areas. Multiple sites are communicating with each other to share experiences and best practices for engaging with tribal colleges in order to reach Native American students.

With outreach to K-12 students, the NNCI is inspiring our future skilled workforce and helping to create an informed citizenry. Many sites participate in summer camps, high school student internship programs, after school programs, career fairs, and both off-site and on-site visits. Highlights of activities include NNI's hosting of students from Paschal Sherman Indian School for a multi-day visit that included the importance of a college education and gave them the chance to use nano-characterization tools. Their coordinator pointed out that nanotechnology is the hook while the important part is exposing students to the campus community. RTNN organized their second Girls STEM Day at Duke with 140 Girl Scouts participating. The following quote is from a high school student who participated in the Nanotechnology course offered through Engineering Summer Academy at the University of Pennsylvania which MANTH staff redesigned and are teaching: "One of the most exciting moments for me didn't happen just once, but rather almost every day: and that is, working on labs in the Singh Center cleanroom."

In order to develop a STEM-literate workforce and informed citizenry, coordinators provide many activities for educators. While the percentage of educators reached in Year 4 was small (2%), it is important to note that the time spent with educators can be significant. Often these interactions are multi-day workshops, summer long RETs, or sessions at conferences in which teachers leave with free resources and a personal connection to a nearby site. Four sites (SENIC, MINIC, SHyNE, NNF) have submitted an RET collaborative proposal. RTNN received an RET grant last spring and hosted their first cohort of teachers. NCI-SW and SDNI also offer summer research experiences for teachers. NanoEarth co-organized a 3-day professional development workshop on nanoscience for 16 high school science teachers. With supplemental funding, they offered travel grants and each teacher took home over $300 in lab supplies and teaching materials. SDNI reached over 1,000 students with their remote SEM and used this outreach tool in order to build connections with the teachers, administrators, and NGSS facilitators in their state. NNF has combined a session on integrating nanoscience into curriculum for both teachers and school administrators with their traveling exhibit.

As part of building a nano-literate skilled workforce, NNCI sites provide technical workshops, short courses, seminars, webinars, and/or symposia for undergraduates, graduates, post-docs, and other professionals. NCI-SW has provided 21 hands-on lab sessions for 10 community college students who are enrolled in Rio Salado College's Nanotechnology AAS/Certificate program. The following is a quote from an undergraduate student who participated in TNF's internship program, "At the beginning of the fall 2018 semester, I received an internship offer from AMD for spring 2019. I had been turned down for the position in the previous semester, but this time I had some technical work experience to talk about. They were very impressed with the amount of personal responsibility I demonstrated at my position at MRC and I believed it to be one of the main contributing factors to me receiving the offer. Leaving my job at the MRC has been one of the most difficult decisions in my life, but it was thanks to it I am where I am now." SHyNE helped organize the spring 2019 Illinois Nano Centers Consortium workshop. NanoEarth has the Nanotechnology Entrepreneurship Challenge which encourages students to solve sustainability problems with nanotechnology. RTNN, SENIC, and nano@Stanford all provide outreach training to undergraduate and graduate students in order to help them better serve their communities.

Undergraduate students who participate in an REU at an NNCI site are able to attend the REU Convocation. Eleven NNCI sites participated in the 2019 REU Convocation hosted by CNF. Sixty-five students gave 8-10 minute presentations on their research and presented posters. When asked if their experience with the convocation program was positive, the average response from students was 4.7 out of 5. Each sites' REU information is listed on the NNCI website, the NSF REU website, and coordinators are encouraged to promote REUs across the network when they attend conferences to recruit for their own program. As a continuation from the NNIN program, the coordinating office surveys the students. Faculty and mentors are also surveyed in order to help with the selection process for CNF's iREU in Japan program. KY Multiscale shared that two of their summer interns won the prestigious Barry Goldwater Scholarship for college sophomores and juniors who intend to pursue research careers in the natural sciences, mathematics and engineering.

NNCI sites participate in science festivals, science cafes, science days at their institutions, National Nanotechnology Day and Nano Days celebrations to help enable an informed citizenry. MINIC participated in The Central Wisconsin Science and Engineering Festival. The festival is held every two years at Northcentral Technical College. The two-day event brings 4,000-5,000 6th and 7th grade students on the first day with demonstrations and hands-on activities; it is opened to the general public on the second day. During the Atlanta Science Festival, SENIC's education and SEI coordinators worked together on an event inspired by "Nano Around the World," a game created by Associate Director for SEI Jameson Wetmore and available through NISENet. Feedback from attendees included, "I loved this activity! Very clever way to integrate science and social activities."

Moving forward, there is a large amount of interest among education and outreach coordinators to further engage with their community and technical college ecosystems. To serve their local communities, sites provide resources for both students and faculty of community colleges. There are internship and REU opportunities, assistance with course development and access to facilities, remote access, tours, and workshops for educators. As a network, coordinators regularly discuss their local programs and give advice for sites that are working to implement something similar. Another topic frequently discussed among sites are online resources to train new and non-traditional users of facilities. Many sites are looking to online training courses and videos to supplement existing in-person training. Using the experience of sites that have already started producing content to guide them and leveraging what has already been developed across the NNCI, more sites will become involved in producing online content to train users.

More details on these future efforts and activities, as well as information on community outreach and evaluation, can be found in the working group reports (Section 6). The report of the *Workforce Development and Community Colleges* working group (Section 6.10), led by Dr. Ray Tsui from NCI-SW, includes information on conversations with SEMI Foundation and summaries of activities at many of the NNCI sites. The *Technical Content Development* working group (Section 6.12), co-led by Drs. Angela Hwang from nano@stanford and Maude Cuchiara from RTNN, is developing efforts to use online learning to lower barriers to access to NNCI facilities. Their report outlines current online content offered at NNCI sites and their plans to encourage more educational and training videos. The report of the *K-12 Teachers/RET, Students, and Community Outreach* working group (Section 6.9), led by Dr. James Marti from MINIC, discusses the multi-site RET proposal that has been submitted to NSF, updates to the NNCI education pages, and network wide activities for National Nanotechnology Day. The report of the *Evaluation and Assessment* working group (Section 6.11), led by Dr. Quinn Spadola from SENIC, includes information on their efforts to understand the impact an NNCI internship has on students. Collaborating with the Workforce Development working group, they intend to develop surveys for the students and possible employers.

4.2. Societal and Ethical Implications

Nanotechnology holds great promise, but the NNCI Coordinating Office recognizes that the introduction of any new technology can have significant societal and ethical consequences. We believe it is important to think about the impacts of nanotechnologies as we conceive them, develop them, and implement them. To that end, the Coordinating Office is working to help all of the NNCI sites develop Societal and Ethical Implications (SEI) research and engagement programs. Associate Director Jameson Wetmore (also part of the NCI-SW site) is leading these activities.

At the 2018 NNCI Annual Conference, representatives from many of the NNCI sites met and agreed upon a clear explanation of our goals and methods:

> The NNCI works to better understand the social and ethical implications of nanotechnology research, development, and implementation. In these efforts we do work in both micro- and macro-ethics, with an emphasis in the latter since few science or engineering programs address those important issues. We look at both the social impacts of nanotechnology and the social aspects of nanotechnology. We address the variety of societal implications associated with nanotechnology, including social change, equity issues, economics and policy. And while we do include "environmental issues" on this list, because others spend tens of millions of dollars to study the impact of nanotechnology on the environment, they are not our primary focus. We envision numerous audiences of our work – including NNCI users, NNCI practitioners, policymakers, journalists, and the general public. And ideally we envision these groups as not simply consumers of our work, but as partners in developing that work. We want two-way discussions, not one-way communication, in an effort to advance toward the daunting goal (as outlined in the 21st Century Nanotechnology R&D act) of "integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans."

Much of the SEI work is hosted and carried out at four nodes of the NNCI: TNF, RTTN, SENIC, and NCI-SW. Lee Ann Kahlor leads the work at the University of Texas and spent the last year continuing to refine and assess the training module for "integrating societal and ethical implications into the lab" and has trained over 250 individuals thus far. David Berube leads SEI efforts from NC State University and continues to work to make NNCI labs a more welcoming place to outside scholars by collecting and analyzing user satisfaction data. Jan Youtie leads efforts at Georgia Tech and has been testing ways to integrate SEI into I-Corps as well as doing work in nanoinformatics to determine the impact of nanoscale research through the analysis of publications and patent data. Jameson Wetmore leads the work at Arizona State University and has continued to coordinate both the Science Outside the Lab experience and the Winter School for graduate student social scientists (see below) and worked closely with the Department of Labor over the past six months to help them get access to survey participants in order to update and refine the o*net classification "Nanosystems Engineers."

At the 2019 NNCI Annual Conference we again hosted a pre-meeting workshop that brought together all of the core SEI scholars within the NNCI as well as another twenty representatives from across the network. It became clear at the meeting that most of the NNCI sites are interested in participating in SEI, but look to the four core SEI sites to lead that effort. The prospect of program renewal in 2020 has helped to galvanize that relationship. To that end the NNCI Coordinating Office has been working with Kahlor, Berube, Youtie, and Wetmore to develop SEI programs run at their respective universities that other sites within NNCI can plug into without needing to develop and fund their own in house SEI expertise. The concept is that each of the four sites will organize SEI research and programs that other universities can participate in as long as they provide the people and the costs of participation.

Kahlor plans to organize a semi-annual SEI workshop that facilitates an exchange over how best to engage graduate students, scientists, engineers, and the public in discussions about SEI. Berube and Youtie are both developing methods by which to better asses the impacts of NNCI sites on not just patent data, but real world social and economic benefits. Lastly, Wetmore is looking to revise the Science Outside the Lab (SOtL) program by adding an "SEI Ambassador" component whereby SOtL alumni become an acknowledged resource at the NNCI institution carrying out duties such as giving SEI presentations to REU students, being a point of contact for SEI questions within the lab, and helping to recruit for subsequent SOtL programs. Thus far it appears that a number of NNCI institutions will work these proposals into their plans for the renewal.

The NNCI Coordinating Office helps to host two major SEI training efforts every year. The first, a policy workshop in Washington, DC for graduate student scientists and engineers, is co-sponsored and largely funded through the Nanotechnology Collaborative Infrastructure Southwest. In June 2019, 15 students from the NNCI met with over 25 policymakers, funders, regulators, lobbyists, and lawyers in the fourth Nano "Science Outside the Lab". During this program we hosted students from 8 NNCI universities including three from Northwestern, three from the University of Pennsylvania, two from Stanford, two from Georgia Tech, two from the University of Washington, and one each from NC State, University of Nebraska, and ASU.

In addition to our traditional stop at the NSF, students got to meet and discuss science policy with National Academy board directors, EPA regulators, NASA analysts, and the Chief of Staff of NIOSH. Another highlight was being able to sit in on the US Court of Appeals for the Federal Circuit to witness firsthand how decisions over what is and isn't patentable get made. The format of the program allows students to use their intellectual curiosity to ask any questions they want, which usually results in an invigorating conversation that makes many speakers request to participate year after year.

The immediate impact on the students was very clear. Mary White at NCI-SW conducts pre- and post-survey work with all participants and finds clearly measurable changes in the students. "Perhaps the most startling data gathered from the 2019 cohort was the answer to the following question: "The knowledge I provide should be used to help solve societal challenges." In the pre survey only 20% "agreed" or "strongly agreed" with that statement, while after the program 100% of respondents "agreed" or "strongly agreed."

The students always stress how much they learn as well. Most found that they not only learned a huge amount about science policy, but also about how their research fits into societal needs and even possible career trajectories. Post-workshop comments from two of the graduate students who participated this past year clearly describe the impact and excitement the program generates:

> "I thoroughly enjoyed SOtL. Not only was I able to learn much more about the role of science policy in the federal government, I also got to meet people who are like-minded and have a passion for science policy. I think the biggest take-away from SOtL for me is the urgency of incorporating scientists into all three branches the federal government to better inform the public and make logically sound decisions. I'm looking forward to applying to the numerous fellowships mentioned in SOtL, and getting more involved in my local government, as well as my professional societies."
>
> --Emily Lin, Chemical and Biomedical Engineering, University of Pennsylvania

> "Between meeting other like-minded PhD students from around the country and the time we spent meeting with professionals and visiting sites around D.C., the entire Science Outside the Lab program was an amazing experience. I gained new perspectives and learned so much about the intersection between science and policy and how science influences decision-making in D.C. I would highly recommend this program to anyone studying a science or engineering field to get a better understanding of how the scientific research of our daily lives fits into the broader scope of our nation. And I have a feeling that I'll be using what I learned on this trip for many years to come."
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> --Amy Brummer, Materials Science & Engineering, Georgia Tech

In addition to the immediate excitement generated in participants, it is becoming increasingly clear that the program has a long lasting impact on the work that its alumni do. While most former participants are still in graduate school finishing their PhDs, they are already beginning to reach out beyond their labs to promote a better world through science. For instance, Beth Mundy (University of Washington), a 2018 alum, writes a blog for the Royal Society of Chemistry in which she gets readers up to speed on the latest chemical science research as well as explaining the broader societal significance of the work being done. Moriah Locklear (University of Nebraska, Lincoln), another 2018 alum, was eager to engage in policy work soon after she returned from the program and looked for ways to get involved in her local state government. Within a few months she became an intern for Rep. Carol Blood in the Nebraska State Legislature not only helping Rep. Blood understand the science informing the decisions she had to make, but drafting legislation as well.

This year, the fifth annual Nano SOtL program will be held May 31-June 6, 2020. Again we will recruit graduate student participants from across the NNCI.

The NNCI Coordinating Office also sponsored its third annual "Winter School on Responsible Innovation and Social Studies of Emerging Technologies" on January 3-10, 2019. The goal of this program is to train the next generation of SEI scholars. This past year we hosted sixteen early career social science researchers for a week of learning a variety of research tools that they can then deploy in their research and dissertation work. As usual, there was a strong international presence including participants from the UK, Canada, and Mexico. The students worked with thirteen different social science scholars on topics as varied as inequality (with Georgia Tech professor emeritus Susan Cozzens), informal STEM engagement, bibliometric research (with SENIC SEI lead Jan Youtie), scenario development, and survey research.

While this was the third Winter School sponsored by the NNCI, it is the seventh in the series (the first four iterations were sponsored by the Center for Nanotechnology in Society–ASU). Through this series of Winter School events we have developed a healthy alumni network of SEI scholars around the world. Not only do students find moral support through their colleagues, they frequently develop research partnerships and relationships that last long after the winter school ends. This year several students decided to jointly propose sessions at the annual meeting of the Society for Social Studies of Science (the largest annual gathering of SEI scholars in the world). Several of their sessions were accepted and all but one of this year's cohort were able to reconvene in New Orleans at the September conference. In addition to this year's cohort, we also sponsored a happy hour for all alumni from seven years of the winter school at the annual meeting. Approximately 50 alums joined us at the event to visit old friends, network, and discuss their research.

4.3. Computation

Modeling and simulation play a key role in enhancing nanoscale fabrication and characterization as they can guide experimental research, drastically reduce the required number of trial and error iterations, and enable more in depth interpretation of the characterization results. To facilitate access to the modeling and simulation capabilities and expertise available within various NNCI sites, an inventory of available modeling and simulation resources and expertise has been complied. The directory is hosted by nanoHub.org and can be accessed via https://nanohub.org/groups/nnci_computation. So far, 10 sites have reported collectively more than 65 commercial simulation tools and 40 internally-developed simulation tools available for internal and/or external users (with and without fee).

In addition to software resources, 9 supercomputers or major computing clusters are available at various sites. In the past, these hardware resources served internal users only with the exception of the UT-Austin computing cluster which can be accessed by external users with a nominal fee. Last year, the CNF Nanolab Computing Cluster has become available to all users. The Nanolab cluster provides users the opportunity to use a wide range of modeling software tailored for nanoscale systems. The users can run simulations using existing codes, develop and test new codes, or bring their own license for commercial software. Several classes of nodes, all linked via Gigabit Ethernet, are available on the cluster. A new head node with 9TB of shared disk space and 2 new compute nodes each with 256GB RAM, 2 Intel Gold 6136 are the new additions to the 18 legacy nodes each with 24GB/32GB of RAM, Intel Xeons. The cluster runs Scientific Linux 7 with OpenHPC and Slurm is the batch job queuing system. The facility is open to local and remote users. More info can be found at http://computing.cnf.cornell.edu/Cluster.

On the modeling and simulation side, researchers at the University of Minnesota (MINIC) led by Professor Tony Low have greatly expanded their database of electronic and optical properties of 2D materials and their heterostructures. Some of the key new additions include: 1) thousands of 2D heterostructures calculation results and 2) machine learning predictive tools that can derive materials design rule of thumb. They are now working to make the new results and capabilities available on their website.

A complementary effort at Stanford led by Prof. Eric Pop created a database of measured data on 2D materials. The results can be sorted and plotted based on various metrics such as bandgap, mobility, and length as well as growth and processing conditions (e.g. exfoliated, CVD or ALD grown). Only reliable data points based on scientifically sound measurement and extraction method have been added to the database. The database is available at http://2d.stanford.edu/2D_Trends.

Another major modeling and simulation database is Pseudopotential Virtual Vault developed by researchers at Cornell University (CNF). The database includes over 1100 pseudopotential or PAW files. The pseudopotentials are available for Abinit, Quantum Espresso, Qbox, and Siesta and users can search by periodic table elements or for pseudopotentials with specific properties. The database is available at http://nninc.cnf.cornell.edu.

Researchers at Arizona State University (NCI-SW) have made major improvements to their CdTe Lab which is a 2D diffusion-reaction simulator of Cu migration in polycrystalline CdTe solar cells with grain boundaries. Some of the major limitations that were addressed include:

1) Difficulties in extending the solver to incorporate new defect chemistry for Cl, As dopants. The sources of these difficulties were related to the lack of a user-friendly method for incorporation of DFT parameters and the challenges in identifying the root causes of various issues.
2) Numerical Algorithm instabilities with As defect chemistry for 0D reactions mainly because of chain reactions.
3) Cl diffusion and segregation at grain boundaries (GB) was not clear with the modeling assumptions.

The new generation of the simulation module is called “PVRD-FASP Solver”, which is a unified solver for modeling carrier and defect transport in photovoltaic devices. The tool has a graphical user interface and it can be accessed on-line at http://pvrdfasp.com/. The Python based community version is available online at https://gitlab.com/abdul529/pycdts.

The NNCI coordinating office has started negotiating with major software tool vendors regarding discounted academic licenses for NNCI sites and waived tuition fees for NNCI academic users attending hands-on training workshops. Another major activity is to explore the utility of various software packages for wider adoption within NNCI. This is done by talking with vendors, surveying current academic users, and experimenting.

5. NNCI Subcommittees

In addition to the work of the Coordinating Office and specific topical areas of the Associate Directors, several subcommittees of the Executive Committee have been formed to tackle high-level issues related to the NNCI network as a whole (Table 4). Positions on these committees were offered to each member of the Executive Committee (site PIs), along with any site co-PIs who wished to participate. Most Site Directors serve on two of these subcommittees with a subcommittee chair selected by the Coordinating Office. Additional input may be sought from members of the External Advisory Board and other experts as needed. Members of the Coordinating Office serve on some of the subcommittees as ex-officio members. As a starting point, the Coordinating Office created a number of guiding questions for each subcommittee. One of the subcommittees is selected to report to the full group of site directors and coordinating office (Executive Committee) every other session during the regular monthly meetings. At the beginning of 2019 some of the chairs were changed and memberships were expanded, and this will be reflected in the 2020 reports below. Reports of the subcommittees on current and future activities are presented below as provided by the subcommittee chair.

Table 4: NNCI Executive Committee Subcommittees

Subcommittee Topic	Subcommittee Chair
Diversity	Jacob Jones (RTNN)
Metrics and Assessment	Stephen Campbell (MINIC)
Global and Regional Interactions	Vinayak Dravid (SHyNE)
New Equipment and Research Opportunities	Kevin Walsh (KY MMNIN)
Entrepreneurship and Commercialization	Mark Allen (MANTH)
Building the User Base	Shyam Aravamudhan (SENIC)

5.1. Diversity Subcommittee

In December of 2018, the previous Chair of the Diversity Subcommittee, Mike Hochella (NanoEarth, Virginia Tech), retired and a new committee Chair, Jacob Jones (RTNN, NC State), was appointed. Other members of the Diversity Subcommittee in Year 4 are indicated at the end of this report.

Charge: The Diversity Subcommittee redefined its charge to read: **The NNCI Diversity Subcommittee seeks to broaden participation in the NNCI and nanotechnology nationally by positively impacting culture, developing assessment strategies, identifying strategies to overcome common obstacles, collaborating with sites to share and disseminate best practices, and inspiring and challenging each other.**

Priorities: The Diversity Subcommittee prioritized several actions for Year 4, including:

1. Diversify membership in the subcommittee (completed in January 2019)

2. Identify a contact at each site to help coordinate NNCI-wide communications on topics of diversity (completed in February 2019)
3. Assess current state of diversity in NNCI by deploying, e.g., site and staff demographic assessment, staff climate survey, and describing the diversity in site research strengths (completed August 2019)
4. Propose metrics by which we can evaluate diversity and the impact of broadening participation initiatives in the NNCI (ongoing)
5. Initiate 'common obstacles' and 'best practices' discussions (ongoing)

State of Diversity: The "state of diversity" in the NNCI could be assessed by considering several different aspects of groups participating in the NNCI and could include (*indicates those items that were assessed in 2019):

1. *Institutional characteristics of NNCI sites (e.g., HBCU, MSI status)
2. *PI/co-PI of NSF NNCI grants (i.e., NNCI site leadership)
3. *NNCI/Site user institutional characteristics (e.g., HBCU, MSI status)
4. *Site staff demographics (technical and administrative)
5. Site or facility leadership team demographics
6. Site user demographics (internal and external)
7. Site REU or other program participant demographics
8. Site outreach/education activity participant demographics

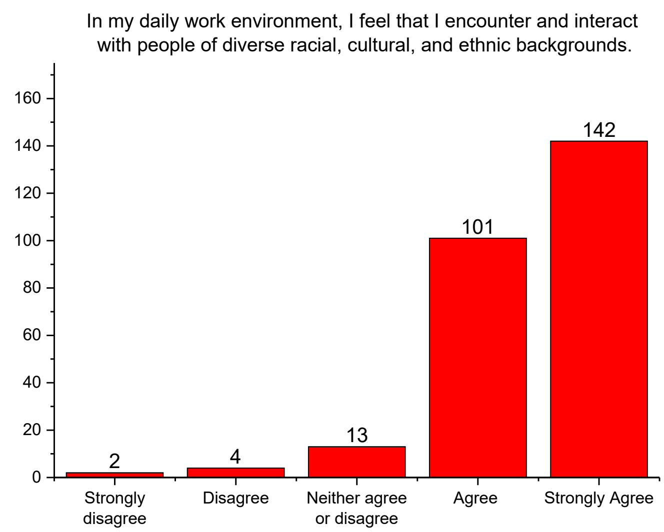
The NNCI sites (**#1 above**) include one HBCU (NC A&T in SENIC), one Minority-Serving Institution or MSI (UNC Greensboro in SENIC), one Primarily Black Institution (Community College of Philadelphia in MANTH), and four *emerging* Hispanic Serving Institutions or HSIs (UT-Austin in TNF, Arizona State in NCI-SW, UC San Diego in SDNI, and Stanford in Nano@Stanford). This institutional diversity reflects innate connections to underserved populations of nanotechnology students and users. Note that *emerging* MSI status is not well-defined nationally but is defined here as an institution with undergraduate student populations that are between 15% and 24% minority students.

Of the 61 individuals listed as PI or co-PI on the NSF awards (**#2 above**), 9 (or 15%) are women, which is comparable to the number of women in the Electrical and Computer Engineering professoriate (13%) and the Engineering professoriate (17%) [https://research.swe.org/2016/08/tenure-tenure-track-faculty-levels/]. Though there are many ways beyond gender to characterize the diversity in groups of individuals, these percentages for women in co-PI positions suggest that sites should continue to diversify their leadership teams.

In Year 3 of the NNCI, external users of NNCI facilities (**#3 above**) came from 241 different academic institutions. Of these external user institutions, 36 were identified as being HBCUs or MSIs with an additional 16 that are Emerging HSIs. A few examples of the HBCUs and MSIs from which users originated include San Jose State Univ., Howard Univ., Morehouse College, NC Central Univ., New Mexico Tech, Univ. Puerto Rico, and Nueta Hidatsa Sahnish College. These numbers reflect that the 16 NNCI sites are serving nanotechnology needs of researchers from many HBCUs and MSIs.

Diversity of site staff (**#4 above**) was assessed using a voluntary survey sent to all 486 NNCI technical staff, admin. staff, and facility or site leaders identified by their site PI or diversity point-of-contact. 262 responses were received, a response rate of 54%. The survey was for internal NNCI purposes to guide strategic endeavors of the NSF-supported NNCI facilities and assess long-term progress on diversity initiatives in the NNCI. It was not part of a research project and individual responses were anonymized for evaluation by aggregate. Only limited observations are summarized here. Overall, *technical* staff members who responded to the NNCI survey identified as 57% White, 20.5% Asian, 3.3% Hispanic or Latino/Latina, and 2.0% Black or African American. The percentages of Hispanic or Latino/Latina and Black or African American responding to the survey are lower than the percentages of the same groups in the US population that hold science and engineering (S&E) highest degrees and work in S&E occupations (e.g., 6% for Hispanic and 4.8% for Black [2]). In total, 30% of respondents identified as female (21% of technical staff, 73% of admin. staff, and 16% of facility/site leaders).

Climate for Inclusivity: The climate for inclusivity in NNCI facilities was also assessed in the staff survey. 93% of the respondents either strongly agreed or agreed that they encounter and interact with people of diverse racial, cultural, and ethnic backgrounds (see figure below right). 92% of respondents either strongly agreed or agreed that their site/facility was a welcoming environment for persons from all backgrounds and perspectives. Concerning their own comfort level in their environments, 89% of respondents either strongly agreed or agreed that their site/facility is a comfortable place to work. The results of the staff diversity climate survey were shared with site directors and diversity points-of-contact and it was asked that the directors bring the report and the site-specific response data as a discussion item at facility and site staff and leadership meetings, to discuss the factors that influence a positive and welcoming environment, and brainstorm on pro-active changes to those environments.



Select Highlights of Successes and Best Practices in the NNCI:

The NNI site at the University of Washington and Oregon State has worked to increase the diversity in its leadership and users through a rigorous search for a new Director of the Washington Nanofabrication Facility (WNF) as well as through outreach to underserved communities with special focus on Native American engagement. After the hire of Maria Huffman as Director of WNF, now half of the NNCI leadership team are women scientists and engineers. WNF has also hired three new permanent staff, all women, of diverse backgrounds, ethnicity and age groups. The NNI hopes to continue to increase diversity across NNI staff and users by providing a diverse and inclusive working environment.

NanoEarth's Multicultural and Underrepresented Nanoscience Initiative (MUNI) is designed to help broaden participation in STEM by members of multicultural, historically underrepresented, and other underserved populations. MUNI provides financial support for travel and facility usage to individuals engaging with NanoEarth for research or educational purposes. In its fourth year, 150 MUNI participants from 43 different organizations, including high school students, undergraduate and graduate students, professors, governmental researchers and professionals, and industry users were supported.

The RTNN collaborates with other organizations in the Research Triangle region of North Carolina to host a "Girls STEM Day @ Duke" event for Girl Scouts and their families (see figure at right). The Girl Scouts perform research across campus, including in the RTNN nanotechnology facilities, allowing Girl Scouts to earn badges in areas of DNA, Robotics/AI, and cosmetics. The event also has sessions for parents, providing information on promoting successful college experiences for students. In 2019, over 140 girls and their families participated.

Michael Hochella (NanoEarth) and David Dickensheets/Heather Rauser (MONT) have been working with Prof. Antony Berthelote (Salish Kootenai College in Montana) to arrange a tribal college faculty visit to PNNL. Prof. Berthelote has proposed a Tribal College Faculty Professional Development Workshop (including the PNNL visit) and has submitted this proposal to the National Science Foundation. Tribal participants in the workshop are from the University of Montana, Navajo Tech, and Salish Kootenai College. Hochella has made the connection to PNNL, and PNNL leadership is willing to host up to 15 faculty members at the Lab. They will organize a visit that will center on possible collaborations and opportunities for the faculty, tribal colleges, and Native American students.

The Community College of Philadelphia (CCP), a partner in the MANTH site, ran its first course in 3D Printing - Additive Manufacturing (Applied Science and Engineering Technology 140) in the Fall 2019 semester and will run its first Introduction to Nanotechnology (Applied Science and Engineering Technology 201) course in Spring 2020. These courses help to bring nanoscale concepts and technologies to broader academic audiences. CCP has approximately 23,000 students taking courses for credit and a student body that is 72% minority, 64% female, and 40% 25 years old or older (https://www.ccp.edu/about-us/key-facts).

CNS runs a "CNS Scholars" program which seeks to support inclusive excellence by offering access to advanced instrumentation and expertise by early-career scientists who diversify the user base and STEM disciplines. Current scholars are from Smith College, Howard University, Mississippi State University, Mount Holyoke, and the University of Alabama at Birmingham. The scholars work on a broad range of topics and some projects have since become supported by the NSF Center for Integrated Quantum Materials at Harvard.

CNF works with Cornell's Diversity Programs in Engineering (DPE) to recruit a diverse community of students and faculty to Cornell, to take part in its annual open house, to send students selected by DPE to act as ambassadors for nanofabrication to the SHPE and NSBE annual meetings and aid its LSAMP program. CNF gives out the Nellie Whetten Memorial Award annually since 1989 to outstanding women scientists who are CNF users and all have gone on to outstanding careers in nanoscience. Past winners are invited back to the CNF annual meeting to serve as role models for the next generation of researchers.

The RTNN created a "Resources for Complaint Reporting" website, after consultation with their Omsbuds Office, which provides resources for anyone who feels they have been the victim of discrimination, harassment, and/or sexual misconduct. The site provides information, advice, and feedback as well as a path to file formal complaints at each of the three participating universities. The Complaint Reporting website is one of many products that seeks to promote an inclusive and welcoming environment for all.

Members: Jacob Jones (NC State, Chair), Mike Hochella (Virginia Tech), Liney Arnadottir (Oregon State Univ.), Kristin Field (Univ. Penn), Joe Graves (NC A&T/JSNN), Christopher Ober (Cornell), Heather Rauser (Montana State Univ.), and Bill Wilson (Harvard)

5.2. Metrics and Assessment Subcommittee

The Metrics Subcommittee addressed the task of how to better quantify the impact of NNCI on the user community. This was driven by comments from the External Advisory Board at the annual meeting in the fall of 2018. The EAB suggested that we need to develop ways to assess the impact of the network on the broad range of funded research projects and on industry start-ups, spin-outs, and large companies. The impact should be measured by both geography and technology area. After initial committee discussion it was decided to pursue academic impact first, as this would be the easier of the two to develop metrics.

Currently, within NNCI the primary academic metric used is the number of users, and in particular, the number of external users. Secondary metrics include the number of publications, the user breakdown by discipline, and the intensity of usage as measured by usage hours. The committee reviewed pilot studies made at the request of NSF in year three by Cornell and Georgia Tech. To be effective in a network, it is essential that all nodes are able to collect the required information. To test this, we investigated how each of the metrics in the pilot studies would be applied at the committee's home institutions (Minnesota, Texas, Virginia Tech, and Nebraska) to determine the level of difficulty associated with each question. Getting some of the needed information proved highly problematic for several of the schools. Finally, the committee made recommendations to the Coordinating Office, which further simplified the request to two categories:

- *The number of grants for each funding source:* For NSF grants, a more granular tally indicating the directorate and division is obtained using the award number prefix. We also determine the total number of PIs (internal and external) included in the data.
- *Additional user information:* This includes the number of users supported for each funding source for internal and external users. The user count is sorted by the user's academic department and funding source as well as by the user's NNCI discipline and funding source. This provides better visibility of the technical areas supported by NNCI investment.

The first such survey, which used year 3 data, was collected by the Coordinating Office from the NNCI sites during the summer of 2019 and reported to NSF in the fall of 2019. Here we summarize only a few of the important points. As shown by Figure 3, the impact of NNCI extends far beyond NSF. Indeed, NSF accounts for only 1236 (21%) of the 5754 projects enabled by NNCI. Other major beneficiaries include industry (18%), DoD (12%) and NIH (11%) of the total number of projects. Similarly, Figure 4 shows that, of the projects enabled within NSF, MPS (37%) has almost as many projects as ENG (41%). Other major sources of user support come from BIO, GEO, CISE, and HER.

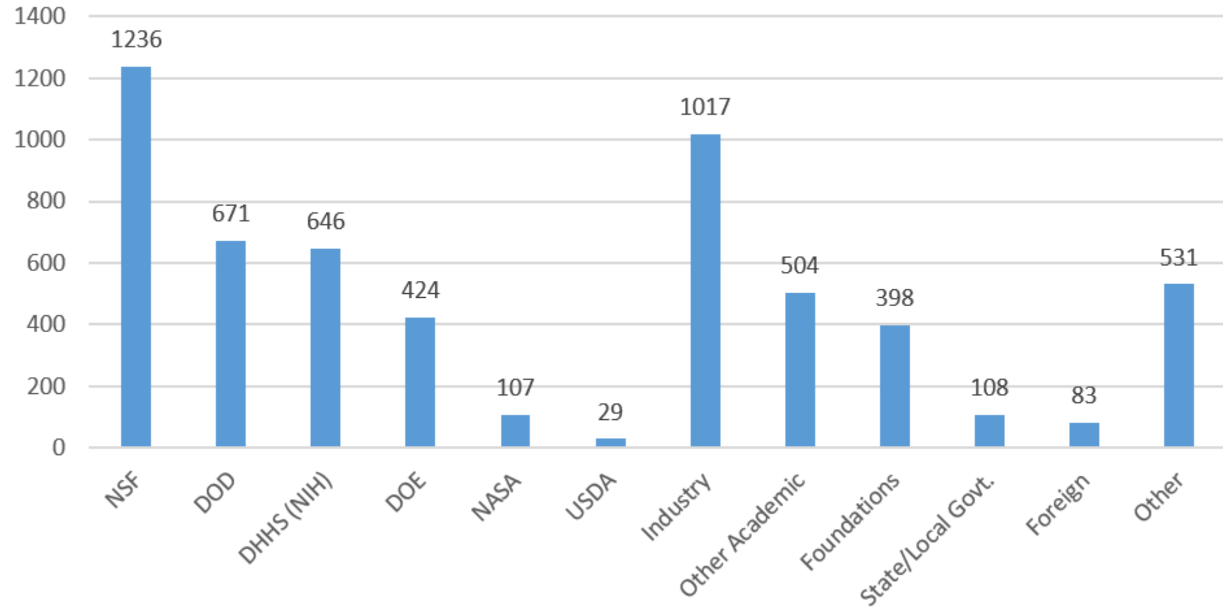


Figure 3: The source of user funding for users at NNCI facilities

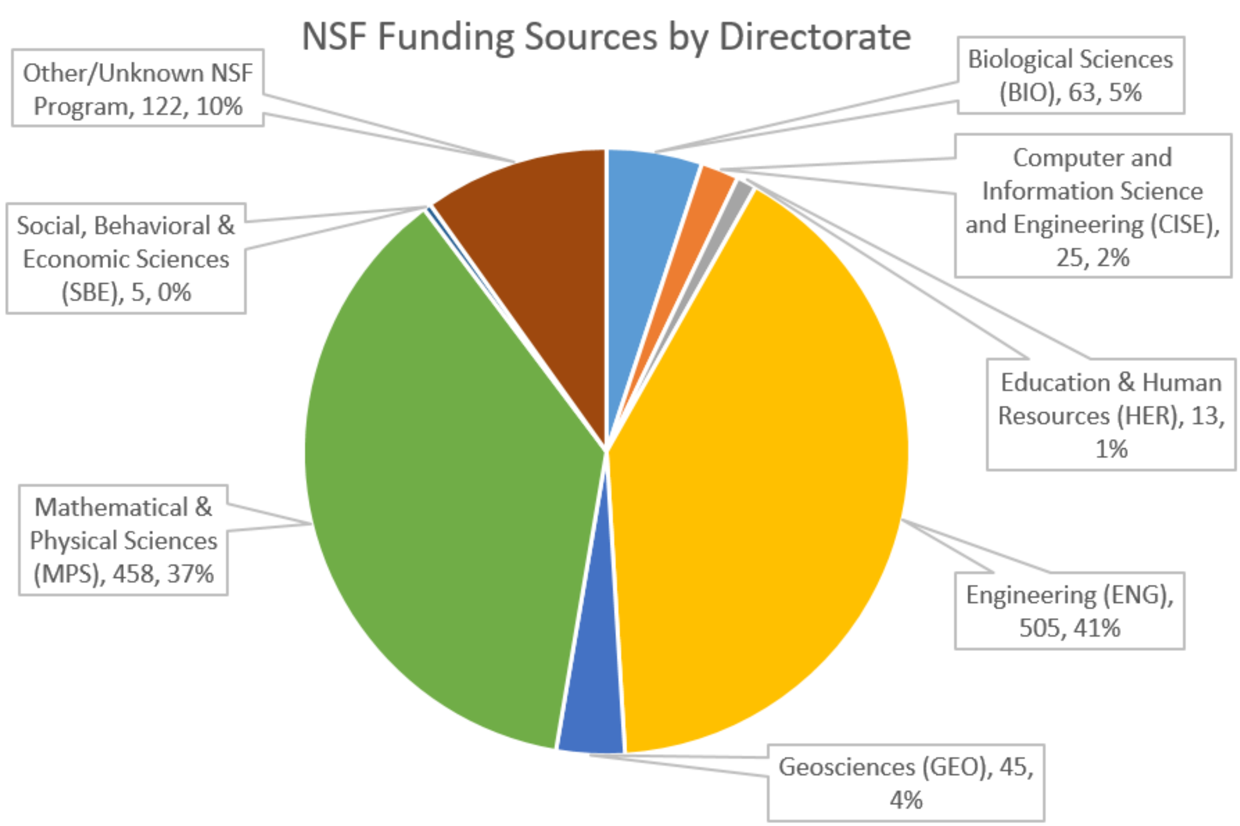


Figure 4: For NSF-funded projects, the directorate within NSF that funds the work

During Year 5, the Metrics Subcommittee has begun determining how to better assess the economic impact of industry usage of the NNCI network. This presents a significant challenge as industrial users are far more reticent about sharing information about their projects, funding sources, and economic data. Nevertheless, the committee feels that we can do significantly better than the current situation.

Members: Steve Campbell (Minnesota, Chair), Sanjay Banerjee (Texas), Mike Hochella (Virginia Tech), Mitsu Muriyama (Virginia Tech), David Sellmyer (Nebraska), David Gottfried (Georgia Tech/CO)

5.3. Global and Regional Interactions Subcommittee

Global and regional interactions (GRI) represent great potential for significant "value-added" for the NNCI programs. These provide for an opportunity to leverage the capstone NNCI program to enhance regional connections, especially to local institutions, non-profits and expand the impact of NNCI globally through potential overseas partnerships spanning education, research and outreach activities. The subcommittee also appreciated the need for the NNCI network to demonstrate that "the whole NNCI network is greater than the sum of its individual parts".

It is in this spirit that the GRI subcommittee convened several times during the recent period and has suggested several ideas for regional interactions for NNCI in general, and regional/local coordination more specifically. Initially represented by Ober (CNF), Alphenaar (KY-MMNIN), Westervelt (CNS), Bohringer (NNI) and chaired by Dravid (SHyNE), GRI activities and ideas have been disseminated across the NNCI network. The subcommittee has also discussed and debated how various initiatives need to be locally/regionally coordinated and the role of the Coordinating Office in managing and resourcing these ideas.

The summary of recent activities and interactions include the following:

1) *Staff Exchange Program:* There is a huge opportunity to leverage the extensive expertise housed within the sixteen NNCI sites to provide in-depth training for NNCI staff and beyond. This is one of the lowest hanging fruits to enhance cross-network interactions, enhance regional strengths and contribute to improved morale of NNCI personnel. *See below for further details.*
2) *Regional Coordination & Interactions*: Virtually every NNCI site has other regional institutions or proximity to national laboratory or related organizations. The subcommittee recognized that these represent added opportunity for each site to enhance their impact regionally through coordination and playing leadership in larger outreach and related programs (e.g. user meeting). One such example is the "iNano" initiative led by SHyNE Resource. Here, SHyNE coordinated Northwestern University with UChicago and Argonne National Lab to hold a one-day workshop. Similar ideas have already been implemented across the NNCI network, and the subcommittee felt that NNCI should broadly publicize such events and provide assessment of the impact in terms of attendees and exit questionnaires to continue to enhance expected impact of such regional events and activities.
3) *Miscellaneous Discussion Topics:* There were other discussions regarding coordinating global partnerships or hosting potential nanotech-related workshops or exchange program with key overseas institutions. It was felt that priority should be first given to ensuring vibrancy and coordination of the NNCI internal US network. However, in the second phase

of the NNCI program, it would be important to initiate some global activities and coordination to demonstrate US leadership in the world for such infrastructure/facilities program and leverage global talent and expertise for broader infrastructure and instrumentation across NNCI.

NNCI Staff Exchange Program

Objective:

There is a great opportunity to leverage the extensive expertise housed within the sixteen NNCI sites to provide in-depth training for NNCI staff and beyond. This expertise spans a wide range of topics including specific fabrication or characterization equipment, nanoscience focus areas (e.g. photonics, sensing, etc.), education and outreach strategies and facility management and operations. Currently, most sites offer short courses and workshops at their sites in some of these areas for local user participation. This program seeks to establish a clearinghouse for such activities, make them available for staff across the network and provide a cost-sharing mechanism for travel support. As a secondary goal, such a clearinghouse can serve as a single access point for non-NNCI participation in these educational opportunities.

Development Plan

In order to establish this program, there are several tasks that need to be completed for which the Coordinating Office may take lead in conjunction with the GRI Subcommittee:

1) Establish a shared database to upload training course information
2) Develop application for NNCI staff travel support
3) Establish committee to review travel support applications and make awards

The first task will be to establish a web-based portal to upload information about training opportunities across the network. In general, these courses are expected to be significantly more in-depth than a standard user training course, providing detailed hands-on and/or theoretical curriculum from experts in the field. Training could take the form of workshops, short courses or extensive hands-on training courses. The courses could be part of an existing program or could be tailor-made for this context. It may also be possible to design a course in which the course leader travels to another site to teach a course. The content, dates, cost, etc. for the course would be collected through an online form in order to populate the clearinghouse. A conceptual mock-up of such a form can be viewed here: https://goo.gl/forms/j08q8VC7wWNzzkpJ2

The information collected in the web form would be available to all NNCI staff in the form of a shared document (e.g. Google Sheet). This would allow sites to edit and update course information and link to additional resources. Initially, it is expected that this clearinghouse would be available only to NNCI staff, but opening some or all of the courses to participation from outside the NNCI (without travel support) would be the ultimate goal. The cost for the course, if any, would be the responsibility of the site benefiting from the training. The Coordinating Office would provide support to cover travel costs through an application process. An example of such an application can be viewed here: https://goo.gl/forms/7Gd5GMVD3BTqlJUf1

Budget

The NNCI Coordinating Office would establish a committee to review proposal applications and make travel awards. The proposed budget is $48,000 per year, providing up to 3 awards per NNCI site at $1,000 each.

Members: Vinayak Dravid (Northwestern, Chair), Karl Bohringer (Washington), Bob Westervelt (Harvard), Chris Ober (Cornell), Bruce Alphenaar (Louisville), Ben Myers (Northwestern, Secretary)

5.4. New Equipment and Research Opportunities Subcommittee

In Year 4, the Equipment and Research Subcommittee repeated the extensive survey of new equipment purchases that we initiated in Year 2 of our network existence. New surveys were sent to all 16 NNCI sites and we had 100% participation. Precautions were taken to make sure equipment items were not inadvertently recorded in both surveys. The committee asked the sites to provide the following information about each new piece of equipment:

a) Description and cost
b) Fabrication/processing vs metrology/testing
c) Funding source

The data set was tabulated, analyzed and compared to the results from the previous survey. Our findings appear below.

As seen in Figure 5 below, a total of 338 tools were purchased in Period 2 (i.e. Years 3-4) for a total of $88.9M. However, very few of the pieces of equipment were purchased using NSF NNCI funds, as the NNCI award attributed to only 1% of the total cost as shown below. **This demonstrates that the 16 sites have effectively leveraged the NNCI funds to secure the costly equipment needed to provide NSF with a high quality, open-access network.**

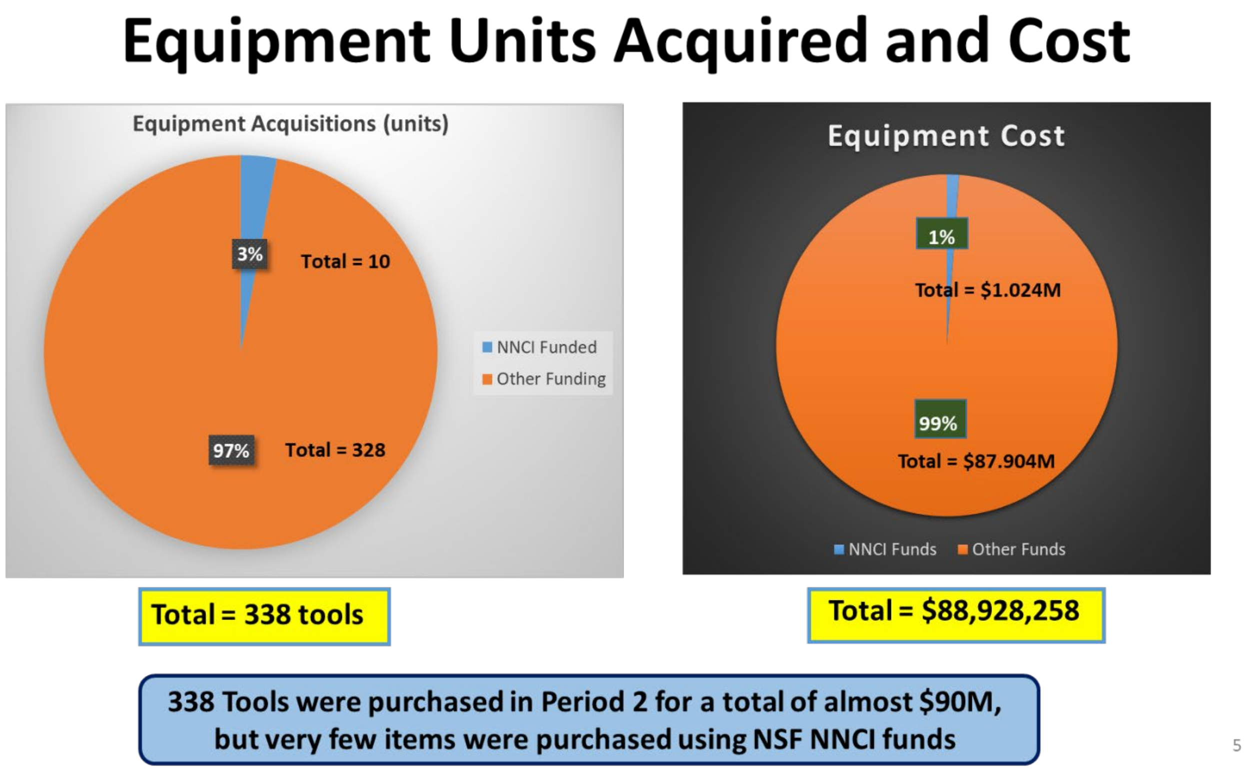


Figure 5: Equipment acquisitions of the NNCI network during Period 2 (years 3 and 4)

Table 5, which compares the type of tool purchases in Period 2, shows that the network acquired about the same number of Fabrication tools as Metrology tools in years 3 and 4, but spent ~$34M (or 2.2X) more on the Metrology tools. This demonstrates the trend that new metrology tools are becoming increasingly expensive, such as the latest generation of Cryo TEMs.

Table 5: Equipment Acquisitions During Period 2

PERIOD 2	# Tools	Cost
Fab/processing	173	$27.6M
Metrology/testing	165	$61.3M
TOTAL	**338**	**$88.9M**

As we did in Period 1, the committee analyzed the source of funding used to purchase equipment in Period 2. Figure 6 presents our findings graphically in terms of dollars spent. *University funding* was by far the dominant source. **It is important to note that all the NNCI sites agree that being part of the NSF NNCI helped them secure internal funds at their respective universities for equipment purchases, which would have most likely not occurred otherwise**. *Grants* were second as a source of funding, followed by *Multiple sources*, then *Donations*, then *NNCI*.

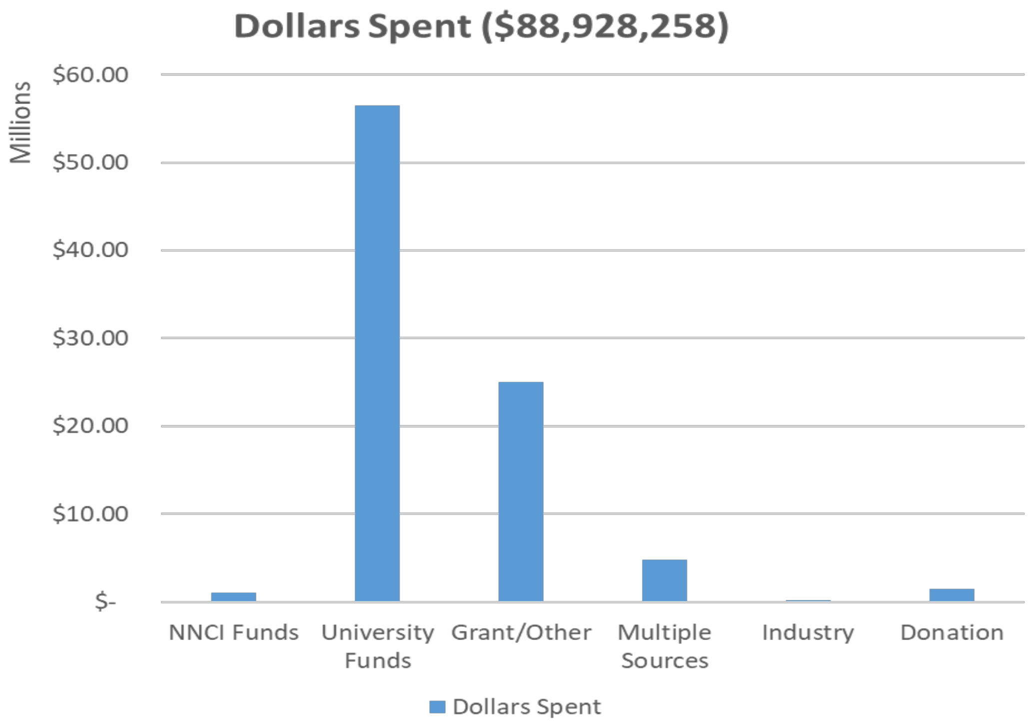


Figure 6: Source of funding for equipment purchases in Period 2

The committee then compared Period 2 data (Years 3-4) with Period 1 (Years 1-2). Table 6 presents a summary of the number of tools purchased and their combined costs for the 2 periods. As shown in the Table, the network purchased about the same number of tools in both 2-year periods, but spent approximately $20M more in Period 2. This reinforces the observation that new state-of-the-art tools continue to advance and increase in price, especially in the field of metrology. ***It is noteworthy to state that the 16 academic sites have collectively purchased over 630 tools exceeding $155M in cost over the first 4 years of the NNCI initiative, with 99% of the costs coming from non-NNCI sources.***

Table 6: Comparison of Totals Between Periods 1 and 2

	# Tools	Cost
Period 1	294	$68.1M
Period 2	338	$88.9M
TOTAL	**632**	**$157M**

Table 7 compares the types of tools purchased across the 2 periods. Interestingly, the network purchased about the same number of Fabrication/Processing tools during each two-year period (177 vs 173). However, the number of purchased Metrology/Imaging/Testing tools dramatically increased from 117 in Period 1 to 165 in Period 2. Not unexpectedly, the amount spent on that category increased by nearly $20M as well. As shown in Table 7, the network continues to spend much more (about 2X) on Metrology tools than Fabrication tools.

Table 7: Comparison of Categories Between Periods 1 and 2

	Fabrication	Cost	Metrology	Cost
Period 1	177 tools	$23M	117 tools	$45M
Period 2	173 tools	$27M	165 tools	$61M
TOTAL	**350**	**$50M**	**282**	**$106M**

The committee further analyzed the types of equipment being purchased by categorizing all 632 tools acquired over the 4-year timeframe into appropriate categories, as illustrated in Figure 7. The dominant category by far was *imaging* (54% for Period 2), followed by *metrology* (14%), *lithography* (10%), *processing* (10%), etc. We then dug deeper into each broad category to identify specific tool purchases. As shown in Figure 8, *imaging* was dominated by 9 new cryo TEMs, *metrology* by 9 film inspection tools, *lithography* by 4 e-beam tools, and etch *processes* by dry etch tools including 2 DRIE systems.

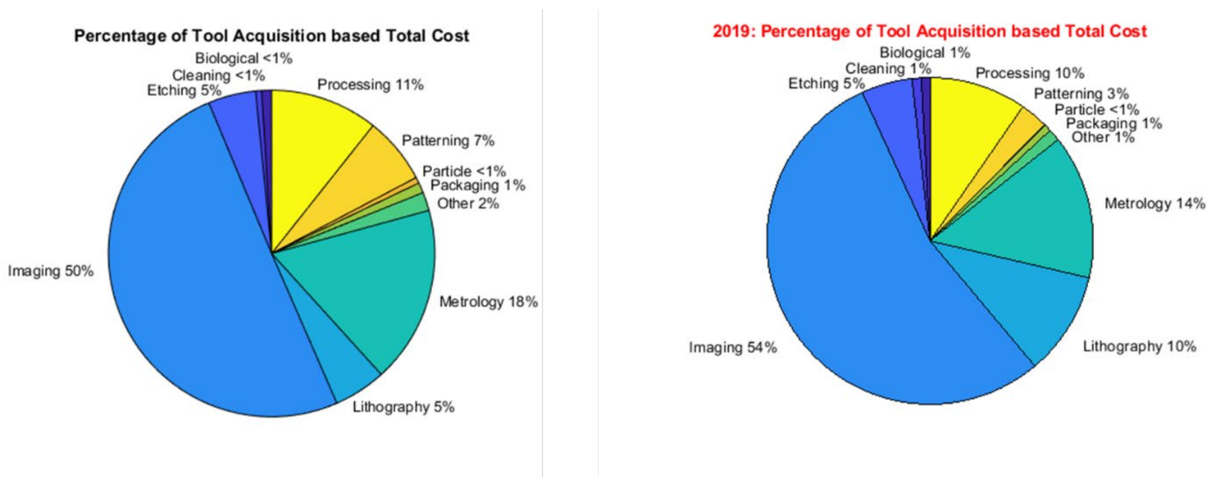
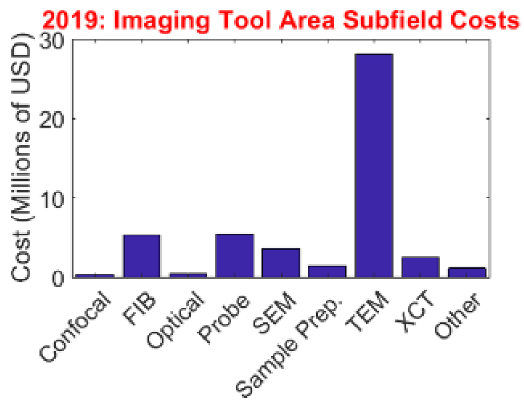


Figure 7: Equipment purchased organized by categories

Imaging – tool area subfield cost

- Spent $48,300,000 (2018: $33,400,000)

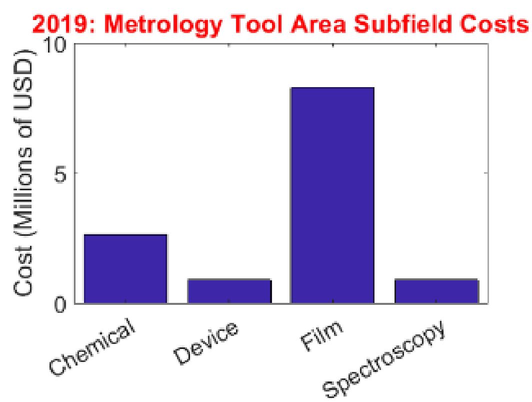
- FIB: $5,253,559 spent on 3 systems.
- Probe: $ 5,452,654 spent on AFMs, atom probe microscopy, and scanning tunneling microscopy.
- SEM: $ 3,639,109 spent on 9 systems.
- TEM: $28,100,000 spent on 9 systems and accessories.
- XCT: $2,500,369 spent on 3 systems.

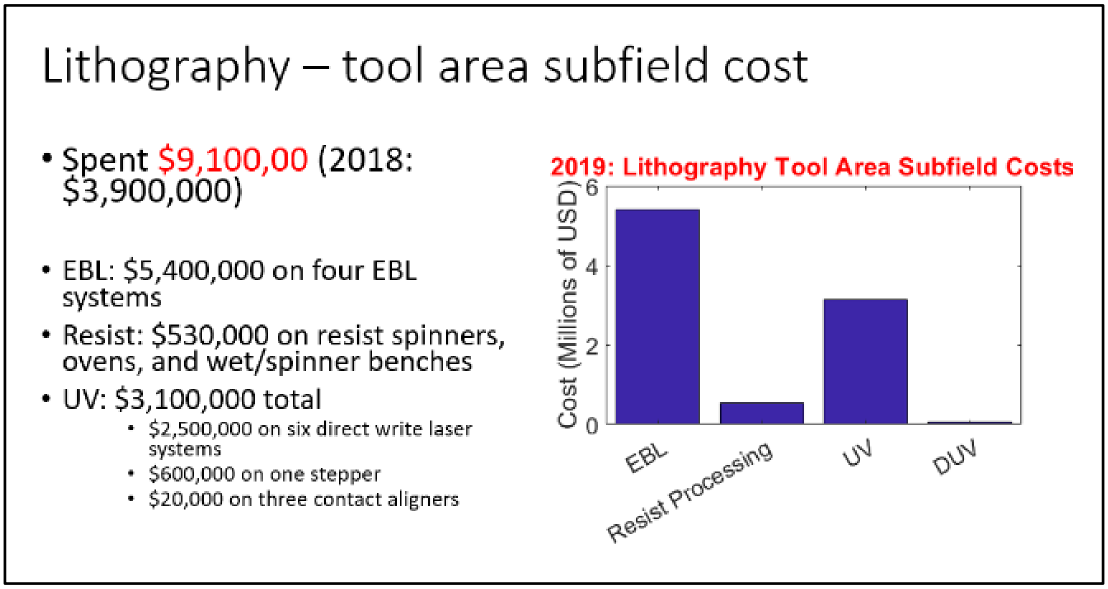


Metrology – tool area subfield cost

- Spent $12,700,000 (2018: $12,000,000)

- Chemical: $2,600,000 total, mostly NMR tools
- Device: $890,000 total, mostly profilometers and Hall Effect Measurement tools
- Film: $8,300,000 total
  - $3,200,000 XRD [5 systems]
  - $2,600,000 XPS [4 systems]
- Spectroscopy: $900,000 total, mostly Raman and FTIR





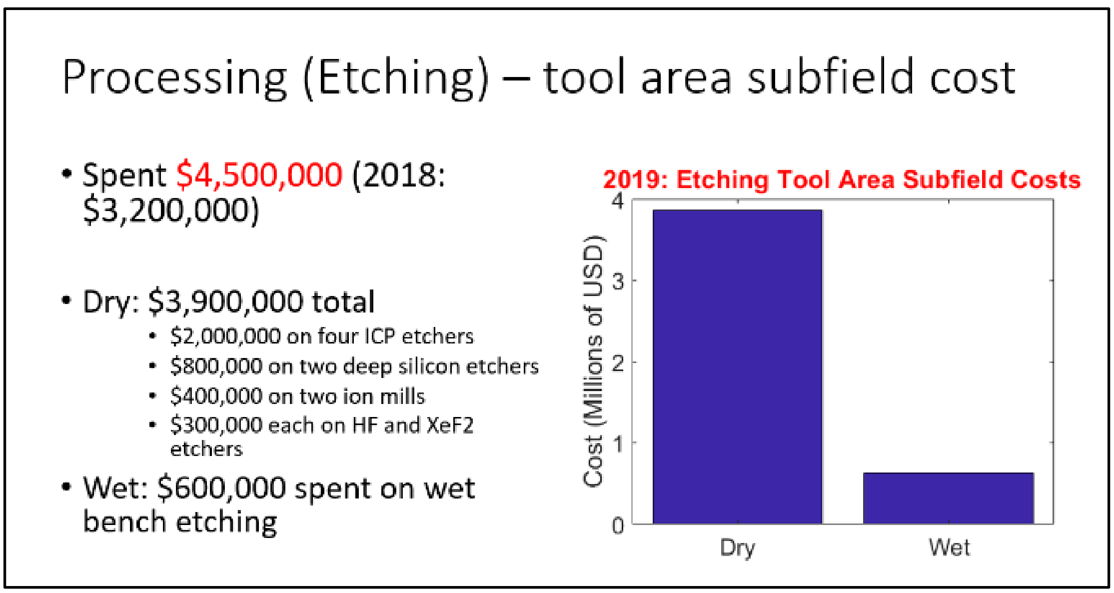


Figure 8: Equipment categories further analyzed

The conclusions from our Equipment and Research subcommittee are the following:

1. During the first 4 years of the NNCI program, the 16 member sites have collectively purchased <u>over 630 tools exceeding $155M in cost</u>, with 99% of the expense coming from **non-NNCI sources**. This is a tremendous resource available to the external clients of the network.
2. *University Funding* and *Grants* remain the dominant funding mechanisms to procure equipment for all sites in the network.
3. The network spends about ***twice as much*** *on Metrology/Imaging/Testing tools as Fabrication/Processing tools*, even though the number of tools are comparable.
4. The cost of Metrology Tools continues to increase.

5. There was a steady and significant amount of spending ($22M) on upgrading and maintaining **workhorse equipment**, which is extremely difficult to fund through grants.
6. Investment in E-beam lithography ($5.4 M with 4 tools) continues.

Members: Kevin Walsh (Louisville, Chair), Jacob Jones (NCSU), Yuhwa Lo (UCSD), Mark Allen (Pennsylvania), Stephen Campbell (Minnesota), David Dickensheets (Montana State), Karl Bohringer (Washington), Vinayak Dravid (Northwestern), Oliver Brand (Georgia Tech, CO)

5.5. Entrepreneurship and Commercialization Subcommittee

Over the past year the commercialization subcommittee has been engaged in understanding and defining metrics for potential use across the network in gauging the economic impact of the NNCI program. We discussed the possibility of creating an 'economic impact statement' that could be used by stakeholders to illustrate the value of the network. Such a statement would need to rely on data collected from individual sites, and that now, halfway through our existing program, would be a good time to retrospectively assess and initiate this data collection.

The subcommittee recognizes that perhaps the largest challenge in creating such a statement is the availability of data. This is not a problem unique to the NNCI network. Currently, university-led efforts to assess economic impact tend to focus on *inputs* into economic activity, such as spinoffs created, patents filed, patents licensed, etc., and less on *outputs* of economic activity, such as jobs created or dollar value of products sold. Although outputs are certainly desirable metrics to have, the non-availability of these data makes creating general metrics in this area challenging. For example, industry users accessing NNCI facilities are often doing so at a relatively early stage, and the connection between that research and ultimate product sales is tenuous. In the rare case where there is a clear direct link, companies may be reluctant to disclose it due to proprietary reasons.

The Entrepreneurship and Commercialization Subcommittee discussed this issue with the Metrics Subcommittee, and are considering a set of intermediate metrics that might augment input metrics discussed above, but be easier to identify than output metrics. Specific examples include:

- Leveraging of facility seed grant funding into subsequent venture funding (perhaps creating an impact or effectiveness ratio of various seed grant programs)
- Accessing the publicly-available SBIR database to understand how NNCI sites help small business raise funding
- Analyzing the usage patterns of companies to identify transitions from NNCI sites to manufacturing

The first two items are straightforward; the third item should be explained. For example, what does it mean when a company initially comes into an NNCI site, grows its efforts, then after a period of time the efforts decline? Sometimes it means the research was unsuccessful, or that the funding for the project has ended. Other times, however, it may mean that the research has been successful and has been transitioned out of the prototyping stage and into pilot or manufacturing stages. Even though this transition often means a loss of hours and users for the site, it should definitely be considered a success. Sometimes this transition is known, either anecdotally (e.g., transition to internal manufacturing), or through foundry partnership announcements. This approach may be a fruitful one to identify NNCI commercialization successes, especially for larger companies that might not fall under seed grant or SBIR funding. Several of our sites have seen this behavior among our users, and we recommend that it be centrally collected.

The subcommittee also discussed the possibility of retrospective analyses of previous economic successes, such as the cellular handset (containing many MEMS devices) or high performance materials (containing nano-enabled features such as mechanical resilience or surface-enhanced properties). Although anecdotal in nature, such successes, especially (but not required) if they can be tied into origins at NNCI sites, could help us make the case for our economic value to non-specialists. The subcommittee suggests enlisting the aid of the NNCI Advisory Board to try to identify particular examples that could perhaps be tied into a white paper or a series of vignettes to make this case. The subcommittee also noted that the goal of understanding the economic value of the NNCI is shared overall with the National Nanotechnology Initiative, and suggests that a pooling of resources/efforts in this area might be of value.

Going beyond economic impact, the subcommittee also discussed the value of broader impacts of commercialization. In particular, two axes were discussed: (i) human resources; and (ii) non- (or quasi-) commercial, but highly impactful, results flowing from NNCI sites.

Along the first axis, the subcommittee recommends collecting data regarding sites' graduates, their degrees, and their ultimate workforce destinations, especially those graduates proceeding to industry. To maintain NNCI relevance, selection criteria such as educational or research use of the NNCI facilities could be used as a filter. In addition to human resource and workforce development, perhaps the economic impact equivalency of their entry into the workforce (average salaries, etc.) could also be collected. Much of this data is collected already by the various universities (e.g., career services offices or the equivalent), and, if available at a sufficiently granular level, could allow a semi-quantitative economic assessment to be made.

Along the second axis, it is important to collect, perhaps anecdotally, high impact NNCI-enabled breakthroughs, even if the economic impact of these breakthroughs themselves is not large. Examples might include paper microfluidics for *in vitro* diagnosis of disease in medically impoverished countries, or bacteria-resistant bandages for these same countries. In such products, the value is large, even if not measured strictly in dollar terms. Such products could perhaps also be captured in vignette format.

Members: Mark Allen (Penn, Chair), William Wilson (Harvard), David Dickensheets (Montana State Univ.), Kevin Walsh (Louisville), Trevor Thornton (Arizona State), Yuhwa Lo (UC San Diego), Daniel Herr (JSNN)

5.6. Building the User Base Subcommittee

The goal of the NNCI Building the User Base (BUB) subcommittee is to disseminate best practices for sites and NNCI as a whole to increase the user base, with particular emphasis on non-traditional users. A non-traditional user may be defined based on (1) Research areas: those that do not typically use nanotechnology facilities; (2) Demographic groups: women and under-represented minorities; (3) Users from non-Research I educational institutions; (4) Small companies; (5) K-12 students, community college students, and teachers.

The BUB subcommittee conducted a survey among NNCI sites to collect information on how sites are: (1) creating awareness among potential users to its facilities, (2) attracting new users to its facilities, particularly non-traditional users and (3) increasing user diversity. 12 of the 16 NNCI sites responded to the survey.

Results of the NNCI sites survey are as follows:

1. How is your site creating awareness among potential users to your facilities?
1. Appealing and easily navigable website; Traditional (flyers, brochures, newsletters, targeted emails, videos) and social media (also targeted Ads)
2. Open houses; Annual user appreciation day; Regular talks/presentations highlighting capabilities, Visiting departments/colleges on campus
3. Short courses, technical seminars, lecture series, new instrument/capability workshops/trainings (either by site staff or vendor-sponsored) – live streamed and archived
4. Word of mouth; Direct contact by staff/faculty; User testimonials
5. (Regional) user recruitment visits (both other academic institutions and industry); Invited presentations at other institutions using current user ambassadors
6. Education and outreach activities – on campus, in other K-12, community and local colleges
7. Acknowledgements in publications and conference presentations
8. (Co)organize focused conferences/regional symposiums; exhibit in other conferences and trade shows in the region
9. Regional nanotechnology core facility managers meeting
10. Partnership with local/regional economic development offices, technology incubators (non-profit, government); reach out to SBIR/STTR awardee using federal award databases

2. Do you have any special initiative(s) for non-traditional users?
1. Seed grant programs – free/subsidized access to non-traditional users
2. Workshops, short courses (in-person/online), MOOCs, seminars and custom trainings for non-traditional users
3. Partnership with research centers/projects in non-traditional areas, e.g. NIH centers, translational medicine projects, geo/earth sciences, environment, food, textile etc..
4. Visits to (non-traditional) non-Res I, HBCU, PUI schools and local colleges in a specific region, based on the location of the NNCI site; initiative for start-up companies
5. Co-organize/sponsor events that bring traditional and non-traditional users together,
6. Using surveys with specific questions; expand facility capabilities and trainings to attract and retain non-traditional users
7. Showcase success stories and user testimonials
8. Participate in conferences and trade shows that attract non-traditional users

3. Do you have any initiative(s) to increase the diversity of your users?
1. Seed grant programs – free/subsidized access, particularly for users from smaller institutions, HBCUs and Women colleges
2. Community/local college internships and workshops for educators; initiatives for tribal colleges and groups
3. REU programs; REV program with community colleges.
4. Outreach activities - Teach the teacher workshops/trainings, mobile/remote access to tools, 4H, events in public places, HS interns, school career fairs, science festivals, capstone projects
5. Partnership with local under-represented/minority area schools and community colleges
6. Focused events for girls – girl scouts, girl STEM day etc.
7. MOOC or online courses
8. Increase (targeted) participation of local organizations/institutions (e.g. HBCUs, community colleges, high schools) in existing and planned workshops

4. Do you offer any free/subsidized (limited) access program to use your facility?

12 of 13 sites responded positively by either offering limited free or subsidized rates using NNCI funds or internal resources to attract non-traditional users and to diversify the user base. Of these responses, 10 NNCI sites offer free or subsidized rates to external academic users, while 5 sites offer free or subsidized rates to industry as well.

From the site survey results, it is clear that NNCI sites:

- Create awareness primarily by directly engaging with potential users through seminars, courses, open houses, visits, education and outreach activities and by using collateral materials, website and other forms of communication.
- Attract non-traditional users primarily by using seed grant programs, workshops/trainings, direct interactions and by partnering with research centers in non-traditional areas.
- Increase user diversity by using seed grant programs, partnerships with HBCUs/MSIs, community colleges, research experience programs and outreach activities.

Members: Shyam Aravamudhan (North Carolina A&T/JSNN, Chair), Nan Jokerst (Duke), Todd Hastings (Kentucky), William Wilson (Harvard), Gregory Herman (Oregon State)

6. Working Groups

One of the greatest strengths of the NNCI network is the combined staff expertise of the individual sites. To leverage this expertise at the network level, the Coordinating Office has initiated the formation of working groups composed of staff members from the NNCI sites. While these working groups meet primarily via phone and video conferences, they also have the ability to organize workshops and/or dedicated sessions at the annual NNCI Conference. We have created and are encouraging working groups (Table 8) in (1) important "network" responsibilities, such as environmental health & safety, vendor relations, or equipment maintenance and training, (2) particular process technologies, such as lithography or characterization (although these are only examples of possible topic areas), (3) research areas of nanoscience and nanoengineering, in particular those targeting "non-traditional" disciplines, such as bio, geo and environmental sciences, and (4) education and outreach activity. Most of these working groups began in Year 1, while new ones were added in Year 2 and 3. Additional topics will be added later on as interest and need arises, and some topics may sunset if importance wanes. In addition, some topical areas (EBL, Etch, and ALD) have begun working groups through grass-roots efforts of NNCI staff, with support from the Coordinating Office. The outcomes of these working groups can have many forms, including process recipes, recommendations to vendors for future equipment development, maintenance and training videos/webinars, recommendations on how to evaluate the safety of new processes, or direct recommendations for new users. Each working group has one or more dedicated coordinators selected from one of the NNCI sites, and staff participation in the working groups can be one measure for site performance. Participation in these working groups can also be considered as a mechanism for staff growth and career development, which might be further supported through certificates earned when participating in related workshops, for example, and this is being explored.

Table 8: NNCI Working Groups

Working Group Topic	Working Group Lead(s)
Network Support Working Groups	
Equipment Maintenance & Training	Meredith Metzler (Univ. Pennsylvania)
Vendor Relations	Charles Veith (Univ. Pennsylvania)
Environmental Health & Safety	Nasir Basit (Northwestern) Greg Cibuzar (Minnesota)
Technical Working Groups	
XPS/UPS	Carrie Donley (UNC) Walter Henderson (Georgia Tech)
E-Beam Lithography	Devin Brown (Georgia Tech)
Etch Processing	Vince Genova (Cornell)
Atomic Layer Deposition	Michelle Rincon (Stanford) Xiaoqing Xu (Stanford) Mac Hathaway (Harvard)

Photolithography	Pat Watson (Penn)
Additive Manufacturing	Tim Gornet (Louisville) Ed Tackett (Louisville)
Imaging and Analysis	David Bell (Harvard)
Education and Outreach	
K-12 and Community	Jim Marti (Univ. Minnesota)
Research Experience for Undergraduates	Lynn Rathbun (Cornell)
Workforce Development and Community Colleges	Ray Tsui (Arizona State)
Evaluation and Assessment	Nancy Healy (Georgia Tech) Quinn Spadola (Georgia Tech)
Technical Content Development	Angela An-Chi Hwang (Stanford) Maude Cuchiara (RTNN)
Societal and Ethical Implications	Jameson Wetmore (ASU)

During NNCI Year 4, sites or groups of sites hosted numerous technical workshops related to processing or research topics (see Section 9.1). The Coordinating Office encourages working groups to use these programs as opportunities for the working group to meet in a face-to-face setting, as a supplement to virtual discussions. Three of these programs in Year 4 featured concurrent meetings of working groups, with financial support (up to $1000 travel funding each for 5 attendees) provided by the Coordinating Office.

- NNCI Advanced Lithography Workshop, Stanford University (July 11-12, 2019) – Attended by members of the Photolithography working group.
- NNCI ALD/MOCVD/MBE Symposium, Harvard University (Oct. 3-4, 2019) – Attended by members of the Atomic Layer Deposition working group
- NNCI Etch Symposium, Harvard University (Dec. 5-6, 2019) – Attended by members of the Etch Processing working group and the Equipment, Maintenance, and Training working group.

Received reports of current working groups, as provided by the leads, are presented below.

6.1 Equipment, Maintenance, and Training

Represented by NNCI sites Penn, Stanford, UT-Austin, Cornell, UNC Chapel Hill, University of Washington, and University of Minnesota, this working group is tasked with sharing expertise on how to keep complex equipment in nanofabrication facilities properly operating by considering the characteristics of tools, how they are maintained, and how researchers operate them. MANTH Senior Manager Meredith Metzler chairs the working group.

Communication occurs through email exchanges, one-on-one phone conversations, and a face-to-face meeting coinciding with the NNCI Etch meeting at Harvard Dec. 5-6, 2019. The group's effort remains focused on the collection and collation of common lore knowledge and information on troubleshooting and maintenance of vacuum and RF process equipment. Much of this information is not readily available in literature or online.

Members: Meredith Metzler (Penn), Mary Tang (Stanford), Bob Geil (UNC-Chapel Hill), Jesse James (UT-Austin), Jeremy Clark (Cornell), David Nguyen (Univ. Washington), Tony Whipple (Univ. Minnesota)

6.2 Vendor Relations

This year, the group has grown from 4 to 5 schools. We would like to have a contact at all schools so there can be clear and concise communications and this will improve efficiencies and cost savings across the network. The following activities have taken place over the past year.

- The working group has developed and started evaluations of resist alternatives to Dow Products. While the project has been moving very slowly, some gains have been seen. Some of the changes are the replacement of MF 319, Remover PG, replacement of S1813 with testing for the replacement of PMMAs and KMPRs. In addition, this will improve the robustness of the supply chain thus lowering the chances of a catastrophic event.
- We have increased the number of reseller firms from two to three. With only two vendors available to bid on RFQs, we are experiencing significant increase in costs. With the addition of Thomas Scientific, we expect an opportunity to see better competitive bidding and lower prices.
- The group began discussion to get manufacturers into the bidding process to improve communications, product development, and pricing. A half-dozen firms have stepped up and are willing to work with NNCI on materials required to build and equip labs.
- General sourcing expansion has also been of interest, as presently many times only one option exists. This failure to develop alternatives has led to significant stoppages in research due to materials availability (HSQ, Sylgard 184, many Sigma Aldrich products). To this end, we have established links with firms like Gelest (Sylgard 184 alternative), All Resist (HSQ alternative), and Capitol Scientific (Sigma Aldrich, VWR and Fisher Chemical alternatives).

This coming year, we plan to continue with the above areas of work as well as developing a Rare Earth Metal Collaborative, a stronger centrally-coordinated collaborative on purchasing between the 16 NNCI sites. We will also begin taking over OEM negotiations to improve cost, tool development (savings here will be up to 50%) and begin evaluation of the development of a Virtual Laboratory (cost saving would be in the range of 84% versus present system).

Members: Charles Veith (Univ. Pennsylvania), Julia Aebersold (Louisville), Michael David Martin (Louisville), Curtis McKenna (Louisville), Andrew Wayne Ott (Northwestern), Matthew Hull (Virginia Tech), Heather Rauser (Montana State Univ.)

6.3 Environmental Health & Safety

In the 2019 NNCI Annual Report, the EHS working group proposed a series of recommendations for Emergency Procedures, Safety, Incidents, Buddy Rule, and Safety Training.

During the 2019 NNCI Annual Conference, a breakout session on Envirronmental Health and Safety was convened with approximately 25 representatives from various NNCI sites. After introductions, attendees were polled for any "hot button" issues they may be facing. None were brought up, so more general topics were discussed as listed below. For each topic there were several sites that had experience/history and policies in place. While there are some variations amongst the sites, there is considerable consistency on major safety policies.

- Dealing with non-traditional materials in cleanrooms and characterization facilities.
- Interactions/involvement of campus safety departments (there is considerable variation in this among sites).
- Funding the replacement of aging safety-related equipment (toxic gas monitoring systems, gas cabinets, etc.).
- The importance of establishing a short written report for safety incidents, for historical and liability reasons.
- Personal protective equipment (PPE) practices—one site requires a face shield for any wet bench use (even if other PPE is not required). Others generally agreed this to be a simple, effective measure, but there can be issues with face shield fit for small heads and reliability issues with fit-adjustment mechanism.
- Buddy rule policies (some sites only require buddies depending on the type of work being done (e.g. working with acids) while others always require a buddy).
- Hazardous waste disposal policies.
- Camera/video systems for monitoring/compliance enforcement.

Finally, the previous NNCI user survey asked responders to provide opinions about health and safety practices at the NNCI facilities. NNCI Survey. After review of the survey responses, the following recommendations are made

- Dedicated acid processing areas with splash guards
- Safety policy implementation should be a priority
- Elimination/reduction of false alarms

Members:

Name	Affiliation	Safety Expertise
Nasir Basit (Co-lead)	NUFAB Northwestern University	Microfabrication equipment safety, facility setup and growth
Greg Cibuzar (Co-lead)	Minnesota Nano Center University of Minnesota	Facility management and safety protocols
Philip Infante	Cornell Nanoscale Facility Cornell University	Lab safety and safety related infrastructure
Robert Rose	IEN Georgia Tech	Lab safety, policies & procedures, emergency response
Mark Walters	Shared Materials Instrumentation Facility (SMIF) Duke University	Research facility management, cleanroom fabrication, XPS, SEM, TEM

Andrew Lingley	Montana Microfabrication Facility Montana State University	Facility management, safety training, procedures, and documentation

6.4 E-Beam Lithography

After a long hiatus, the EBL working group held one meeting this past year on Dec. 3, 2019. The previous meeting was Oct. 17, 2018.

The group's main mission and purpose has been to network and connect EBL tool owners across the NNCI in order to provide assistance. This will continue to be a priority going into 2020, however, we hope to add some new activity, such as how to promote EBL usage in the NNCI and attract more users to the NNCI facilities.

One issue we identified in our meeting on December 3rd was problems with HSQ resist ordering and delivery. Currently Dow Chemical is the provider of this negative tone high-resolution resist with excellent etch resistance selectivity to silicon. It is an important resist particularly to the optics/photonics research community. This year there have been problems with delivery of the resist. For instance, Shane Patrick at UW placed an order for HSQ back in June 2019 and as of yet, 6 months later (December 2019), has not received delivery of his order. Many other NNCI sites report long delays of HSQ shipment as well. We have become aware of a provider of HSQ powder. The provider is Applied Quantum Materials (AQM) and based in Canada. To reduce cost and increase shelf life, they ship HSQ as a powder and the customer mixes it at their local facility. We have scheduled a meeting with AQM on December 18, 2019 to review their product and see how we can start using it across the NNCI. Furthermore, we are in contact with another USA based resist supplier to see if they could help mix the powder and then resell the HSQ, potentially for further ease of use. This work is ongoing, and a great example of how we can work together to help each other, as well as the research community in the US.

Members:

Devin Brown, chair (Georgia Tech)
Harold Madsen (NC State)
Jay Dalton (Duke)
Gerald Lopez (UPenn)
JD Deng (Harvard)
Amrita Banerjee (Cornell)
Brian Wajdyk (Univ. Kentucky)
Kevin Roberts (Univ. Minn)
Kevin Nordquist (ASU)
John Tamelier (UCSD)
Stanley Lin (Stanford)
Steven Crawford (JSNN)
Talmage Tyler (Duke)
Amar Kumbar (UNC)
Yuan Lu (Harvard)
Alan Bleier (Cornell)
John Treichler (Cornell)
Peter Duda (Univ. Chicago)
Sarmita Majumder (UT Austin)
Maribel Montero (UCSD)
Rich Tiberio (Stanford)
Shane Patrick (UW)

6.5 Etch Processing

The objective of the Etch Working Group is to provide an interactive forum for all etch personnel from all the NNCI participating sites. This interaction includes but is not limited to the sharing of information regarding etch capabilities, established etch processes, processes under development, maintenance issues, preventative maintenance, baselining efforts, equipment modification, and the acquisition of new etch tools. Identification and documentation of the broad and complementary etch tools within NNCI allows us to effectively process wafers within the network to meet the diverse specifications of individual projects, and to provide back-up systems within the network to avoid any extensive downtimes in user processing.

In addition to the current communication paths of a LinkedIn-NNCI Etch Group and an NNCI Etch list serve, we have established an Etch Working Group page on the NNCI website (https://www.nnci.net/working-groups). This page contains a news blog, where announcements can be made as well as postings of interest to all etch personnel. Currently the page contains links to workshop and symposium presentations, as well as an NNCI etch capabilities listing. In addition, there is a public forum for etch related questions/answers and discussion.

The 2019 NNCI Etch Symposium was held at Harvard University on December 5-6. The symposium organizers were Vince Genova (Cornell), Ling Xie (Harvard), Usha Raghuram (Stanford), and Sarmita Majumder (Texas). The 2-day symposium was attended by more than 120 people from academic, industrial, and government research sites. Day 1 was open to both NNCI and non-NNCI etch personnel in which each site was asked to report on their current etch capabilities, and to provide an interactive forum for discussion of etch related process and equipment issues. The following NNCI sites participated in the symposium: Cornell, Harvard, Stanford, Pennsylvania, U. Washington, Georgia Tech, Minnesota, Texas, and UC San Diego. Non-NNCI sites participating on day 1 included Michigan, U. British Columbia, Boston University, and MIT-Lincoln Labs.

Day 2 was open to all from the industrial, academic, and government research communities and consisted of talks from universities and technical presentations from vendor researchers. The academic talks included:

- "Next Generation Electronics: Transforming Technologies from the "Lab" to the "Fab", Prof. Max Shulaker (MIT)
- "Making High Aspect Ratio Wires with Greater Precision", Dr. Peter Starts (Harvard)
- "Flat Optics with Metasurfaces", Prof. Federico Capasso (Harvard)
- "What Will Quantum Bring?", Prof. Evelyn Hu (Harvard)
- "Interfacing Silicon Vacancy Centers with Optomechanical Crystals in Diamond", Cleavan Cai (Harvard)
- "AlN Piezo-MEMS Process: Impact of Crystal Quality on Plasma Etching", Dr. Ben Davaji (Cornell)

The government/industrial/vendor presentations included:

- "Integrated Ultrahigh Performance Electro-Optic Circuits-Etching Enabled Photonics Breakthrough", Dr. Mian Zhang (Hyperlight Co.)

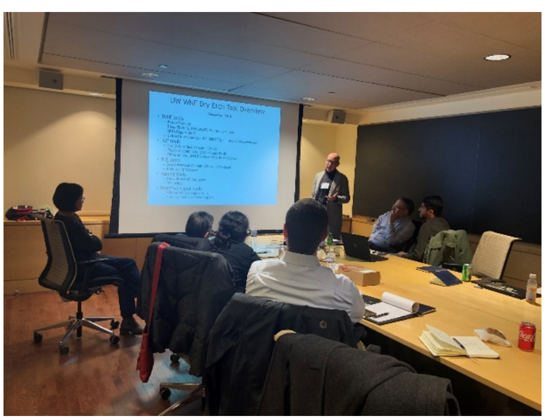
- "Avoiding Redeposited Material When Etching Difficult Materials", Dr. David Lishan (Plasmatherm)
- "Advanced Nanoscale Etching Solutions", Peter Wood (Samco)
- "Impact of Etching on Superconducting Q-bit Fabrication", Dr. Bethany Huffman (MIT-LL)
- "Plasma Processes for Wide Bandgap Materials for Power and RF Applications", Dr. Steve Fargo (SPTS)
- "Dry Etching for Diamond Applications", Colin Welch (Oxford Instruments)

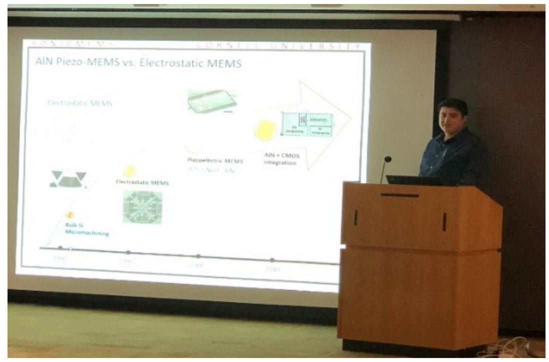
The above presentations will be posted on the NNCI website. Vendor exhibits were held each day to explore new equipment offerings and to allow attendees to have discussions with the equipment suppliers. We will issue and review the results of a survey given to symposium participants. The NNCI assisted 5 attendees from various NNCI sites with their travel expenses. The overwhelming impression from the participants is that the symposium not only promotes communication between universities, but is also a mechanism for learning about new developments in etch related technology.

Future events of the NNCI Etch Working group are being co-organized by V. Genova (Cornell), Usha Raghuram (Stanford), Ling Xie (Harvard), and Sarmita Majumder (U.Texas) and include:

- An on-site 2-day workshop/symposium to be held tentatively in April 2021 at the University of Texas with invited technical talks by NNCI and non-NNCI sites on specialized topics in etching. It is our hope to have an etch symposium every 12-18 months to foster interaction among the NNCI sites and to keep all informed on the latest developments in etching and etch capabilities.
- A "Zoom" teleconference may be held for all interested network and non-network sites midway between the on-site symposiums to collectively discuss any equipment or process issues, along with any new process developments. There will be monthly teleconferences between the co-organizers to effectively plan for the next on-site symposium
- The continued use of the NNCI-Etch mailing list and the NNCI Etch Working Group page to provide a continuous forum for discussion and announcements.

Some photos from the 2019 NNCI Etch Symposium at Harvard:





Members:

Cornell University (V.Genova, J.Drumheller, T.Pennell, J.Clark)
Harvard University (L. Xie, K.Huang)
Stanford University (U.Raghuram, J. McVittie)
Georgia Institute of Technology (T.Averette, H.Chen, M. Thomas)
University of North Carolina (B.Geil)
University of Louisville (E. Moiseeva, J. Beharic)
University of Minnesota (T.Whipple, P. Kimani)
University of Nebraska (J.Hua)
University of Pennsylvania (M.Metzler, G. Kim, H. Yamamoto)
University of Texas-Austin (R.Garcia S. Majumder)
University of Washington (M.Morgan)
Arizona State University (S.Ageno, S. Myhajlenko)
UC San Diego (X.Lu, D.Prescott)
Montana St, (J. Heinemann)
Virginia Tech (D.Leber)
U. Chicago (P.Duda, C. Posada)

Non-NNCI members who have been added to the NNCI-etch listserve are:

University of Michigan (Kevin Owen. Jorge Barreda)
University of British Columbia (Kashif Awan)
MIT Lincoln Labs (Jeffrey Dalton)
Boston University Photonics Center (Paul Mak)

6.6 Atomic Layer Deposition

Stanford and Harvard University co-hosted the 2019 NNCI ALD/MOCVD/MBE Symposium on October 3-4, 2019 at Harvard University. The goal of the symposium is to build networks between university shared labs by sharing knowledge focused on the specific areas of ALD and MOCVD. The meeting was a two-day event. The first day was a closed session for NNCI/NNIN participants only, and the second day was open to the public. Similar to the previous symposia, Day 1 included presentations by each of the attending universities explaining shared facility capabilities, ALD tool management, support, and process knowledge sharing, and an update on the MOCVD facility at Stanford.

This year also included an invited speaker, Dr. Simon Elliot from Schrodinger, who spoke about first principles simulations of ALD processes. In addition, Professor Adrie Mackus, from Eindhoven University, spoke about their shared research facility as well and the ALD systems and capabilities there. Window tours of the Harvard CNS shared facilities and a faculty lab were also given.

Nine different universities in total participated in the event, including seven from within the NNCI network: Harvard, Stanford, University of Minnesota, Cornell, Georgia Tech, University of Washington, University of North Carolina, and two schools that are not part of NNCI but were part of NNIN (Penn State and the University of Michigan). Two universities (Cornell and the University of Michigan) participated via Zoom since they were not able to attend on site. There was a mix of lab capabilities as well, ranging from well-established ALD systems with relatively large ALD user base, to labs with one system and some staffers who were new to their role as an ALD coordinator. There were many discussions related to managing the user base that were very helpful.

Day 2 was an opportunity for engineers from both industry and academia to attend talks and network over lunch and breaks. There were technical talks by vendors interspersed with research-oriented talks from noted ALD and MOCVD faculty from four different universities. Professor Adrie Mackus of Eindhoven University, Steve George of the University of Colorado-Boulder, and Dr Simon Elliot, previously of the Tyndall National Institute and currently of Schrodinger presented talks on various aspects of ALD and ALE research. Professor Srabanti Chowdhury of Stanford University and Professor Julia Mundy from Harvard gave talks focused on MOCVD and MBE. All of the speakers presented to a broad audience and educated the attendees who were both new to the areas of ALD and MOCVD/MBE as well as provided insight to the attendees that work with those systems. There were many participants to whom MOCVD/MBE and its applications was a brand new topic. We received a lot of feedback from the group that they really appreciated being given the chance to learn in this setting. All told, there were approximately 50-60 participants in Day 2, many of whom were industrial participants. Funding for the event was supported by donations from sponsoring vendors ranging from equipment, simulation, and precursor suppliers.

In our ongoing efforts to maintain a vibrant ALD network across the NNCI, many people were added to the ALD Working Group. The following list includes those members, and serves as an opportunity for shared learning to continue, including tips about alternative sources for ALD parts, novel ALD processes, and troubleshooting.

Members:

Location	NNCI Site	Equipment	Name
Cornell	CNF	ALD Oxford PECVD	Vince Genova Tom Penell Jeremy Clark
Univ. of Louisville	KY MMNIN	ALD MOCVD	Julia Aebersold
Univ. of Pennsylvania	MANTH	ALD	Noah Clay Kyle Keenan Meredith Metzler
Univ. of Minnesota	MINIC	PECVD	Robert Amundson
Georgia Tech	SENIC	ALD	Gary Spinner

			Ben Hollerbach Hang Chen
Virginia Tech	NanoEarth	ALD	Don Leber
Arizona State Univ.	NCI-SW	ALD	Stefan Myhajlenko
Univ. of Washington	NNI	ALD	Darick Baker Fred Newman
Univ. of North Carolina	RTNN	ALD	Bob Geil Jun Yan
Northwestern	SHyNE	ALD	Anil Dhote
Stanford	nano@stanford	ALD MOCVD	Michelle Rincon Xiaoqing Xu J. Provine
Univ. of Texas	TNF	ALD	Sarmita Majumder David Farnsworth
Harvard	CNS	ALD	Mac Hathaway
UC San Diego	SDNI	ALD	Xuekun Lu Bernd Fruhberger
Univ. of Minnesota	MINIC	ALD	Tony Whipple Paul Kimani
Penn State		ALD	William Drawl Bangzhi Liu
UC Santa Barbara		ALD	Bill Mitchell
Univ. of Maine		ALD	David Frankel Michael Call
Univ. of Michigan		ALD	Matt Oonk

6.7 Photolithography

The NNCI Photolithography Working Group is composed of representatives from 12 NNCI sites, plus representatives from UC Berkeley, and is charged with sharing photolithographic techniques and processes with member sites and the larger research community. Following the process we developed last year, we first held a teleconference with group members in the Spring of 2019 to flush out topics of interest and to plan for an in-person meeting. Among the topics that were discussed were sharing photoresist evaluation studies in light of the consolidation of some suppliers and the possible price increases of common materials. Group members voted to hold another 1-day working group workshop at Stanford in the Summer, as it was in 2018.

The one-day workshop was organized for July 11, 2019, the same week as SEMICON West, and the day before the Stanford-sponsored Advanced Lithography Symposium on July 12. The workshop was organized by members from Stanford, Penn and Cornell. Over 20 Members from 10 NNCI sites and UC Berkeley attended.

In the morning session, a representative from each site described their capabilities and outlined a particular lithography problem that was encountered. In the afternoon, discussion topics included process issues with negative tone resists and the use of new laser-based 3D printers. Stanford organized an in-lab tour of their direct-write and laser printers to complement the discussions.

Some travel expenses for the participants were paid for by funds from the Coordinating Office and from equipment vendors who participated in the Direct-Write Symposium the next day. Meals were provided by Stanford University and the vendors.

Members from UC Berkeley implemented a poll to assess the working group's impressions of the meeting. Of the 15 respondents, 100% thought this meeting was useful and that they would attend again next year.

A presentation of the lessons learned from these working group workshops was given at the September 2019 NNCI Site Director's monthly teleconference.

Members:

Allison Dove, UCB
Ben Hollerbach, Georgia Tech
Garry Bordonaro, Cornell
Brian Wajdyk, Kentucky
Mark Brunson, Washington
Shivakumar Bhaskaran, Stanford
Curtis McKenna, Louisville
Christine Yi-Ju Wang, Harvard
David Jones, Penn
Emily Beeman, UCB
Eric Johnston, Penn
Mark Fisher, Minnesota
Pat Watson, Penn
Guixiong Zhong, Harvard
Jiong Hua, Nebraska
Jean Nielsen, Washington
John Tamelier, UCSD
Paul Kimani, Minnesota
Gyuseok (Q) Kim, Penn
Mahnaz Mansourpour, Stanford
Mary Tang, Stanford
Laura Parmeter, Minnesota
Shane Patrick, Washington
Phil Himmer, Stanford
Kevin Roberts, Minnesota
Grant Shao, Stanford
Shu Xiang, UCSD
Swaroop Kommera, Stanford
Stanley Lin, Stanford
Rich Tiberio, Stanford
Tran-Vinh Nguyen, Georgia Tech
Xuekun Lu, UCSD

6.8 Imaging and Analysis

This working group is just getting started and has activities planned for 2020. The current working group, comprised of 11 participants with more to come, will complete a questionnaire that will be emailed in February 2020 that will discuss group questions in general, how best to feed into the NNCI and what, if anything, extra is needed and topics for the first topical workshop. Currently the tentative topical workshop focus will be on ion beam preparation of nanomaterials and the location is yet to be determined. The annual working group meeting will be held in conjunction with the Microscopy and Microanalysis conference August 2-6, 2020 in Milwaukee WI. This leverages the fact that the majority of participants will be attending this meeting.

Site	Location	Contact
NanoEarth	Virginia Tech	Elizabeth Cantando
SDNI	University of California-San Diego	Ryan Nicholl
RTNN	NC State	Phillip Strader
TNF	University of Texas at Austin	Sarmita Majumder
MONT	Montana State	Recep Avci
nano@Stanford	Stanford University	Tobu Beetz

NCI-SW	Arizona State University-Eyring Materials Center	Shery Chang
MANTH	University of Pennsylvania	Matthew Brukman
NNF	University of Nebraska-Nebraska Center for Materials and Nanoscience	Lanping Yue
SHyNE Resource	Northwestern University	Ben Myers
CNS	Harvard University	David Bell

6.9 K-12 Teachers/RET, Students, and Community Outreach

Main activities during the past year included:

1. *Updated and resubmitted a proposal to NSF for a multi-site RET program.* Three of the sites represented by WG members signed on to develop a revised proposal to NSF for a multiple-site RET program: Northwest Nanotechnology Infrastructure (University of Washington), Nebraska Nanoscale Facility (University of Nebraska-Lincoln) and Midwest Nanotechnology Infrastructure Corridor (University of Minnesota). While the NNI later withdrew from the group, the joint proposal was submitted in September of this year.

2. *Working to develop the NNCI web site Education Pages.* The WG has discussed several ways to develop and expand the education content of the NNCI website. Members have explored ways to easily aggregate and add new nanotech educational content to the site, and have looked at methods employed by other educational archive sites. The group has extensively debated the pros and cons of placing these materials on a) the NNCI site only, b) co-posting on nanoHub, and c) posting them on nanoHub only. Ultimately, the WG decided that placing NNCI and NNIN-created education content primarily on the NNCI site supports our "brand", and demonstrates to NSF that we are active in this area. At the same time, members feel that the NNCI Ed web page should function as a portal to the larger pool of resources available on nano-Hub. The WG is compiling a list of recommendations for the NNCI Education Portal.

3. *Planning for Nanotechnology Day 2019.* The WG brainstormed several ideas for Nano Day for October 2019 that might help to tie together the NNCI network. The WG decided that events like Nano Day are inherently local affairs, with limited cross connections between sites. Thus, individual sites represented by WG members pursued a variety of local events for NanoDay, including hands-on programming for visiting school groups, big public events at local science museums (NNI—University of Washington), and social media campaigns (MINIC—University of Minnesota). These activities were in addition to individual sites' contributions to the very successful Image Contest run from the Coordinating Office.

Members: Jim Marti, Chair (University of Minnesota), Maude Cuchiara (NC State University), Terese Janovec (University of Nebraska), Dan Ratner (University of Washington), Angela An-Chi Hwang (Stanford University), David Mogk (Montana State University).

6.10 Workforce Development and Community Colleges

In following up with Lisa Friedersdorf's suggestion to explore potential collaborations with SEMI on workforce development, a web meeting with SEMI's Mike Russo (VP of Global Industry

Advocacy) and Robert Weinman (Program Manager) was held in March 2019. Quinn Spadola, Trevor Thornton, and Ray Tsui were in attendance for NNCI, while Bob Ehrmann represented the NSF-funded NACK Network that focuses on nanotechnology workforce development. SEMI briefly reviewed the plans for its SEMI Works program which aims to attract, develop and retain the talent critical to the electronics industry by promoting appropriate educational programs for all age groups. These plans appear to have some overlap with what was presented as NNCI's objective to work with CCs and TCs on workforce development, and NACK's work in establishing nano-focused education standards and personnel certificates with ASTM.

Subsequently, NACK gained ASTM's approval for SEMI to access and review the 6 standards on nanotechnology workforce education. This allowed SEMI to compare the standards' contents with their competencies models for alignments. In a follow-up conference call in April, SEMI mentioned it is initially concentrating on establishing the competencies models for Advanced Manufacturing before moving on to those for the semiconductor industry. For the latter, the initial review of the ASTM standards indicated to SEMI that the contents should align well with the competencies required at the sector and occupation levels in their multi-tiered model.

In May, RTNN also hosted a visit from SEMI at NCSU. Maude Cuchiara mentioned that potential use of the node's cleanrooms was brought up, but no specific plans were identified. This and the earlier interactions with SEMI were reviewed by the WG in a teleconference in September. A number of potential ways for sites to participate in the SEMI Works program were discussed.

The interaction with SEMI was renewed following a discussion at the NNCI Annual Conference with EAB member Joe Magno, who is working with SEMI and SUNY on the SEMI Works program now funded in part by the NSF. Robert Weinman of SEMI plans to re-engage with the NNCI and NACK in Q1 of 2020 to review potential program alignments. The outcome of those discussions will be shared with the entire network. The possibility of three programs funded separately by the NSF working together is encouraging.

Appendix:

This Appendix contains highlights from several NNCI sites for activities related to workforce development and community college engagement during the past project year. The list is for illustrating the diversity in efforts and is not meant to be comprehensive.

MANTH: The Community College of Philadelphia (CCP), with support from MANTH, ran its first course in 3D Printing – Additive Manufacturing in the Fall 2019 semester and will run its first Introduction to Nanotechnology course in Spring 2020. Since CCP serves about 23,000 students with a make-up of 72% minority, 64% female, and 40% 25+ years old, these courses help to bring nanoscale concepts and technologies to broad academic audiences.

MONT: The site teamed with NanoEarth, PNNL, and Salish Kootenai College to pro-pose to NSF a Tribal College Faculty Professional Development Workshop. Students from Flathead CC also used characterization tools at MSU. MONT has also contributed to the successful award of numerous SBIR grants to local and regional companies, thus opening up a number of professional development opportunities for their immediate workforce.

nano@stanford: An internship program was established with 2 local community colleges (Foothill College and College of San Mateo), and 3 students were hired to work at SNF with duties ranging from administration to tool calibration.

NanoEarth: Virginia Tech staff were involved with a workshop for public and environmental health professionals, in which engineered nanoparticles were discussed and their characterization demonstrated remotely. The site also hosted a 3-day professional development workshop for high school teachers. An introduction to nanoscale science and technology and their applications was part of the agenda, and included both lectures as well as hands-on activities.

NCI-SW: ASU continued its collaboration with Rio Salado College (RSC) by supporting 9 different labs that are part of the curriculum for RSC's AAS degree in Nanotechnology. A total of 24 such lab sessions were conducted during the past project year for 11 students. The RSC program now has 8 graduates, with 2 furthering their studies and 3 known to have found tech jobs. The site also hosted 2 REU students and 1 RET instructor from CCs.

NNI: The WNF at UW employed a record-breaking 34 student lab assistants this past year, of which 10 were women, 2 were Native American, and 2 were Hispanic or Latino. During the current reporting period, 4 of the assistants transitioned to working in the facility for industrial clients. UW's MAF also currently employs 3 paid UW undergrad research assistants all of which are women. Through April, the NNI facilities at OSU had 27 undergraduate researchers working on different nanotechnology related projects under the guidance of NNCI faculty and staff. Close to a third of these students at OSU identify as female or other underrepresented groups in engineering.

RTNN: The site again hosted its annual nano workshop for CC educators and had 14 attendees. In a collaboration with Durham Technical Community College, lectures and labs on SEM were integrated into 3 courses there, and RTNN's REU and RET programs hosted 2 students and 1 instructor, respectively, from the school. RTNN also hosted booths at the Spring and Fall STEM Days of Wake Technical Community College. There are also plans underway to pilot an internship program in which CC students will work in site facilities.

Members: Ray Tsui, Chair (NCI-SW), Maude Cuchiara (RTNN), Kristin Field (MANTH), Angela Hwang (nano@stanford), Terese Janovec (NNF), Dave Mogk (MONT), Tonya Pruitt (NanoEarth), Dan Ratner (NNI), Trevor Thornton (NCI-SW)

6.11 Evaluation and Assessment

As a result of discussions on student interns during the monthly education and outreach coordinators call, the evaluation and assessment working group began discussing methods to assess the impact of NNCI internships on undergraduate and community and technical college student interns. The working group asked sites if they have student interns (not including REUs), if they are tracked, and if industry users have ever been surveyed about possibly hiring student interns. Six sites reported having internships, one site formally tracks their students, and none have surveyed users about hiring student interns. While the network does survey users, there are no questions about hiring practices. The Coordinating Office suggested creating a new survey for industry users, rather than adding questions to the existing one. The working group has developed three possible questions:

1. Do you hire/plan to hire/hope to hire student interns you interact with in the facility?
2. What things can we do to better prepare students to support your workforce needs?
3. If you have hired a student intern, what has been the utility of the worker?

Moving forward, the evaluation and assessment working group plans to partner with the workforce development and community college working group on developing a plan to track student interns.

At the request of the associate director of the NNCI Coordinating Office, Caroline Plumb (MONT) and Mary White (NCI-SW) reviewed the annual NNCI user survey. They both provided feedback on the wording and order of questions to improve the clarity of the survey.

Following increased efforts across the network to carry out assessment, the working group decided to discuss next steps during the Education and Outreach Coordinators pre-conference meeting. Dan Ratner (NNI) led the discussion on adapting activities in response to participant feedback. Part of the discussion was spent on specific sites sharing how they have changed some activities, in particular larger events for a general audience. Understanding what activities drive people to NNCI online educational content was also discussed. There was a lot of interest in creating a single page with links to more information that coordinators could direct participants to during events. Each event would use a unique bitly for the same page so the number of redirects for each event could be monitored.

Members: Quinn Spadola, Chair (SENIC-GT), Ray Tsui (NCI-SW), Carolyn Plumb (MONT), Tonya Pruitt (NanoEarth), Ana Sanchez Galiano (KY MMNIN), Mary White (NCI-SW), Dan Ratner (NNI)

6.12 Technical Content Development

Activities to date:

The Technical Content Development working group consists of three NNCI sites: RTNN, MANTH (UPenn), and nano@stanford. Our goal is to develop and share educational materials to support existing users, potential users, and non-traditional users to lower the barriers to entry in our facilities and improve foundational knowledge. Two sites, RTNN and nano@stanford have implemented online resources to support the education of users as well as growth of the user base, while MANTH has focused on creating resources to be shared on their online repository.

RTNN's Nanotechnology, A Maker's Course has been very successful. Since the course launch, over 70,000 people have visited the course website, over 14,000 have enrolled, and over 2,000 have completed all course components. Students hail from more than 140 countries; learners from India (27%) and the United States (18%) account for 45% of total learners. Overall the course has been well-received with a rating of 4.8/5 stars. For the next round of funding, RTNN hopes to expand upon the current modules by focusing on tool applications, unique RTNN tools, and more advanced techniques.

In addition to the Coursera NanoMaker course, staff members at NC State's Analytical Instrumentation Facility (AIF) continue to develop new training videos dedicated specifically to facility instruments. In addition, AIF's short courses are being filmed and edited to create an online library of short courses. These videos are easily accessed and can serve as refreshers for users after their training periods. This eliminates the need to contact staff for minor questions or troubleshooting, enabling users to proceed with their work more quickly and freeing up staff time for technique development, user training, and service work. The training videos are housed on an NC State website (https://reporter.ncsu.edu) but anyone can access via a guest login. A complete list of videos is below:

- **Quanta BSE Detector:** This course shows how to use the Backscatter Detector that is attached to the Thermo (formerly FEI) Quanta 3D Focused Ion Beam (FIB). The detector is the concentric style solid state detector that is sold by the instrument manufacturer.
- **Multiprep:** This course shows how to perform the proper alignment procedure for the Allied Multiprep housed in the AIF sample prep lab. This procedure should be followed each time the equipment is used at the start of a user's session to insure that the instrument is operating in the expected range and to set the instrument to its base state.
- **FIB/TEM Prep:** This course shows the steps for creating a TEM sample from a bulk on the Thermo Quanta 3D Focused Ion Beam. The course is patterned after a Si profile but can be modified for other materials.
- **Cressington Sputter Coater:** This course shows how to operate the Cressington 108 sputter coater and how to apply a AuPd coating to the sample.
- **Quanta STEM Detector:** This course shows how to use the STEM detector in the FEI Quanta 3D FIB.
- **Introduction to FIB:** This is a brief introduction to using the FEI (Thermo) Quanta 3D FIB. This should be used as a resource by users to remind themselves the steps required to insert a specimen and start the system. There are several videos available for examples.
- **AIF Safety Training:** Required safety training to AIF facility equipment for users wanting independent access.

MANTH had developed a survey in 2018 to understand the needs of non-traditional users amongst NNCI sites. One main takeaway demonstrated that videos would provide a needed resource for cleanroom training that could take some of the burden off the staff. MANTH has been developing training videos for cleanroom orientation, supported by a work-study student and overseen by a lab manager. There has been a steep learning curve to create high quality videos inside of the lab and challenges with video production. However, MANTH has developed a set of 5 videos that will be used as cleanroom orientation tools, which will cover the following:

- Introduction, Entry, and Gowning
- Use of Benches
- Additional Rules for Wet Processing
- Emergencies and Evacuation
- Introduction to IRIS (IRIS is UPenn's homegrown reservation and billing application)

These videos are housed in a repository (https://repository.upenn.edu/scn_video/) which will be tested and implemented in January 2020. MANTH has been creating videos to supplement training, which include LayoutEditor, a popular software tool used in cleanrooms for fabrication. They have also documented lessons learned to improve video production and quality, which can be shared amongst NNCI sites.

nano@stanford has been continuing to add and improve the educational training modules on Lagunita (edX based platform) that will be open and free to use by the public, similar to RTNN's Coursera course and training content. The primary focus of the course is to support staff in training users or potential users in various ways of fabrication and characterization tools. nano@stanford staff have been developing generic lithography course on Lagunita, which will be shared with lab managers NNCI-wide to adapt for their own sites and/or labs, as well as feedback to improve the content. Overall the modules on Lagunita have been positively received through feedback surveys.

Of the 110 users surveyed, over 85% of respondents answered ‘agree’ or ‘strongly agree’ to the statement “The training/learning experience improved my basic understanding of the fabrication processes” and 89% of respondents answered ‘agree’ or ‘strongly agree’ to the statement “The training/learning experience better prepared me for the in-lab, hands-on training”. Projects have included the following:

- Deposition process and Stanford deposition tools
- Heidelberg & direct write
- Microfluidics in a cleanroom
- Nanoscribe
- Wirebonder
- Transmission Electron Microscopy

nano@stanford plans continue to growing these online learning modules through graduate student fellowships. Fellowships are funded on the condition that projects will support new or non-traditional users and the larger lab member community in obtaining background knowledge on instruments, tools, and/or processes. Further, nano@stanford plans to spearhead a NNCI-wide initiative to support training on a network level for the next grant cycle.

Future Work: In preparation for the close of this funding period, the working group brainstormed several potential projects for the upcoming grant period. These aims will enhance the collaborative nature of NNCI and universally support sites with their respective trainings. It is clear that training is a pivotal part of all sites, and we hope our working group grows with interest from NNCI. Over the next grant period, we plan to achieve the following goals:

- Creating a catalog of existing training videos and background information on tools
- Leveraging the network with educational content and resources
- Developing guides on creating online resources (media production, copyright, managing digital content, etc).

By creating and cataloging a variety of resources for NNCI sites to utilize, we can leverage existing training materials to minimize duplicate efforts and focus on new and unique content. Further, we can enable sites that do not have existing online materials to create their own or utilize pre-existing content in order to expedite training.

Members: Angela Hwang, Chair (Stanford), Maude Cuchiara (RTNN), Eric Johnston (Penn)

7. NNCI Network Promotion

7.1. Marketing and User Recruitment

Marketing and user recruitment strategies vary widely across the NNCI network, based on particular site local and regional needs and situations. During the January 2017 NNCI Conference, a breakout session on marketing and user recruitment identified a number of strategies as a way to help sites develop their plans to increase facility usage and those were provided in previous reports. A follow-up breakout session on this topic was held at the October 2019 NNCI Conference and the updated discussion is given below. While much of the focus is on recruiting new external users, many of the approaches and best practices apply to internal users, particularly non-traditional users, as well. Some sites have staff with external user engagement as a primary job responsibility, while other sites do this on a more ad hoc basis. Previous NNIN sites generally seem to have a more mature marketing strategy based on previous trial and error, although most new sites have significant pre-NNCI experience with external users as well. Challenges to any marketing strategy include the often significant time lag between when a certain marketing tactic is employed and when actual usage may happen. This can make it particularly difficult to gauge the effectiveness of various approaches. Certain NNCI sites also possess geographic advantages and a built-in clientele of tech companies, start-ups, and other academic users, while other sites need to work hard to engage non-traditional users. Finally, IP concerns and overly burdensome access agreements can often discourage new users.

User Marketing and Retention Breakout Session (NNCI Annual Conference, October 25, 2019)

<u>Discussion:</u>

Facility managers were surprised to hear over and over users comment, "I didn't know this (*fill in the equipment/capability)* existed on campus." As well as ignorance to facility existence!

We should be doing continuous internal marketing including:

- Brown bag seminars
- Posters around campus
- Departmental seminars throughout institution
- Take 10 minutes in departmental faculty meetings
- Facility tours
- Send info posters to pertinent student groups

There was a discussion on billing and how sites handle delinquencies:

- Pre-payment for start-ups with no track record

Sites had some of the same challenges that impact usage:

- Needed equipment upgrades
- Down time (opportunity to refer other NNCI sites)
- Space needs
- Staff retention/turnover
- Cap rates on student time in facility. PIs will send only one student to reach the fee cap quickly when more students could be trained in a facility

- Some sites had reviewer comments to target diverse users in specific community groups (Hispanic/Latino, Native American).

Sites also had some very unique challenges:

- How to be sensitive to a neighboring facility that is 30+ years outdated and struggling? How can this site be complimentary and not competitive?
- Paperwork process for external users that can take 2-4 months before external users can get in the facility.

Ideas for increasing external users:

- Some sites have a position that at least a fraction of FTE is devoted to external user development.
- Give and go to talks at industry symposia
- Join local industry groups, attend their meetings
- Focus on SBIRs; find recent awardees; incubate current SBIR grantees to apply for addition funding and have them write the facility into proposals.
- Give and attend seminars/brown bags at neighboring institutions, community colleges
- Facility open houses for industry/Industry summits your institution
- Watch key accounts and investigate any major changes in usage. *Ex: Why hasn't company XYZ been for the last several months?*
- Find business incubators and see if your institution has something similar
- Short courses (both for internal and external users)
- Alumni associations donor resources (funding)
- Talk with deans and department heads
- Undergraduate interns from other institutions paired with research at your institution
- Contact economic development offices, manufacturing extension services, chamber of commerce
- Note that building these external relationships takes time and persistence

<u>Action Items:</u>

- A users marketing/retention working group would useful
- Sites should post APPLICATIONS of tools on websites, this easier for potential user to understand what they could accomplish rather than just a list of tools
- We should share examples of "unusual/out of the daily scope" usage and applications so sites could be thinking about how to approach users/departments that are not normally in our facilities. For instance, MONT has new users from the entomology and art departments.

The consensus of the sites is that the role of the Coordinating Office in marketing and user recruitment efforts should include the following:

1. *Represent the network at national conferences.* An exhibit booth was hosted at the *June 2019 TechConnect* conference in Boston, MA. Staffing of the booth was provided by volunteers from CNF, CNS, MINIC, NNF, TNF, and SENIC. Collateral at the booth was provided by sites. In addition, banners and an NNCI flyer were prepared by the Coordinating Office. Suggestions for additional conferences for national attention were solicited from the sites, and many individual sites also host booths at other conferences. A

page of the NNCI website is used to highlight participation by NNCI sites at regional and national expos, trade shows, and conferences. However, user survey results (See Section 7.3 below) indicate that effectiveness of conference booth hosting is minimal for user recruitment.

2. *Provide an NNCI website with tools and expert databases.* At the January 2017 NNCI Conference, there was significant discussion about the website and a desire to present a more applications-focused user experience. During the first year of its existence (2017), the website contact forms generated approximately 25 inquiries related to becoming a new user, education/outreach, or other general information, and this increased to 75 inquires during 2018 and this rate (1-2/week) has remained constant in 2019. Any potential users are referred to NNCI sites for follow-up, and we have recently begun tracking of outcomes in order to assess the efficacy of this user recruitment mechanism. More discussion of the website is provided below.
3. *Create an NNCI email list.* During 2017, a listserve was created for subscription by all interested NNCI site staff to share information on site activities, as well as provide another mechanism for sites to solicit assistance on technical and user support matters. Currently there are more than 100 subscribers to this email list with almost 60 announcements or discussions initiated in this forum yearly. Furthermore, an option to create an email list for individual working groups was offered, and both the etch and lithography groups have used this successfully. Other working groups have their own lists, not created by the Coordinating Office.
4. *Create an NNCI newsletter for periodic distribution by all sites.* This is currently under discussion.

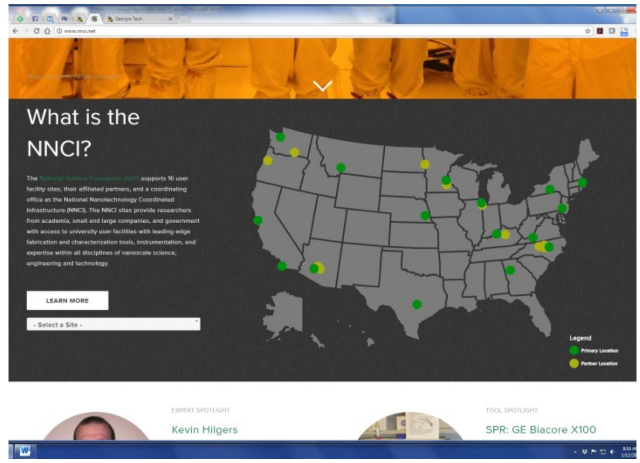
7.2. NNCI Website

During the first year of the NNCI Coordinating Office, one of the main activities was the creation of a web portal (www.nnci.net) to provide a comprehensive list of tools and experts available within the network for both user recruitment and support. The design of a new, comprehensive website was predicated on the desire to accommodate the different needs of users, potential users, the public, and NNCI staff. The design concepts and structure of the website were reported in detail in the Year 1 report with additional upgrades made during Year 2. Additional features and content were added during Year 3.

The original launch of the NNCI website (December 2016) included the following basic components:

1. Overall design implementation
2. Basic NNCI information
3. Individual site pages
4. Tool database (>2000 tools)
5. Experts database (>200 experts)
6. Contact forms (general information and new user gateway)
7. Education and outreach content (including REU and site-specific information)

8. SEI programs (including site-specific information)
9. Additional resources (other nano infrastructure, link to computation at nanoHub)
10. NNCI news blog

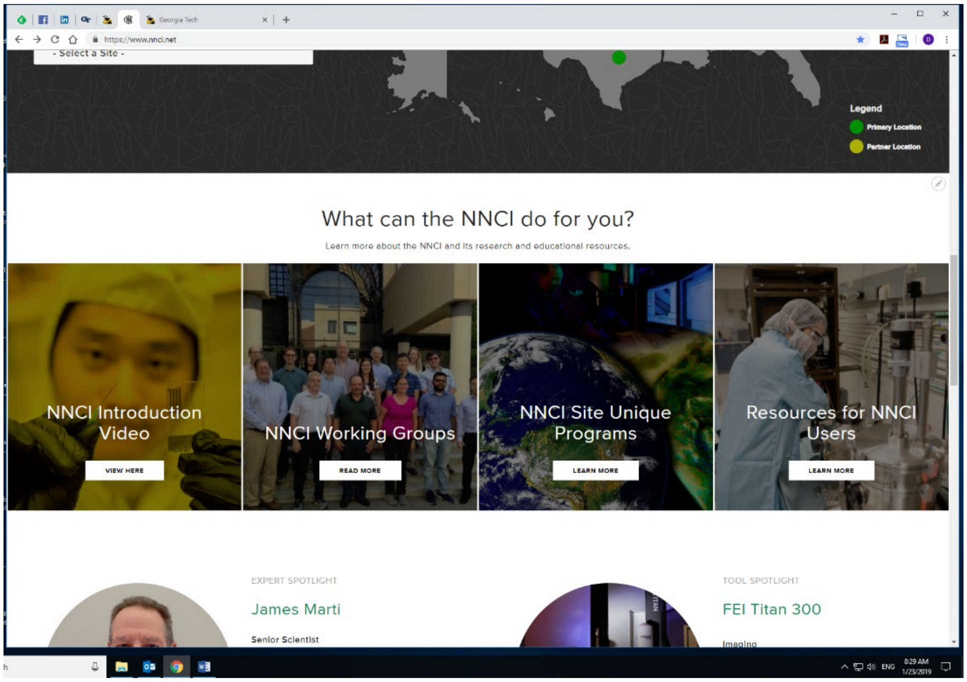


Beginning in March 2017, and with input from site directors, site staff, the External Advisory Board, and our website vendor (Cool Blue Interactive), planning began for the website's Phase 2 development. This plan included changes that improved on existing content and design elements, as well as implemented new features and content. Phase 2 was launched in 2 steps in October 2017 and January 2018 and included the following:

1. Improvements to Home page, including the map of NNCI sites
2. Improvements to contact forms, including addition of a Spanish language version.
3. Improvements and design refinements to the tools and experts database searches
4. Improvements to individual site pages
5. Alternative to 3rd level menus which provides improved navigation of the Learn pages
6. Fixes to and redesign of the Nanooze page
7. Global website search capability

Sites were notified of the revisions in February 2018 with additional content solicited from them to improve the look of the individual site pages. In addition, during 2018 new pages for Technical Working Groups were added which contain (a) list of group members with contact information, (b) a news blog for posting of content by the working group, and (c) a public forum for posting of questions with follow-up discussion. As of December 2019, the Electron Beam Lithography, Etch Processing, and Photolithography working groups have established pages on the NNCI website.

The most recent mini upgrade finished in January 2019 addressed a need to highlight more ongoing activities and news on the home page by creating a four block section ("What can the NNCI do for you?") in the middle of the page. Items in these blocks are changeable and can include a link the NNCI video, link to an events page, and updatable news or information items. The current single news item at the bottom-right of the home page has been changed to a list of the latest 5 news items.



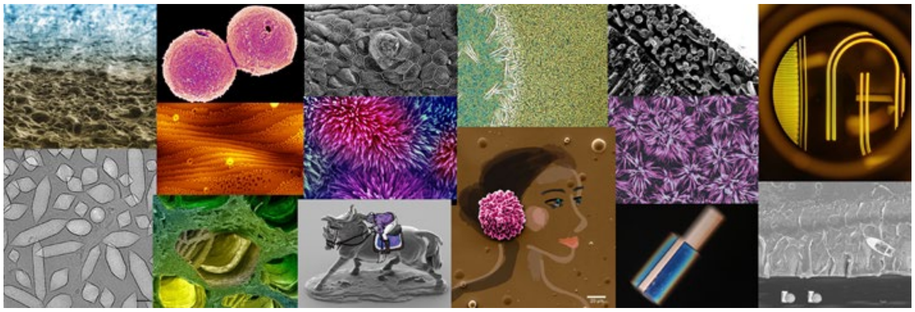
The NNCI Introduction Video was produced at the end of 2017 and publicly released in February 2018. It was finally posted to the NNCI home page with this latest upgrade (see above at left). The YouTube URL is https://youtu.be/72ZXh-ESt3U. As of Dec. 31 2019 the video had been viewed more than 1200 times.

Since the original launch new content has been uploaded regularly including:

1. News items on the blog
2. NNCI Annual Reports
3. NNCI Annual Conference agendas and presentation materials
4. NNCI On the Road (list of upcoming NNCI site presence at meetings and conferences)
5. K-16 Educator Resources
6. Technical Resources, including Remote Work Contractors and Seed Grant Opportunities.
7. Home page news spotlights
8. Backend improvements, changes, and bug fixes

During 2019 each NNCI site was asked to update their list of experts and tools on the website, to reflect changes since 2016. As of December 2019, all of the experts database information received has been updated. The tool database update is much more extensive than anticipated, with a majority of tools requiring some changes and hundreds of deletions and new tool additions. Work on updating the tool database will be a focus during 2020. In addition, a searchable education resources database, in place of the current listing of lessons, is also planned.

In celebration of National Nanotechnology Day (October 9, 2019), the NNCI website hosted the "Plenty of Beauty at the Bottom" image contest. Images featured in this contest were produced at one of the 16 NNCI sites during the previous year. Public voting occurred during Oct. 7-12 in categories "Most Stunning", "Most Unique Capability", and "Most Whimsical".



Since December 2016, the website contact forms have received more than 150 inquiries (1 per week on average). In all cases these were forwarded to the appropriate site for action on technical requests, or to the Coordinating Office education and outreach director for answering questions related to those matters.

Google analytics for www.nnci.net indicate that in calendar year 2019 there were more than 35,600 visitors to the website, a 66% increase over the previous year. In October, there were 6,700 visitors to the site, mostly to participate in the image contest voting. For the year, 88% were new visitors with 59% from the United States. There were more than 94,000 page views which is a 36% increase from the prior year. The average session duration was slightly less than 2 minutes, with an average of 2.1 page views/session, both small decreases compared to 2018. During this time period, the top ten pages visited are shown in Table 9 below. Significant differences this year include large numbers of views of education-related pages (careers, what is nano, and the image contest pages).

Table 9: NNCI Website Page Visits (2019)

Page	Pageviews	% Pageviews
/	12,784	13.60%
/careers-nanotechnology	9,334	9.93%
/research-experience-undergraduates	5,169	5.50%
/plenty-beauty-bottom	5,159	5.49%
/sites/view-all	3,736	3.97%
/what-nano	3,472	3.69%
/plenty-beauty-bottom-2	3,263	3.47%
/plenty-beauty-bottom-0	2,972	3.16%
/nature-helps-nanotechnology	2,313	2.46%
/about-nnci	2,307	2.45%

Site acquisition (how visitors get to the website) is primarily through four routes: organic search, direct, referral from another website, and social media (see Figure 9). The social media component is significant this year (2.7%) compared to previous years, with Facebook being the predominant platform, while email and other routes remain a small fraction. The organic search rate of 63% continues to increase (56% in 2018 and 42% in 2017) indicating that the website is gaining traction and appearing more frequently in online search results.

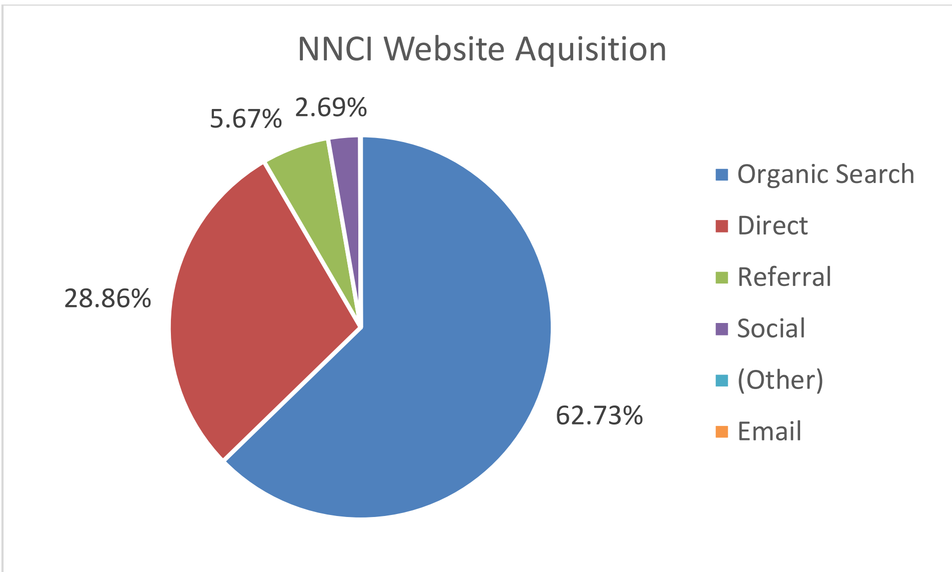


Figure 9: Site Acquisition (how visitors get to the website) for www.nnci.net

A Google search analysis indicates that searches resulted in nearly 1.4M *impressions* (how many times an NNCI website page appeared in the search results) and 34.5K *clicks* (when someone selects an NNCI website page) during the 2019 calendar year. While overall this resulted in a 2.5% *CTR* (click through rate) and an average *position* (position of the particular page in the search results list) of 21 in the results list, the top query terms (Table 10) produced much better performance including many searches with nnci.net pages in the top 5 positions and CTR >10%. While it is obvious that "nnci" and "national nanotechnology coordinated infrastructure" would produce the most direction to the NNCI website, most of the other queries are generic questions about nanoscale materials and structures as well as interest in careers/jobs in the field.

Table 10: Google Search Queries (2019)

Query	Clicks	Impressions	CTR	Position
nnci	3249	8575	37.9%	1.2
what is nano	957	24460	3.9%	4.4
nanotechnology careers	496	3576	13.9%	3.0
jeff tok*	383	1780	21.5%	3.0

national nanotechnology coordinated infrastructure	226	416	54.3%	2.0
nanotechnology jobs	205	6771	3.0%	8.4
careers in nanotechnology	187	1104	16.9%	2.9
what are other examples of nanostructures	163	963	16.9%	4.3
nanotechnology in nature	160	835	19.2%	1.8
nanotechnology in nature examples	144	458	31.4%	1.0
nano	140	121268	0.1%	10.5
jobs in nanotechnology	123	1411	8.7%	6.2
what is nano?	120	958	12.5%	4.2
examples of nanostructures	118	963	12.3%	7.2
nano measurement	111	5626	2.0%	2.7
energy transfer worksheet answers	105	1098	9.6%	5.4
career in nanotechnology	104	768	13.5%	3.1
how does a microscope work	96	7267	1.3%	10.5
nanotechnology job opportunities	89	522	17.1%	2.8
how small is a nanoscale	88	1097	8.0%	5.1

*Jeff Tok is an NNCI expert from the Stanford site

7.3. User Satisfaction Survey

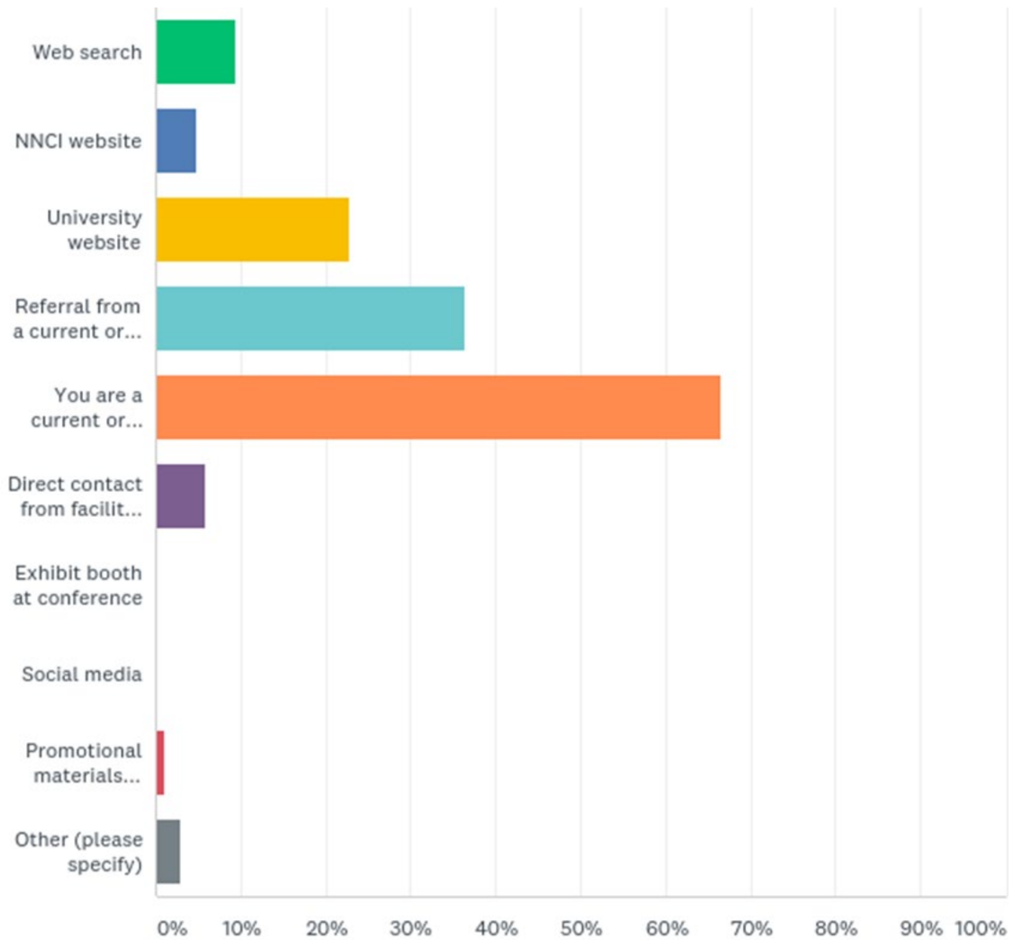
As a result of site director discussions, as well as recommendations from the Advisory Board, the Coordinating Office created a User Satisfaction Survey for implementation throughout the NNCI network. Using a *Survey Monkey* platform, the survey was first made available to sites for forwarding to their user bases during the fall/winter 2017. After receiving nearly 700 responses from 10 sites that participated and combined with the responses from five sites that had already developed their own internal surveys, the results (N>1300) were reported in the NNCI Year 2 Annual Report. Based on the first year of the common survey, the Coordinating Office solicited suggestions for modifications to the survey questions and a number were received and implemented for the 2018 survey which generated 638 responses from 8 sites that participated and an additional 747 responses from the remaining 8 sites which conducted internal surveys over a similar time period. These separate surveys did not all use the same questions as the common version on Survey Monkey, but responses were added to the overall results when possible.

For the 2019 NNCI User Survey, significant changes were implemented based on recommendations from professional evaluators at Arizona State University (Mary White) and Montana State University (Carolyn Plumb). All sites were encouraged to use the common survey vehicle when possible and 15 sites had respondents (N=1254). These results are shown below. The site-specific filtered results, with comments, were provided to individual sites for identification of action as needed.

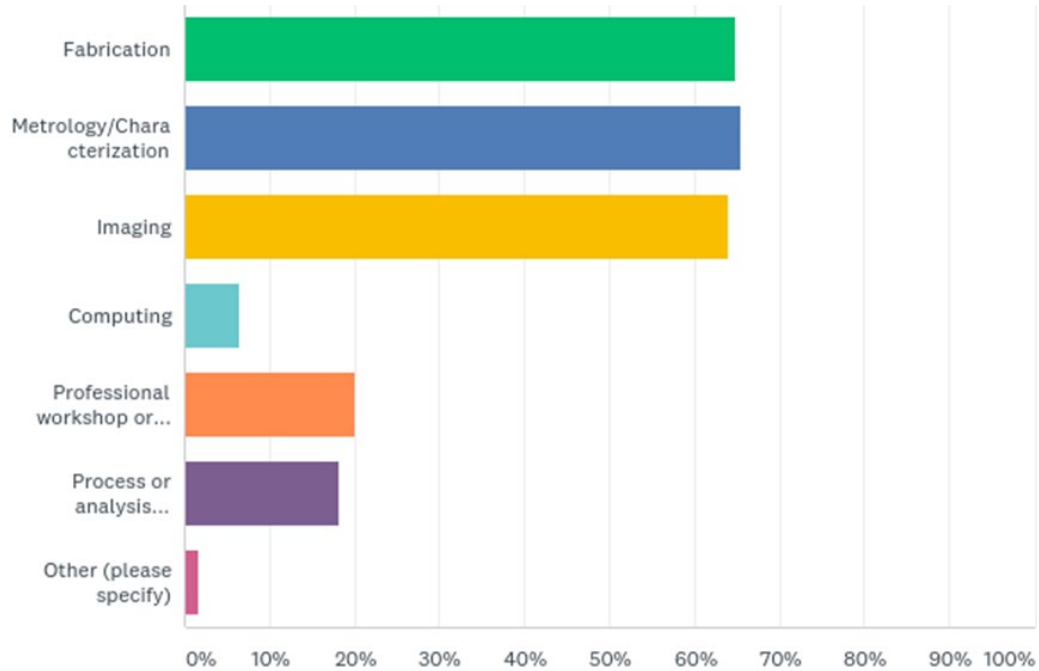
The NNCI facility that was primarily used during the previous 12 months.

The number of responses from each site varies from 7-213 (mean=83.6). In this year's survey, users were not asked if they used more than one NNCI facility during the past year although we know anecdotally that this number typically is around 5% of users.

How did the user find out about the NNCI facility? (N=1252)



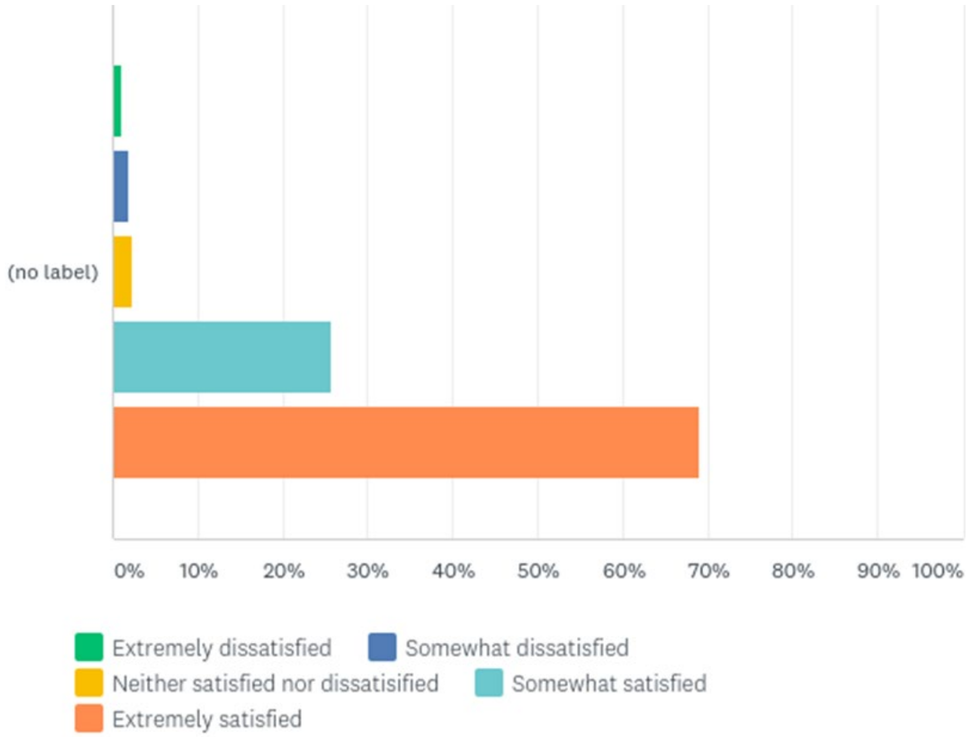
Which services were used at the NNCI facility? (N=1250)



Regarding this NNCI facility, rate your satisfaction with the following:

	EXTREMELY DISSATISFIED	SOMEWHAT DISSATISFIED	NEITHER SATISFIED NOR DISSATISFIED	SOMEWHAT SATISFIED	EXTREMELY SATISFIED	N/A	TOTAL	WEIGHTED AVERAGE
Ease of gaining access	0.72% 9	1.92% 24	3.21% 40	23.64% 295	70.11% 875	0.40% 5	1,248	4.61
Tool training	0.96% 12	2.48% 31	4.16% 52	26.74% 334	63.09% 788	2.56% 32	1,249	4.52
Ease of tool scheduling	0.65% 8	2.66% 33	4.92% 61	25.18% 312	64.57% 800	2.02% 25	1,239	4.53
Cost of the usage	1.85% 23	5.14% 64	17.51% 218	29.00% 361	39.60% 493	6.91% 86	1,245	4.07
Time it took to complete the project	0.88% 11	3.53% 44	9.62% 120	29.59% 369	46.43% 579	9.94% 124	1,247	4.30
Safety within the facility	0.72% 9	1.20% 15	2.96% 37	16.59% 207	77.08% 962	1.44% 18	1,248	4.71
Quality of available services and tools	0.56% 7	1.76% 22	4.17% 52	27.08% 338	65.95% 823	0.48% 6	1,248	4.57
Courtesy and attentiveness of the staff	0.96% 12	2.08% 26	3.84% 48	16.63% 208	75.94% 950	0.56% 7	1,251	4.65
Skill and knowledge of the staff	0.48% 6	1.28% 16	2.48% 31	17.51% 219	77.46% 969	0.80% 10	1,251	4.72

Rate your overall satisfaction with this NNCI facility (N=1254)



The average overall satisfaction rating is 4.6/5.0, with nearly 95% indicating either somewhat or extremely satisfied.

Would you recommend this NNCI facility to a colleague? (N=1254)

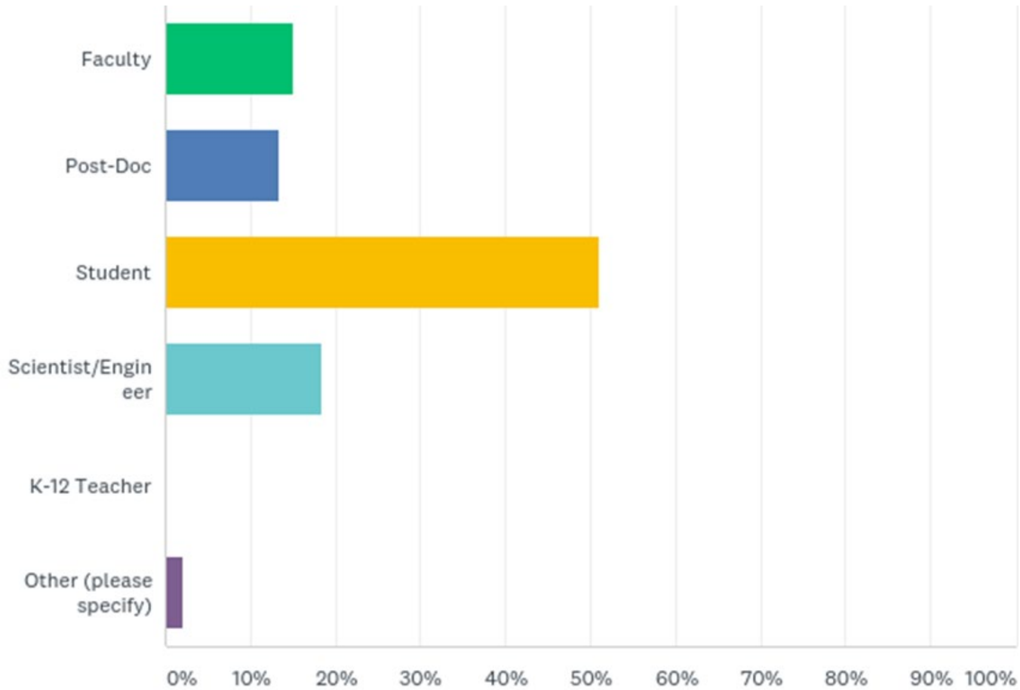
Yes: 97.2%

No: 2.8%

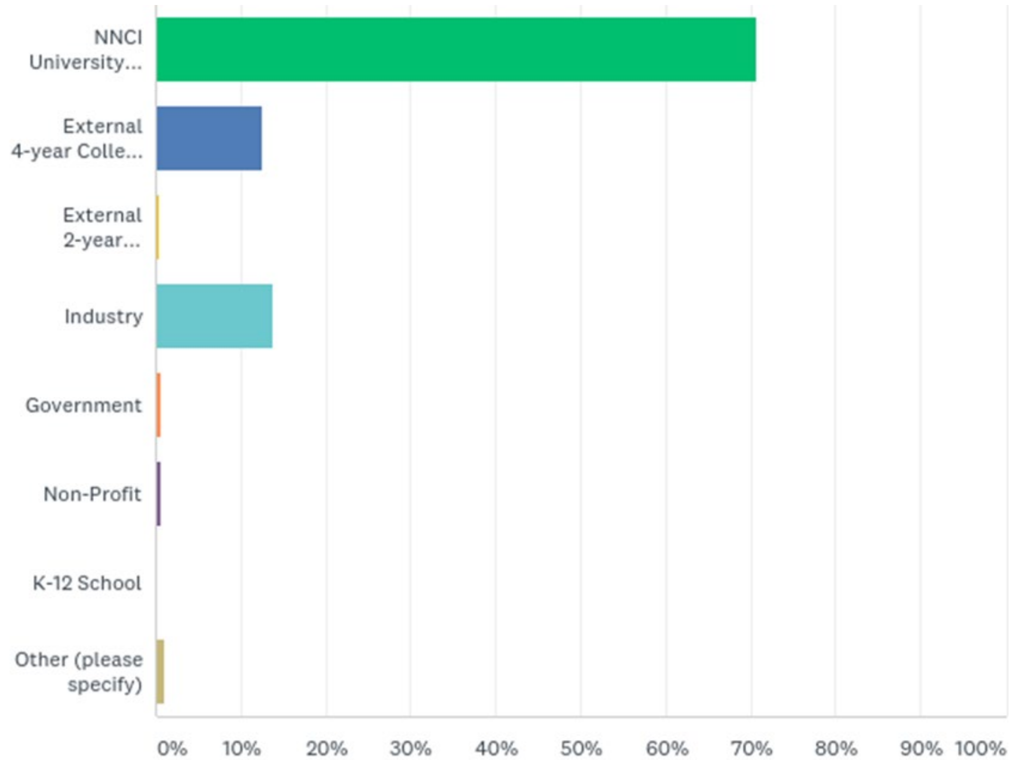
If you have any recommendations for specific new tools or services at this NNCI facility, please indicate them.

More than 250 suggestions were received and provided to the sites. Examples include environmental SEM, atom probe tomography, new FIB, 200 mm wafer capability, additional E-beam lithography, maskless photolithography, confocal Raman microscope, process module training, and additional staff.

User Position (N=1254)



User Affiliation (N=1254)



Note that this distribution closely mirrors the actual user affiliation distribution for the NNCI network as a whole (see Section 10.1, Figure 13) suggesting that the survey is probing a reasonable cross-section of NNCI users.

In addition to responses to the survey questions noted above, more than 100 individual free-text comments were provided, both positive and negative, and a selection of these is provided here:

"Having the … equipment available to us has been helpful to our product development. Even more helpful would be the availability of staff who could assist on three levels. 1. Be available to give advice on process development, 2. Assist with actual processing of prototype devices and 3. Perform metrology on devices with equipment at …."

"NNCI is vital to our business product development."

"I am not only very satisfied with the benefits the facility provides but have gone to great lengths to get other outside entities to use its equipment and services."

"I have worked at the … for nearly 20 years and the current staff and tool base are the best they've ever been. Looking forward to any expansions in tools and capabilities made possible with additional funding."

"A formal cost analysis should be performed and an equitable model should be developed for tool charges that is sustainable for the facility."

"The facility at Penn is an excellent resource and enhances the projects that are possible at our university which is primarily undergraduate."

"Tool training often has long lead times and extreme delays in email responses to schedule dates. This process should be streamlined to respect everyone's time."

"Overall a great facility. Has allowed us to successfully & reliably fabricate viable devices. Staff is very responsive and happy to share their knowledge to help improve our processes not only at … but where transferred to other facilities as well."

8. NNCI Annual Conference (October 2019)

In the proposal for the Coordinating Office, it was suggested that "A flagship event for the NNCI network will be the annual ***NNCI Conference***, which will be held at different network sites and will not only highlight the research supported by the NNCI facilities, but also provide a venue to share best practices as a result of the work of various working groups and committees." It was further detailed: "The Coordinating Office will work with the site directors to organize the annual ***NNCI Conference***, which will be held each year at a different NNCI site. The conference attendees will include the site directors and other site management personnel, the External Advisory Board, as well as NNCI site staff who are members of the working groups. As mentioned above, individual working groups might organize parallel sessions where findings in the specific topical area can be shared with other interested NNCI staff...We envision a 1.5-2 day meeting, that includes half-a-day of network overview and site presentations, half-a-day of user presentations, possibly in parallel sessions, and at least a half-a-day of time for dedicated panels on E&O, SEI, computation and select working groups (safety, vendor relations, etc.). The goal is to have a working meeting that strengthens the network and its sites, helps with future planning and is not just a review. As an example, each year's conference could have a dedicated panel on "Emerging Research Areas", using invited talks to stimulate discussion among the NNCI sites on promising future research directions and the tools required to support these. We also envision that satellite events, such as an SEI Conference, could be organized in conjunction with the annual NNCI Conference. Poster and presentation awards as well as certificates for certain panel participation may be a way for student and staff development, respectively, as part of the annual event."

The fourth annual NNCI Conference was held October 23-25, 2019 at Harvard University (CNS site) in Cambridge, MA. The 2.5-day event had an attendance of approximately 100, including senior representation from every site (14 site directors and 2 co-directors), 7 of 8 advisory board members, NSF officials Dr. Larry Goldberg, Dr. Kershed Cooper, and Dr. Carmina Londono, Dr. Lisa Friedersdorf, Director of the NNCO, as well as three invited speakers (see group photo below). The invited lectures were used to highlight an NNCI user, an emerging research area, and a comparison to another shared facility network.

- Prof. Klara Nahrstedt (Univ. of Illinois, Urbana-Champaign): "4CeeD: Real-Time Operating and Data Management Cyber-Infrastructure for Scientific Instruments"
- Prof. Marko Loncar (Harvard Univ.): "New Opportunities with Old Materials"
- Prof./ Research Director Michel de Labachelerie (EuroNanoLab): "National Nanofabrication Networks in Europe and the EuroNanoLab Project"

The agenda also featured:

1. Presentations by the Deputy Director (filling in for the Director) and the three Associate Directors of the Coordinating Office with an NNCI Overview and Reports on Education & Outreach, Societal & Ethical Implications and Modeling/Simulation.
2. Short site reports from each of the 16 NNCI sites. To assist with the organization and flow of these reports, each site was provided a template presentation to follow. The reports were grouped into four panel sessions, each with a different theme. Each site presenting in that panel provided one slide on the topic and participated in the open discussion. These themes were:
    - Aligning NNCI with National Research Priorities
    - NNCI Impact and How to Measure It

- Resource Allocation and New Equipment
- Collaborations Beyond NNCI

3. Six breakout groups in 2 sessions with subsequent reporting back to all attendees. The breakout group topics were:
    - Facility Management
    - Researcher (User) Training and Education
    - Diversity
    - Best Practices for Health and Safety
    - User Recruitment and Marketing
    - Getting Ready for Renewal
4. A separate meeting of Education and Outreach Coordinators held the day before the main meeting.
5. A separate meeting of SEI coordinators held the day before the main meeting.
6. Group discussion between the Site Directors and the Coordinating Office.
7. A banquet which included presentation of the NNCI Staff Awards (Section 9.3) and a lecture by invited speaker Carol Lynn Alpert of the Museum of Science on the topic "Beyond Nano… Addressing Quantum Science & Engineering with Public Audiences."
8. A private meeting of the External Advisory Board. These discussions resulted in a written report to the Coordinating Office which is attached here as Appendix 13.1.

Both the Coordinating Office presentations and the site reports are provided, along with the full meeting agenda, on the NNCI website at http://www.nnci.net/nnci-annual-conference.

The 2020 NNCI Conference is scheduled to be held at Northwestern University (SHyNE) on October 26-28, 2020.

9. Network Activity and Programs

9.1. Cooperative Network Activity

The NNCI sites and Coordinating Office have continued to make a concerted effort to develop and engage in activities that demonstrate the network "whole being greater than the sum of its parts." These activities include the following: (1) activities where all (or nearly all) NNCI sites participated, (2) activities between sites or with multiple NNCI site partners, and (3) activities where a single NNCI site acted on behalf of the entire network. Below are provided examples of such activities during this past year of the NNCI program.

Network-Wide Activities

1. Participation in monthly NNCI site director meetings
2. Participation in monthly NNCI education and outreach coordinators call
3. Chairing and membership of Subcommittees
4. Leading and membership of Working Groups
5. Participation in National Nanotechnology Day Activities (Fifteen NNCI sites submitted entries for the "Plenty of Beauty at the Bottom" image contest in 2019.)
6. Attending NSF Nano Grantees Conference (December 2018 and 2019)
7. Attending NNCI Annual Conference (October 2019)
8. Sending students to REU Convocation (August 2019)
9. Participation in NNCI site visits with the Coordinating Office
10. Providing content for the NNCI website
11. Participation in the NNCI Outstanding Staff Awards program
12. Discussions between site staff on equipment repair and maintenance issues
13. Promotion of NNCI, network events, and opportunities (workshops, job postings, etc.) through electronic communications and other marketing
14. User referrals to other sites, via NNCI email list or responses to NNCI website contact form

Multi-Site Activities

1. Hosting and participation in NNCI supported workshops and technical events (host site in parentheses), not including individual seminars and webinars:
    a. Dec. 2018: CryoEM Workshop (NCI-SW)
    b. April 2019: Startup Forum (CNS)
    c. May 2019: iNANO Consortium Meeting (SHyNE)
    d. May and Oct. 2019: NanoFANS Forum (SENIC)

e. June 2019: Quantum Engineering Symposium at TechConnect (CNS)
f. June 2019: 2D Materials and BioNano Short Courses (MINIC)
g. July 2019: KY Multiscale Nano+AM Symposium (KY MMNIN)
h. July 2019: Biomedical Characterization Workshop (NNI)
i. July 2019: NNCI Advanced Lithography Workshop (Stanford) – Attended by members of the Photolithography Working Group
j. Sept. 2019: Annual User Meeting (CNF)
k. Sept. 2019: Enabling Quantum Leap (NSF Workshop, co-sponsored by MANTH)
l. Oct. 2019: NNCI ALD/MOCVD/MBE Symposium (CNS) – Attended by members of the ALD Working Group
m. Dec. 2019: Fabrication of Wide Bandgap Power Devices Short Course (RTNN)
n. Dec. 2019: Nanomagnetism Symposium (NNF)
o. Dec. 2019: NNCI Etch Symposium (CNS) – Attended by members of the Etch Processing Working Group and the Equipment, Maintenance, and Training Working Group

2. Participation in SEI Programs:
    a. ASU Winter School on Responsible Innovation and Emerging Technologies: Dr. Jameson Wetmore and colleagues from the NCI-SW SEI User Facility hosted the annual Winter School in January 2019. 16 students from Mexico, Canada, the UK, and the US participated in the week-long program. This year drew upon expertise across the NNCI by bringing in SEI scholar Jan Youtie (Georgia Tech).
    b. Science Outside the Lab (SOtL): Sponsored by the NCI-SW SEI User Facility, this event hosted 15 participants from 8 different NNCI institutions in June 2019.
3. User project support: User projects continue to be triaged and referred to and between NNCI sites where work can be done more efficiently. This process, driven and aided by direct cross-network staff technical interactions, an email listserve, and NNCI website contact forms, has become an important dynamic within the network which allows for maximizing the network's resources for the nation's benefit. Examples include:
    a. A MONT industrial user visited NNI's Washington Fabrication Facility for AML Bonder training.
    b. SDNI has active interactions with NNI, MANTH, Stanford, and MONT and have referred users to other sites for TEM (Stanford, NanoEarth, NCI-SW), NanoAuger (Stanford, MONT), Laser Direct Write (MANTH) for inter-site collaborative processing and characterization. Examples include collaboration with Stanford in high-k dielectrics, and with MONT on fabrication of optical devices.
4. Staff technical interactions:
    a. CNS hosted a Georgia Tech team visit for ALD/Safety/User Processes best practice information sharing and a Penn team visit for operations best practice information sharing.

   b. MANTH and CNF node have a collaboration to develop techniques to deposit and etch scandium-doped AlN piezoelectric films. The etch and deposition experts from both sites are discussing the details of the sputter deposition of this material as MANTH plans to install a tool dedicated to this purpose later this year. CNF engineers have experience with AlN deposition and are sharing their insight. MANTH plans to develop and characterize etch processes for these scandium-doped materials as well, and are sharing their experiences with CNF to further enhance the network's collective knowledge base.
   c. MANTH has shared their experiences with CNF regarding operation of the Nanoscribe tool.
   d. Stanford has supplied thick (6 um), doped poly-Si wafers grown on oxide to MANTH for the graduate-level nanofabrication course. Stanford's unique expertise in growing thick, conductive, poly-Si layers provides the students with material to fabricate and test sophisticated micro-electro-mechanical systems in the MANTH cleanroom.
   e. Kevin Roberts (MINIC) has worked with Devin Brown (SENIC), and Shane Patrick (NNI) on methods to improve e-beam resist processing for waveguide applications.
   f. MONT has interacted with SDNI, MINIC, nano@Stanford, CNS and NanoEarth for user project support and staff technical interactions.
   g. Greg Herman (NNI) visited NCI-SW to discuss lab management, equipment upgrades, and student educational programs.
   h. WNF manager of business outreach and customer development Jason Tauscher (NNI) has contacted the University of Louisville to explore Pt etching, and he has connected at least 3 NNI users with other NNCI sites.
   i. SENIC communicated with SDNI on equipment repair and maintenance issues.
5. Lab management software support:
   a. MONT continues its collaboration with Georgia Tech (SENIC) to link their facility to management software (SUMS), leveraging the extensive application development that GT has already done and applying it to the much smaller installation at MSU.
   b. Greg Cibuzar (MINIC) continues to consult with multiple sites on the suitability of the lab operating software NEMO for NNCI site operation, and on upgrades to the Badger software.
6. Joint proposals:
   a. NSF "AccelNET: Global Quantum Leap" proposal – led by Karl Bohringer (NNI), with participation by SENIC, CNS, CNF, NanoEarth, RTNN, MINIC, NNF, SHyNE. International participants included Nanoplatform Japan, Excellence Cluster on Quantum Technologies Germany, and the Australian Research Council FLEET Centre of Excellence. The proposal was submitted Feb. 2019 and not funded; a revised proposal is being prepared for submission in 2020 with Steve Koester (MINIC) serving as PI.
   b. SENIC is leading a multi-site proposal to NSF for a Research Experiences for Teachers site with three other NNCI partners (MINIC, NNF, and SHyNE).

   c. SENIC (JSNN) and RTNN have collaborated to respond to state-wide (North Carolina) calls for proposals for new research initiatives.

7. Sharing of best practices:
   a. Assessment and evaluation tools and activities (RTNN, NCI-SW, MONT)
   b. Seed grant programs such as Kickstarter (RTNN) and Catalyst (SENIC)
   c. Regional facility networks such as Northern Nano Lab Alliance (MINIC), Southeastern Nano Fabrication Facility Network (SENIC), and Mid-Atlantic Region Cleanroom Facility Managers (MANTH).
   d. Student Ambassadors (RTNN)
   e. Middle School Teacher Workshop (Stanford)
8. RTNN and JSNN (part of SENIC) have had strong collaborations and interactions due to their geographical proximity. RTNN has participated in JSNN's annual Nanomanufacturing Conference and JSNN faculty and students actively participated in RTNN's Carolina Science Symposium (previously called MRS/ASM/AVS joint symposium). RTNN's David Berube served as the keynote speaker at the "Innovate Workshop for Scientific Communication" hosted by JSNN.
9. Many learners from RTNN's Coursera course have contacted them to find additional online resources. These individuals have been directed to Stanford's online course (housed on Lagunitas, an EdX platform), which complements the RTNN course well as it goes into further detail and offers more intensive training videos.
10. Dave Mogk (MONT), Michael Hochella (NanoEarth), Paul Westerhoff (NCI-SW), and an international group of colleagues published their review article, "Natural, incidental, and engineered nanomaterials and their impacts on the Earth system" (*Science*, v. 363, no. 6434, p. eaau8299), in March 2019. This paper was the result of a special NSF-funded workshop held at NanoEarth in April 2018.
11. A webinar was presented to the National Association of Geoscience Teachers and the NSF-supported InTeGrate (STEP) program by Mogk (MONT) and Hochella (NanoEarth) on "Teaching Nanoscience in the Earth and Environmental Sciences." More information, presentation slides, and video of the webinar can be accessed at: https://serc.carleton.edu/integrate/workshops/webinars/2018_2019/teach_nano/index.html
12. Joint marketing efforts and representation of NNCI via conference exhibit booths and/or presentations (MRS, SEMICON West, EIPBN, TechConnect, ACS, NSTA).
13. NCI-SW, RTNN, NNF, SDNI, and SENIC participate in the Nanotechnology Applications and Career Knowledge (NACK) Network's Remote Access Instrumentation in Nanotechnology (RAIN) coordinated by Pennsylvania State University.
14. Michael Hochella (NanoEarth) and David Dickensheets and Heather Rauser (MONT) have been working with Prof. Antony Berthelote (Salish Kootenai College in Montana) to arrange a tribal college faculty visit to PNNL. Prof. Berthelote has proposed a Tribal College Faculty Professional Development Workshop (including the PNNL visit) and has submitted this proposal to the National Science Foundation with MONT's assistance. Tribal participants in the workshop are from the University of Montana, Navajo Tech, and Salish Kootenai College.

Hochella has made the connection to PNNL, and PNNL leadership is willing to host up to 15 faculty members. They will organize a visit that will center around possible collaborations and opportunities for the faculty, tribal colleges, and Native American students.

15. NanoEarth and SENIC hosted a large joint education and outreach event at Effingham County High School in Springfield, GA.
16. NanoEarth represented the NNCI at the first annual Mid-Atlantic Undergraduate Research Conference.

Site Activity on Behalf of the NNCI

1. Nanooze: CNF publishes Nanooze, and, in addition to direct distribution to classrooms, distributes it to all NNCI sites for use in their outreach activities. More than 100,000 copies were distributed in 2019.
2. NNCI Web Site: CNF provided the temporary NNCI.net web site until December 2016, assisted in the transition of content to the new NNCI web site, and maintains archival NNIN information that has not yet been transferred. Georgia Tech (SENIC) maintains the current NNCI website.
3. Disney NSF Science Portal: CNF is restructuring the Nanooze Disney exhibit into the Disney NSF Science Portal to promote NSF research, NNCI, and nanotechnology in general.
4. CNF manages the iREU program that affords a second year research experience abroad from among the highest rated REU interns from the previous summer. During the summer of 2019, six interns worked in the labs of NIMS researchers in Tsukuba, Japan. Due to an unfunded iREU grant proposal, the 2019 program was jointly funded by CNF and the NNCI Coordinating Office. A new proposal was submitted for 2020 funding. In a reciprocal arrangement Japanese graduate students are placed at NNCI host sites for the summer (iREG). During summer 2019 students worked at NNF, SENIC, and MANTH.
5. CNF and Georgia Tech (Coordinating Office) have conducted longitudinal tracking of NNUN/NNIN/NNCI REU students since 1997.
6. Hosting of REU Convocation by CNF (Aug. 2019)
7. Hosting of NNCI Annual Conference by Harvard University (Oct. 2019)
8. Jacob Jones (RTNN) presented on behalf of NNCI at the annual 2019 NSF Nano Grantees Meeting, which was chaired by Dan Herr (SENIC), Michael Hochella (NanoEarth), and Bob Westervelt (CNS). Quinn Spadola (SENIC and Coordinating Office) also presented on education and outreach within NNCI.
9. SDNI staff hosted a workshop at the Society for the Advancement of Chicanos & Native Americans in Science (SACNAS) 2019 Conference. To bolster diversity and education in nanoscience and nanotechnology, SDNI is collaborating with the NNCI Coordinating Office and the NACK Network to increase outreach.
10. NanoEarth is a sponsor of the Pulse of the Planet syndicated radio program, helping produce 30 radio shows related to Earth and environmental nanotechnology. Over a million people have been reached via the live national listening audience and podcast streams/downloads.

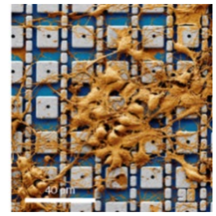
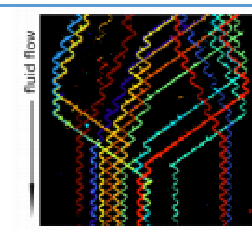
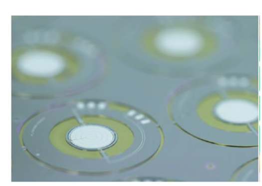
11. KY MMNIN hosts the UGIM website and several NNCI staff are members of the UGIM Steering Committee (Aebersold (KY MMINI), Cibuzar (MINIC), Clay (MANTH), and Tang (Stanford)).
12. MANTH has published over 110 documents in the Penn Library System through Scholarly Commons (http://repository.upenn.edu/qnf/), a resource accessible to NNCI member sites and to anyone worldwide. These documents, covering the spectrum of nanofabrication-related topics are products of the development work of MANTH staff and students. The total number of download of documents since the inception of this program in 2015 is more than 62,000 with requests from 3,074 institutions in 142 countries. Some of the most popular topics concern process recipes for deposition and etching. One report on the deposition of SiO2 using plasma enhanced chemical vapor deposition was downloaded 3000 times in 2018 alone.
13. NanoEarth Mitsuhiro Murayama and Tonya Pruitt represented the NNCI at Japan Nano 2019, the annual conference of Japan's Nanotechnology Platform, the NNCI national network equivalent in Japan. In addition to giving an invited talk, they met with members of the coordinating office at the National Institute for Materials Science (NIMS) and visited the Ultramicroscopy Center (URC), Kyushu University's central characterization facility and a node of Japan's Nanotechnology Platform. NanoEarth initiated talks regarding a joint symposium between the two networks. The joint symposium and further coordination with Japan's Nanotechnology Platform were a leading component of the submitted NNCI NSF AccelNet Proposal.
14. SDNI is organizing an NNCI outreach/education conference scheduled to take place on March 27-29, 2020. The conference will include guest speakers including NNCO Director, California school district officials, high school and community college science teachers, science curriculum content developers, and NNCI site leaders in outreach and education.

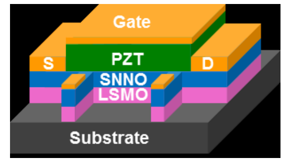
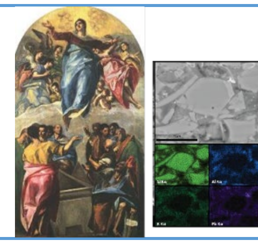
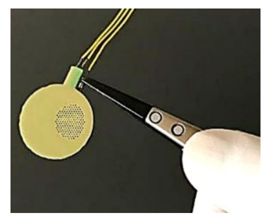
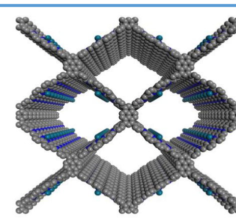
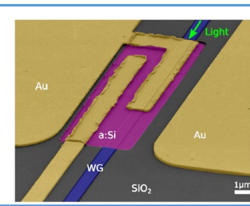
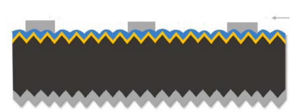
9.2. NNCI Research Focus Areas

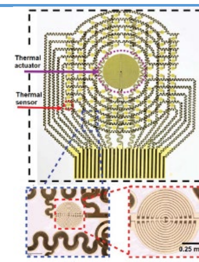
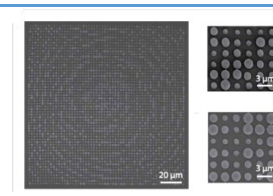
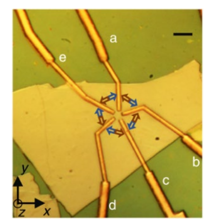
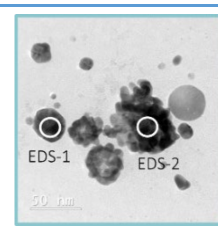
All NNCI sites have extensive tool sets and facilities for nanoscale fabrication and characterization. Some sites have unique capabilities and programs in the technical areas as well as in education, outreach, and commercialization, as well as resources (seed grant opportunities and/or remote work contractors and consultants) available to users. This information was reported in the Year 3 NNCI Annual Report (2019) and has been updated and located on the NNCI website (https://www.nnci.net/blog/nnci-site-unique-programs and https://www.nnci.net/technical-resources) for future reference.

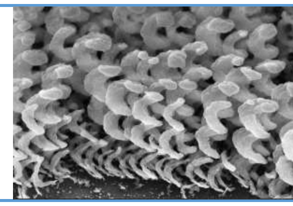
In Table 11 below we present the broad research disciplines and focus areas available at specific NNCI sites with some illustrative examples. This listing was compiled from individual site information (oral and written reports) and is not intended as all-inclusive but rather a representation of research experience and expertise found within the NNCI network.

Table 11: Research Focus Areas at NNCI Sites

Research Discipline and Focus Area	Active Sites	Example
Life Science/Medicine		
Quantitative Biology and Bioengineering (nanomechanics, nanoscale structural analysis, translational bioscience, advanced imaging)	CNS, MANTH	*Nanoelectrode Arrays for High-throughput Intracellular-Recording (Donhee Ham, Harvard/CNS)* 
Bio-nano Interfaces and Systems (drug delivery, diagnostic sensors, bio-scaffolds)	NNI, SENIC, SDNI	*Conversion into Nanocellulose (Wollenberg Paper & Bioresource Science Lab, School of Environmental & Forest Sciences, UW/NNI)* 
Interfaces, Biofilms, Materials, Fluidics, and Heterogeneous Integration	RTNN, MONT, CNF, SENIC	*DNA Manipulation in Nanofluidic Channels (Robert Riehn, NCSU/RTNN/SENIC)* 
Life Sciences and Medicine	Stanford, MANTH, SDNI	*Microfluidics in Space (Penn Engineering and Children's Hospital of Philadelphia/MANTH)* 
Bio 3D-Printing (augmented humanity)	NNI, MINIC	*3D Printed Bionic Eye (McAlpine Group,ME, U. Minn/MINIC)* 
MEMS/Mechanical Engineering		
MEMS	CNF, KY-MMNIN, MANTH, MONT	*MEMS-in-the-Lens for Miniature Laser Scanning Microscope (Montana State/CNF/MONT)* 

Materials/Chemistry		
Magnetic Materials/Nanomagnetics	CNF, SDNI, NNF *Interfacial Charge Engineering for Ferroelectric Control of Strongly Correlated Oxides(Engineering and Physics, UNL/NNF)*	
Soft and Hybrid Materials	SHyNE *Art Work Analysis (Kenneth Sutherland, Art Institute of Chicago/SHyNE)*	
Advanced Energy Materials and Devices (batteries and solar power)	NNI, NNF	
Novel Optical and High Temperature Materials	MONT	
Organic and Inorganic 1D- and 2D Nanomaterials	RTNN, CNF, MONT, MINIC, TNF *Graphene Growth for Enhanced Audio Transducers (GraphAudio/TNF)*	
Complex Nano-hybrid materials	NNF *Iridium Complex Immobilization on Covalent Organic Framework (Univ. South Florida/NNF)*	
Materials Testing	SENIC	
Electronics/Physics		
Quantum Science and Engineering (optics/photonics, spin systems, information systems and devices, nanospectroscopy)	CNS, CNF, MANTH, SENIC *Monolithic Lithium Niobate Photonic Circuits (HyperLight/CNS)*	
Photovoltaics	NCI-SW *Hybrid Photovoltaic Device Architecture (U. Delaware/NCI-SW)*	
Nanoferroic and Nanoelectronic Devices	NNF	

Heterointegration	CNF	
Textile Nanosciences and Flexible Integrated Systems	RTNN, SHyNE *Flexible/Wearable Electronics for Non-invasive Diagnostics (Rogers Lab, Northwestern/SHyNE)*	
Advanced Packaging	MINIC, SENIC	
Optics/Photonics		
Silicon Photonics	CNF, SDNI	
Integrated Photonics	NNI *Inverse Design of Metasurface and Computational Sensor (Majumdar Lab, UW/NNI)*	
Photonic Micro/Nanodevices	MANTH *Integrated Higher-Dimensional Quantum Photonic Platform (Penn Engineering and Stevens Institute of Technology/MANTH)*	
Geo/Environmental		
Nanoscience and Technology of Earth and its Environment	NanoEarth, Stanford, NCI-SW *Scalable Removal of Nanoparticles from Wastewater (Micronic Technologies/NanoEarth)*	
Nanomaterials for Biology and Environmental Assessment	RTNN	
Process Development and Tools		
Advanced Lithography Tools (E-beam and DUV) and Modeling	CNF	
In-house Mask Making	CNF	
Advanced Microscopy and Surface Analysis	SENIC, KY-MMNIN	
Analytical Chemistry	SENIC	
Comprehensive Maker Space	MANTH	

3D Printing Technologies (metals, polymers, biomaterials)	KY-MMNIN *Nano 3D Structures by Glancing Angle Deposition (Chuang Qu, Louisville/KY-MMNIN)*	
Nanoimprint and Roll-to-Roll Manufacturing	TNF	
User Facility for the Social and Ethical Implications of Nanotechnology	NCI-SW	
Computation and Modeling	NCI-SW, CNF, MINIC, Stanford	

9.3. NNCI Outstanding Staff Awards

During 2019 the NNCI Coordinating Office organized the second year of the "Outstanding NNCI Staff Member" awards to acknowledge the significant efforts by NNCI site staff who endeavor to provide excellent service and support to all network users in three categories: Technical Staff, Education and Outreach, and User Support. In May 2019, nominations consisting of a 500-word narrative were solicited from site directors (maximum of one nomination in each category) and these were reviewed by the NNCI External Advisory Board. Nominations were evaluated based on the individual’s activities that align with site/NNCI goals of providing facility access and/or education and outreach, as well as their impact on the site and the NNCI network. Each winner received an engraved desktop plaque presented at the NNCI Annual Conference and travel support to attend the Annual Conference.

<u>Education and Outreach</u>

- Angela Hwang (Academic Program Manager, nano@Stanford
- Holly Leddy (Research and Development Engineer, RTNN (Duke University))

Technical Staff

- Peter Duda (Technical Director of Pritzker Nanofabrication Facility, SHyNE (University of Chicago))
- Usha Raghuram (Senior Member of the Technical Staff, nano@Stanford)

User Support

- Tirzah Abbott (Senior Electron Microscopy and Imaging Specialist, SHyNE (Northwestern University))
- Curt McKenna (Senior Research Technologist, KY MMNIN (University of Louisville))

10. NNCI Network Usage

Individual NNCI site performance, and that of the network as a whole, can generally be assessed based on four major criteria: (1) ability to serve the greatest number and broadest set of researchers from academia, industry, and government, while keeping in mind site's capabilities and focus, (2) impact on the research enterprise and its economic importance in the commercial realm, (3) societal impact based on improved public awareness, diversity, and workforce development for nanoscale activity, and (4) contributions of sites to the NNCI network. Given these broad criteria, each site determines the set of metrics for their annual site report to NSF that best fit their own technical specialization (if any), regional user base and commercial interests, and any partnership arrangements. A non-exhaustive list of examples of potential metrics, many based on experience from NNIN, has been provided in previous reports.

NNCI sites collect statistical data about their users in an effort to assess the strength and success of the internal and external users program. Research disciplines can be used to help track usage in non-traditional areas. Productivity is implied from annual assessment of user research publications, patents, and presentations that rely on use of the shared facilities and the research budgets enabled. It is more difficult to quantify the productivity of industrial usage, where publications are not the norm, but data on numbers of start-up companies, their financial well-being, patent applications and personnel hiring can be used as indirect measures. In addition, sites may decide to conduct regular user and/or PI satisfaction surveys as a means of assessing site quality and making adjustments to operations as needed (see Section 7.4 above). Education and outreach evaluation plans will provide assessments to guide program improvement as well as impact and effectiveness of programs. Finally, each site's contributions to creating a unified network that surpasses the sum of its parts can be assessed by participation of site personnel in network activities (see Section 9 above).

That being said, it is important that a common set of data for the NNCI network sites, as well as aggregated data for the network as a whole, be regularly collected. The NNCI Coordinating Office has established a *Metrics and Assessment Subcommittee* that has agreed upon a common set of site and network metrics, and the collected data are consistent with the user statistics developed under the NNIN program. The following are the definitions provided to all sites for creating a uniform set of metrics.

1. An on-site user is someone who physically comes to a site facility (or partner facility) to access the tool set. A remote user is someone who contracts to have processing and/or characterization done by site staff for them. In general, there should only be one remote user for any given piece of work. Faculty (both internal and external) and industry PIs, unless they actually do hands-on work themselves, should not be counted as users – only the students/researchers who do the work are users. Site staff should not be counted as users, unless they have a dual role and act as a student/researcher as well. All included facilities are OPEN, SHARED, USER facilities, where the tools are available to all researchers (internal and external) for hands-on use. Purely service facilities or individual PI labs should not be included. It is also important to not count users more than once for using multiple facilities of a single NNCI site. In short, every user in the cumulative user count corresponds to a single, unique individual. Even though summer interns/REU students are typically paid with internal funding and working on internal projects, these users are counted as EXTERNAL users as their home institution is another university/college, which is the primary factor that governs affiliation.

2. Stats are broken down by Affiliation, meaning the type of institution, and Discipline, meaning the area of research. Local Site Academic refers to users who are either students or employees of a site (or its partners). All other Affiliations are for external users. A Small Company is defined as one with <500 employees. Disciplines are often self-selected by the user, or perhaps by site staff. In the Discipline category "Educational Lab Use" is NOT intended to count students in a regular university class which uses the NNCI site facilities. Rather, this category is applied to users who attend workshops or short courses, created as part of a sites NNCI education and outreach, where hands-on work (attendees actually go into the lab) is part of the program.
3. Lab Time refers to actual time in the cleanroom OR tool time for all users during a given month. These should not be double counted. In other words, if a student is using multiple tools in the cleanroom, only the time in the cleanroom should be used. If a student is outside the cleanroom, but a process is still running, the tool time can still be counted. Most characterization tools, outside the cleanroom, are counted as straight tool usage time. For cases when users are logged into a cleanroom tool, but he/she is not inside the cleanroom (for example, during extended furnace runs), tool time is recorded.
4. Monthly Users are the total number of unique individuals who access a site in a given month. In this case, the total number may be different than the sum of On-Site + Remote if a user accesses the site via both methods in a given month.
5. Cumulative Users is the running total of all users since the beginning of the NNCI year on October 1. Each year on October 1, the cumulative count starts over with all users counted again.
6. Fees data are the revenue from all user fees for use of a site's facilities. This data does not include indirect charges (if they are assessed). If a site uses a cap on charges after a certain hour limit, only the actual fees charged are reported, but the actual hours used over the cap limit are reported in Lab Time.
7. New Users Trained refers to those users who are first time users (and typically attend a site's orientation program) in that month. In this section all users should only be included ONE TIME during the entire life of the NNCI program.

10.1. NNCI Aggregate User Data (Oct. 1, 2018 - Sept. 30, 2019)

Since each site provides its own usage data as part of their annual report and a subset of this data is provided in the site reports below (Section 11), we have not included exhaustive sets of individual site data here, but rather the aggregate for the NNCI network. In Table 12 below, we provide the NNCI totals, along with the average for the 16 sites, as well as the minimum and maximum values for the sites as an indication of the wide variation among the sites.

Table 12: Summary of NNCI Aggregate Usage Data (Year 4)

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users	13,355	835 (188 – 1,699)
Unique Internal Users	9,503	594 (138 – 1,477)
Unique External Users	3,852 28.8%	241 (50 – 672) 29.3% (13.1% – 47.3%)
External Academic	1,531	96 (10 – 494)
External Industry	1,961	123 (30 – 328)
External Government	251*	16 (0 – 162)
External Foreign	109	7 (0 – 29)
Average Monthly Users	5,292	331 (62 – 829)
New Users Trained	5,194	325 (62 – 700)
Facility Hours**	1,149,788	71,862 (6,398 – 204,221)
Facility Hours – External Users*	298,986 26.0%	18,687 (1,066 – 86,607) 25.6% (5.1% – 45.3%)
Hours/User**	86	78 (34 –143)
User Fees Internal Users External Users	 $23.2M $20.5M	 $1.45M $1.28M

*This category of users shows a large increase in Year 4 because the Stanford site began to categorize users from the SLAC National Lab as federal government users instead of internal users.

**Hours were collected as lab usage hours (time in the cleanroom), tool usage hours (when operated while not in the cleanroom), and tool usage hours for non-cleanroom tools. While we have conveyed this definition to the sites (see above), we have not made an attempt to standardize the data collected.

The data ranges presented above also need to be considered with some nuance and context as to the nature of the individual sites and their sometimes unique roles within NNCI. As has also been discussed previously, sites with large numbers of internal users and total users may have a lower external user percentage while still serving large external user populations.

A comparison of the network aggregate usage data for Years 1-4 is shown in Table 13 below. As can be seen, nearly all metrics show increases from Year 3 to Year 4, with double-digit percentage increases for most external user metrics. There was a significant increase in total external users (14% increase) combined with a small dip in internal users, perhaps indicating a plateau for this self-limited population (or a one-time anomaly due to the Stanford shift in users from internal to government). In addition, academic users increased in Year 4 faster than industry users, inverting the trend observed in Year 3. Facility hours continued its upward growth (11.5% annual increase) with a significant portion due to external usage and a reversal of the 3-year decreasing trend in hours/user to the highest observed during the NNCI program. The changes in internal and external users and usage hours over the first four years of NNCI are illustrated in Figures 10 and 11.

Table 13: Comparison of Years 1-4 NNCI Aggregate Usage Data

	Year 1	Year 2	Year 3	Year 4	Year 3-4 Change
Unique Facility Users	10,909	12,452	13,110	13,355	+1.9%
Unique Internal Users	8,342	9,276	9,731	9,503	-2.3%
Unique External Users	2,567 23.8%	3,176 25.5%	3,379 25.8%	3,852 28.8%	+14.0%
External Industry Users	1,413	1,669	1,870	1,961	+4.9%
External Academic Users	1,060	1,295	1,365	1,531	+12.2%
Average Monthly Users	4,429	4,911	5,001	5,292	+5.8%
New Users Trained	4,116	4,563	4,981	5,194	+4.3%
Facility Hours	909, 151	939,230	1,006,764	1,149,788	+11.5%
Facility Hours – External Users	173,511 19.1%	191,494 20.4%	228,441 22.7%	298,986 26.0%	+30.9%
Hours/User	83	75	77	86	+11.7%
User Fees Internal Users External Users	 $20.6M $13.5M	 $23.0M $14.5M	 $23.6M $16.9M	 $23.2M $20.5M	 -1.7% +21.3%

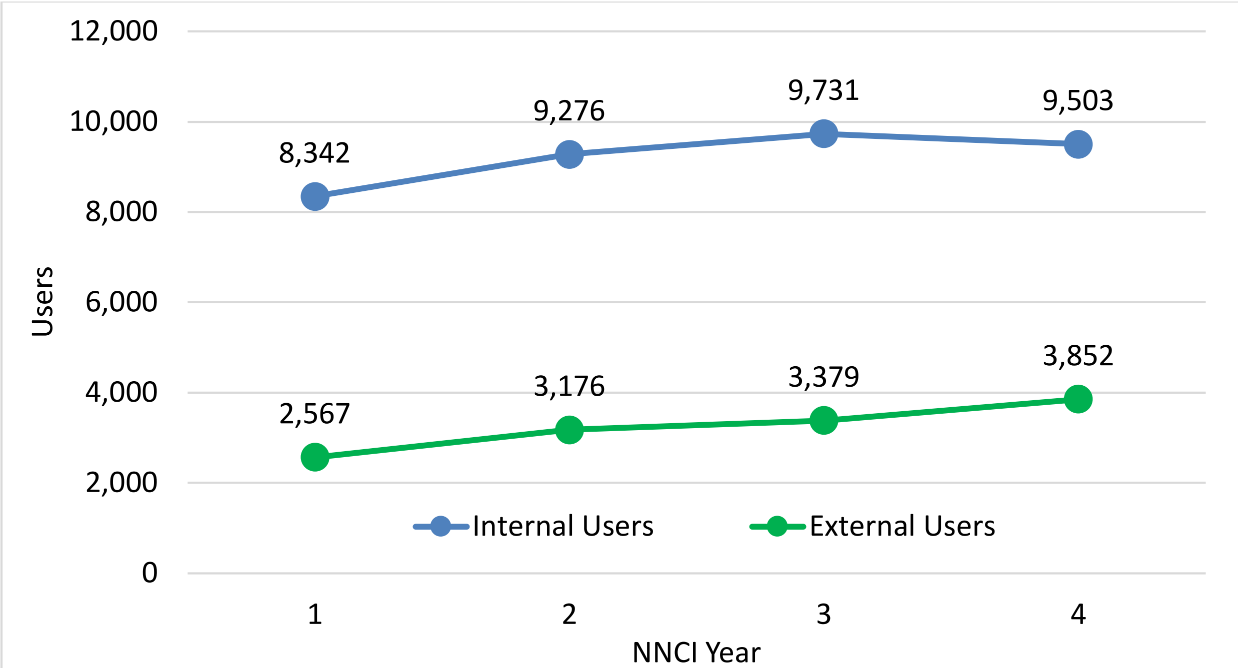


Figure 10: NNCI Users by Year

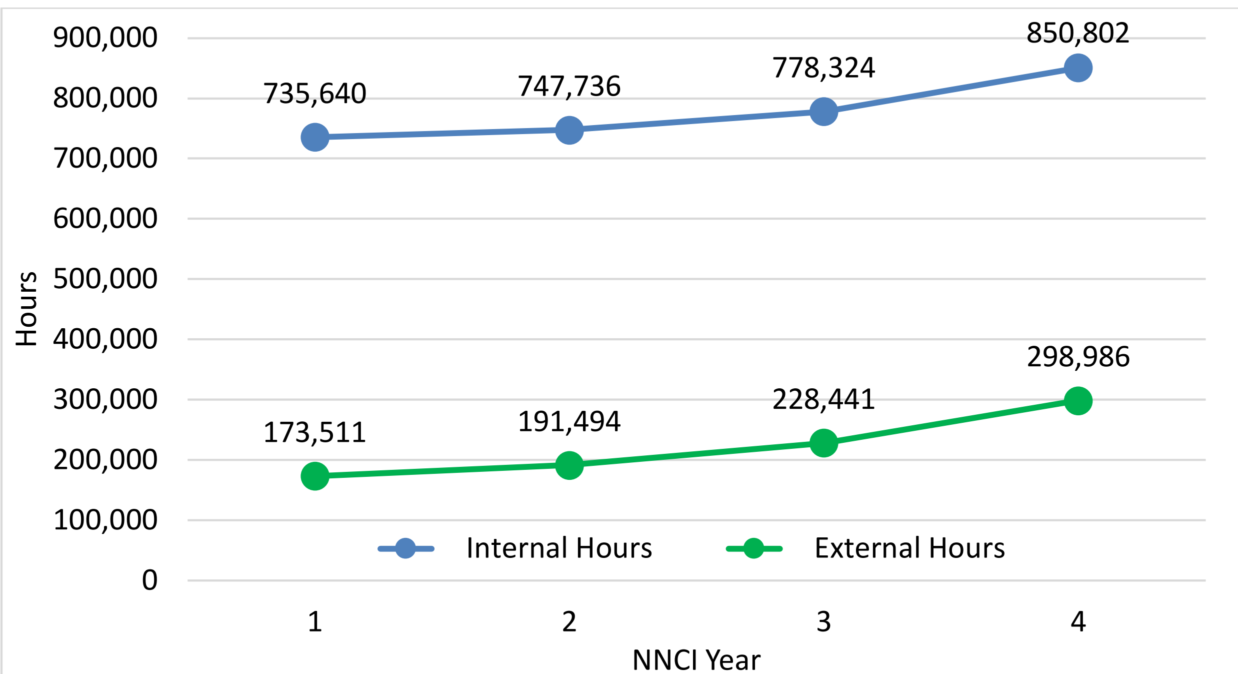


Figure 11: NNCI Usage Hours by Year

The nearly 3,900 Year 4 external users come from 1,207 distinct external institutions (full list shown in Appendix 13.2), including 247 academic institutions (Figure 12), 600 small companies, 234 large companies, 30 US local/federal government organizations, 67 international institutions (from Europe, Asia, South America, Africa, and Australia), and 28 other institutions (museums and non-profits, for example). This number does not include cases where an external institution (not necessarily the same PI or user) is working at multiple NNCI sites. It also does not include 128 institutions that remain anonymous due to contractual requirements with one of the NNCI sites and may or may not overlap with those listed in the appendix.

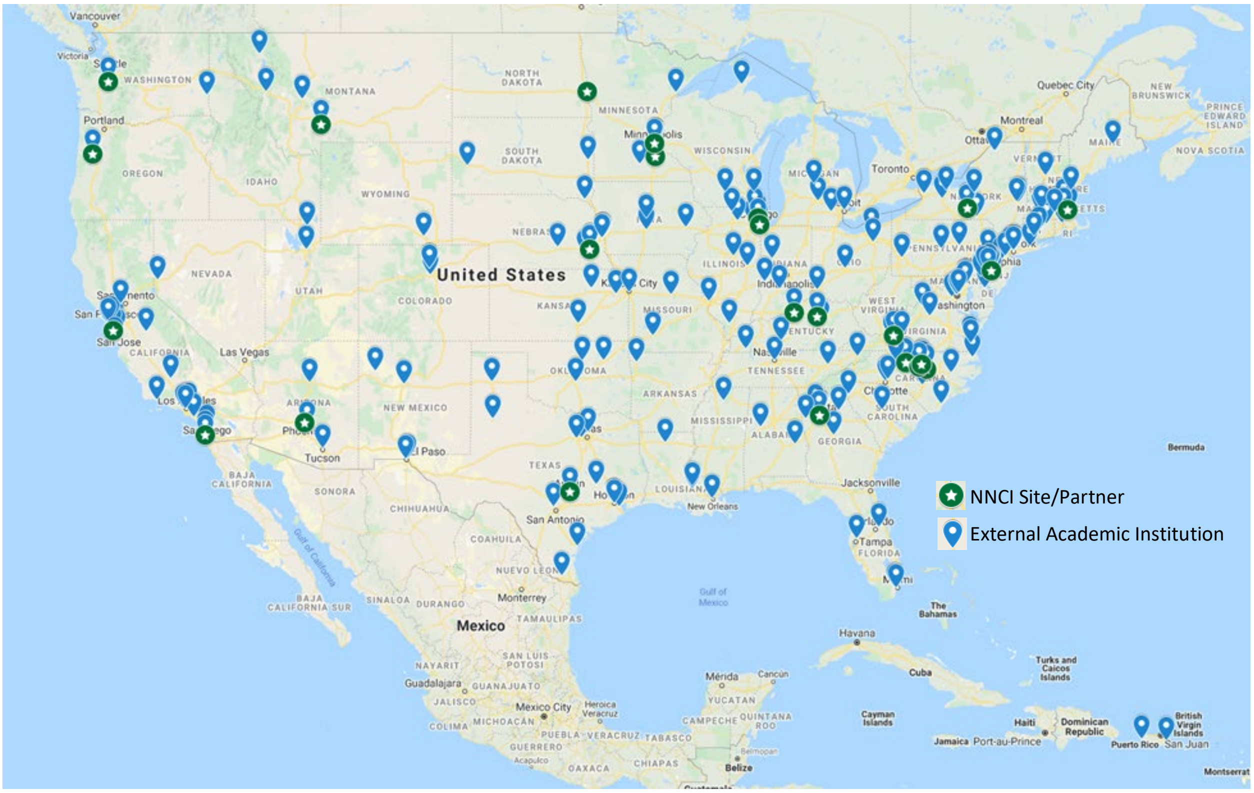
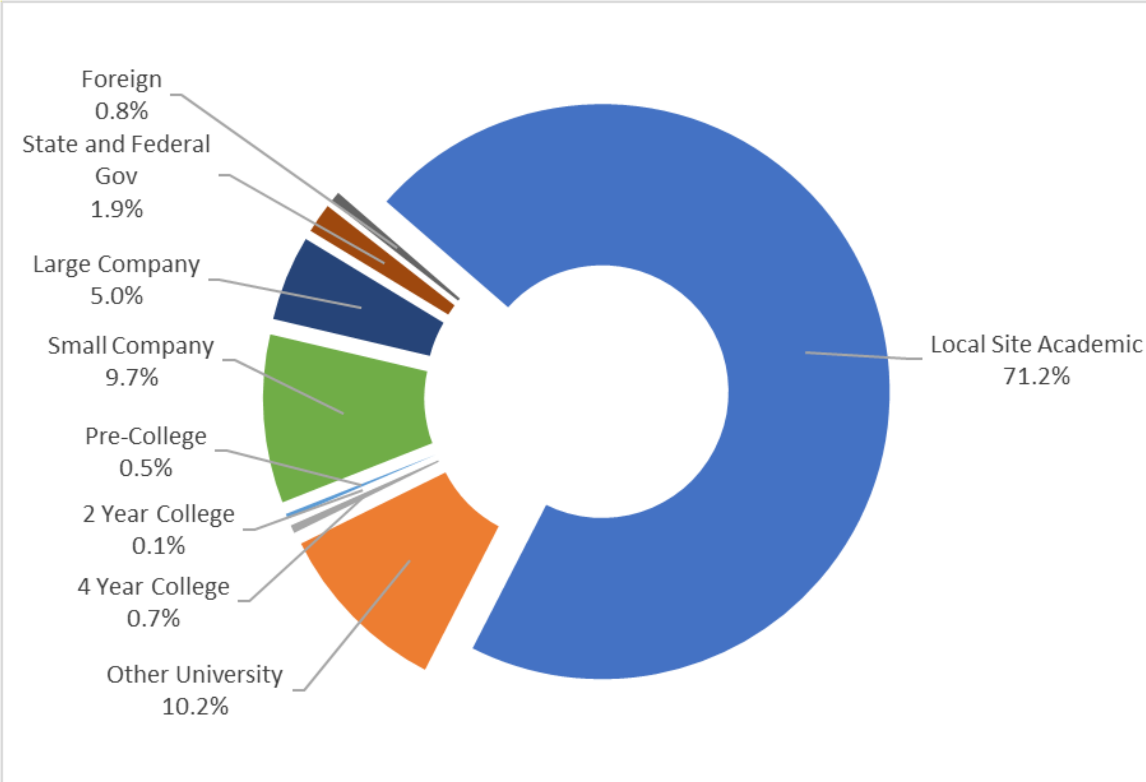


Figure 12: NNCI Year 4 Academic Institutions (247 External)

Figure 13 show the breakdown of users and lab hours by affiliation for the entire network. Individual affiliation plots are shown for each site in the data of Section 11 below. While external users make up 28.8% of total users, external hours are 26.0% of total hours. As noted in previous reports, this discrepancy is likely due to the proximity and ease of access of internal users to the facilities, which provides them opportunities for greater overall use, although the difference between percentage of external users and external hours is diminishing each year with nearly 31% increase in external user hours in Year 4 compared to Year 3.

A comparison of Year 4 cumulative users (by affiliation) by site is provided in Figure 14 for all users and Figure 15 for external users only. Care should be taken when analyzing these data and particularly when comparing different sites. The NNCI sites are diverse: some are located in "nanotechnology" hub areas, others are not; some serve a general NSE user base with a broad tool set, others have a particular research focus; some have been part of the NNIN program, others have not; some have a large number of tools and staff, others have not. Thus, it can be difficult to draw conclusions from a site-to-site statistical comparison.



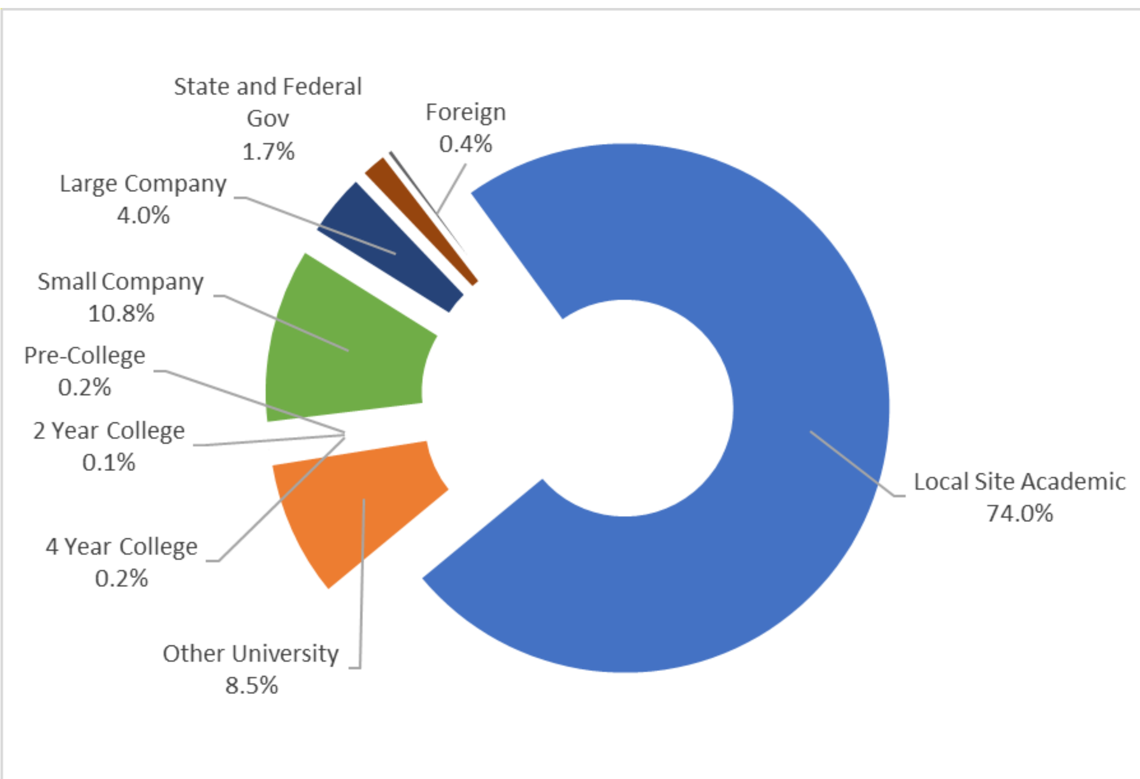


Figure 13: NNCI Users (top) and Usage Hours (bottom) by Affiliation (Year 4)

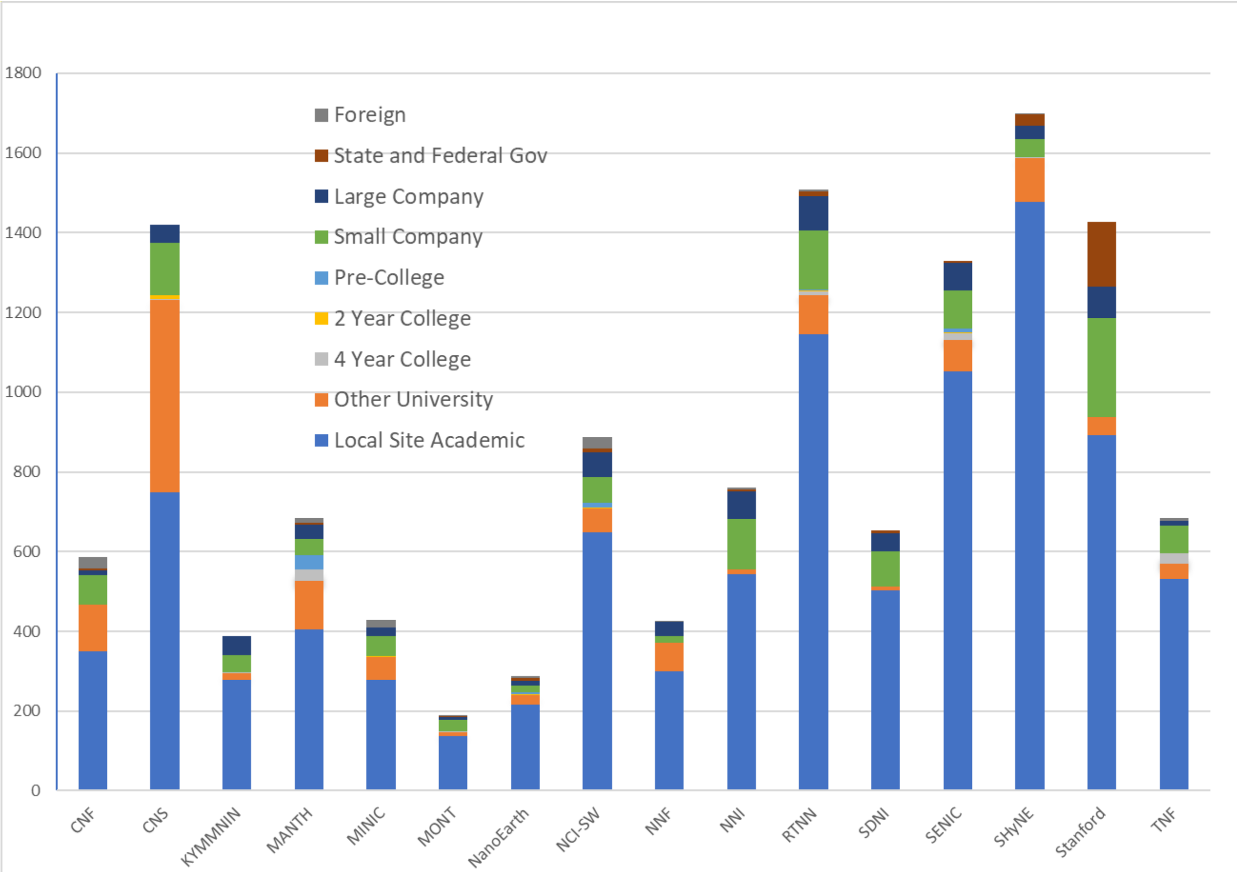


Figure 14: NNCI Cumulative Users by Site (Year 4)

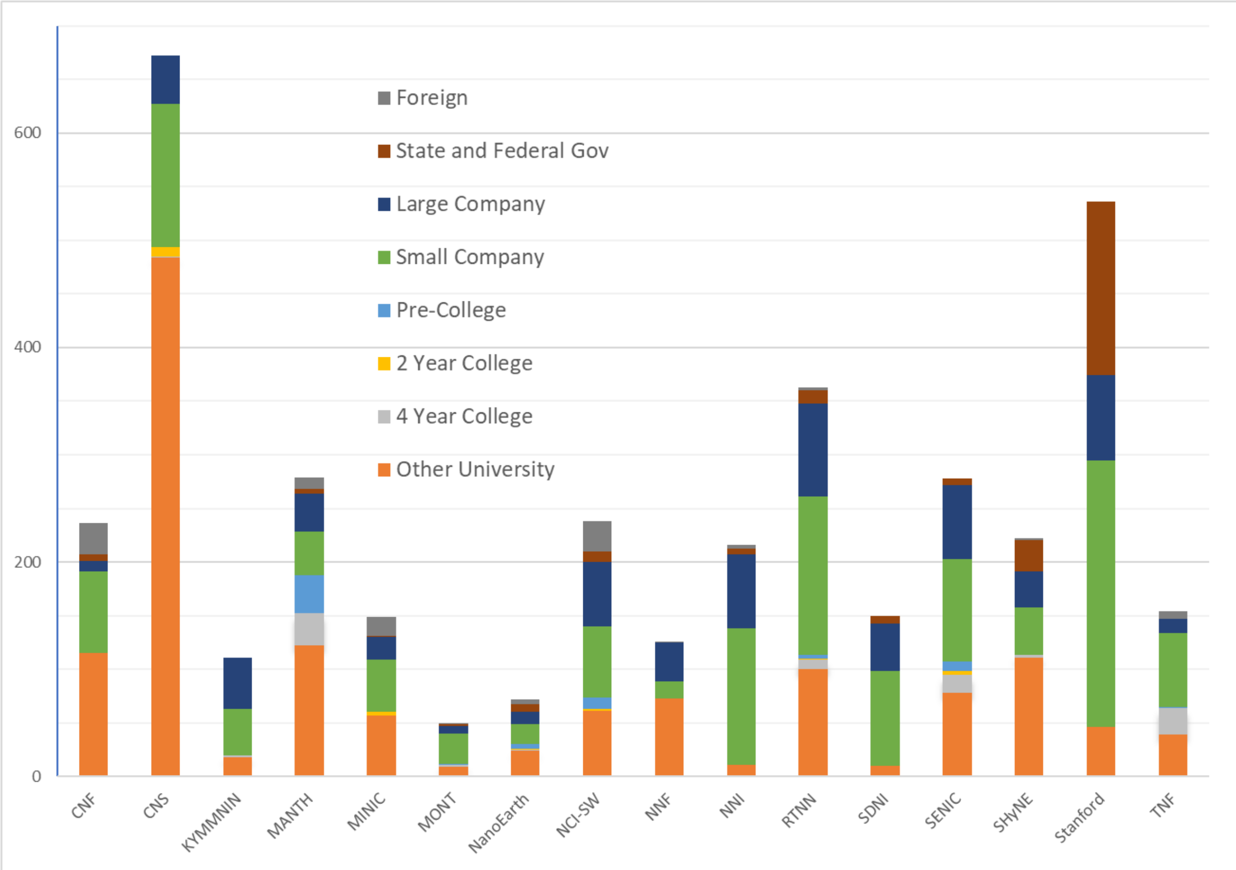


Figure 15: NNCI Cumulative External Users by Site (Year 4)

For academic institutions a network map showing the NNCI nodes and associated US colleges and universities (from 45 states and Puerto Rico) is shown in Figure 16 below. The size of the NNCI node (blue circle) is proportional to the number of unique academic entities it has as users. Universities with projects at three or more NNCI sites (22 in Year 1 and 35 in Year 4) are labeled in Figure 10, including one institution (Cornell) with projects at 6 different NNCI sites and 3 (MIT, Texas A&M, and Univ. South Carolina) with projects at 5 sites. Year 1 had 296 linkages between institutions, and this has increased each year reaching 395 in Year 4. In addition to the academic usage depicted by the figure, it was also observed that approximately 50 companies, government agencies, or foreign entities accessed facilities at multiple NNCI sites, although it cannot be determined if these resulted from the same or unique users or projects.

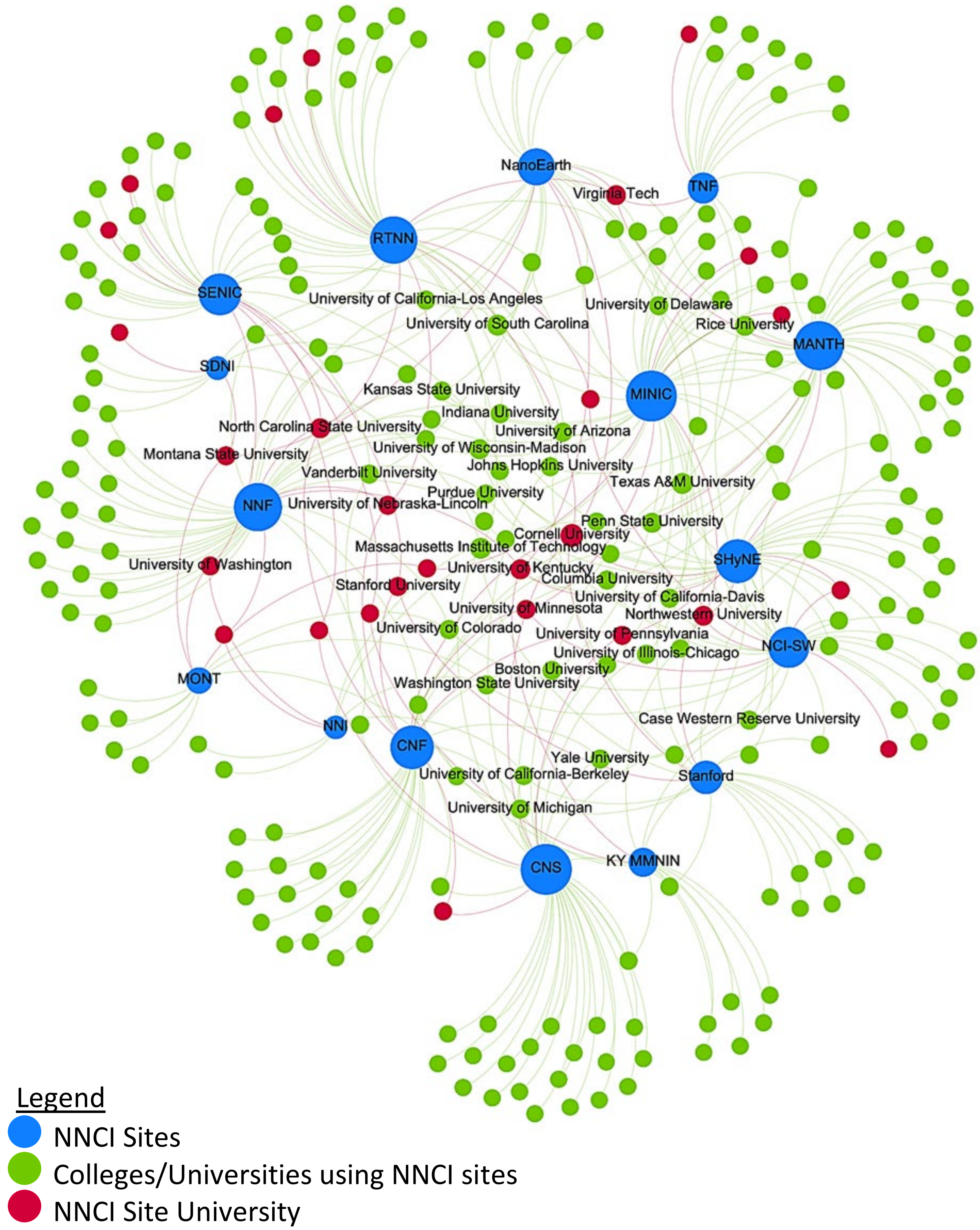


Figure 16: NNCI Academic User Network Map (Year 4)

10.2. Non-Traditional Users

One important, though difficult to define, metric is how well NNCI reaches and assists non-traditional users. In order to determine the best way to assess this aspect of NNCI activity, a breakout session on this topic was held at the 1st NNCI Annual Conference (January, 2017), and a summary of that discussion was included as part of the Year 1 NNCI Annual Report (March 2017).

The charts below illustrate the usage of the NNCI network by users in specific disciplines (internal and external). It is worth noting that in many cases these disciplines are self-selected, and may reflect the user's home department or their specific area of research, and these may be different from each other. Figure 17 illustrates the breakdown by number of users in specific disciplines, while Figure 18 illustrates the usage hours by discipline. Furthermore, Figure 19 illustrates the average number of hours/user across the network based on the user's discipline, illustrating that the fabrication-heavy disciplines of electronics, MEMS, optics, and physics tend to require more lab usage by researchers. These distributions are similar to previous years, continuing the rapid growth in Geology/Earth Sciences users (4.7% in Year 4 compared to 2.4% in Year 1) and usage hours (5.2% in Year 4 compared to 1.2% in Year 2), and this is also reflected in the hours/user for that discipline. The annual changes in number of users in each discipline are graphically displayed in Figure 20 (with "Educational Lab Use", "Process", and "Other" removed for clarity).

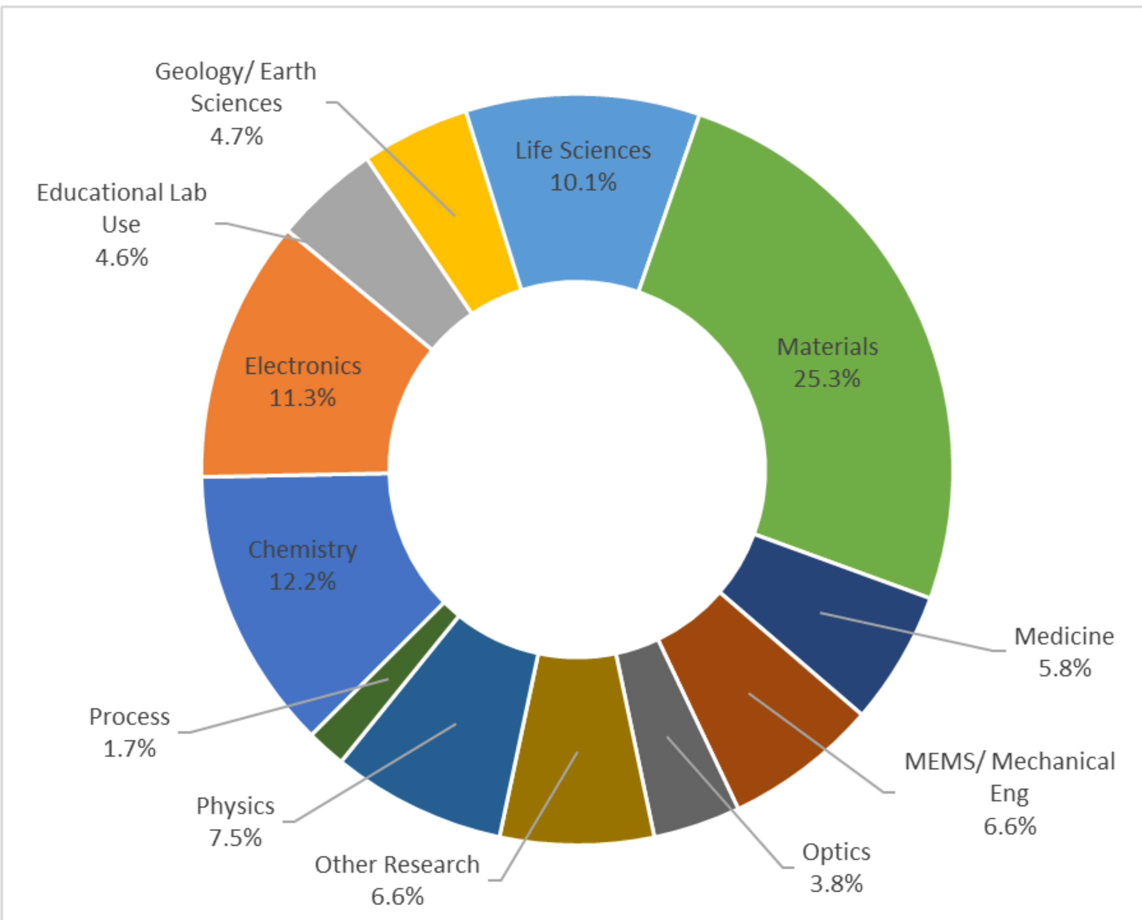


Figure 17: NNCI Users by Discipline (Year 4)

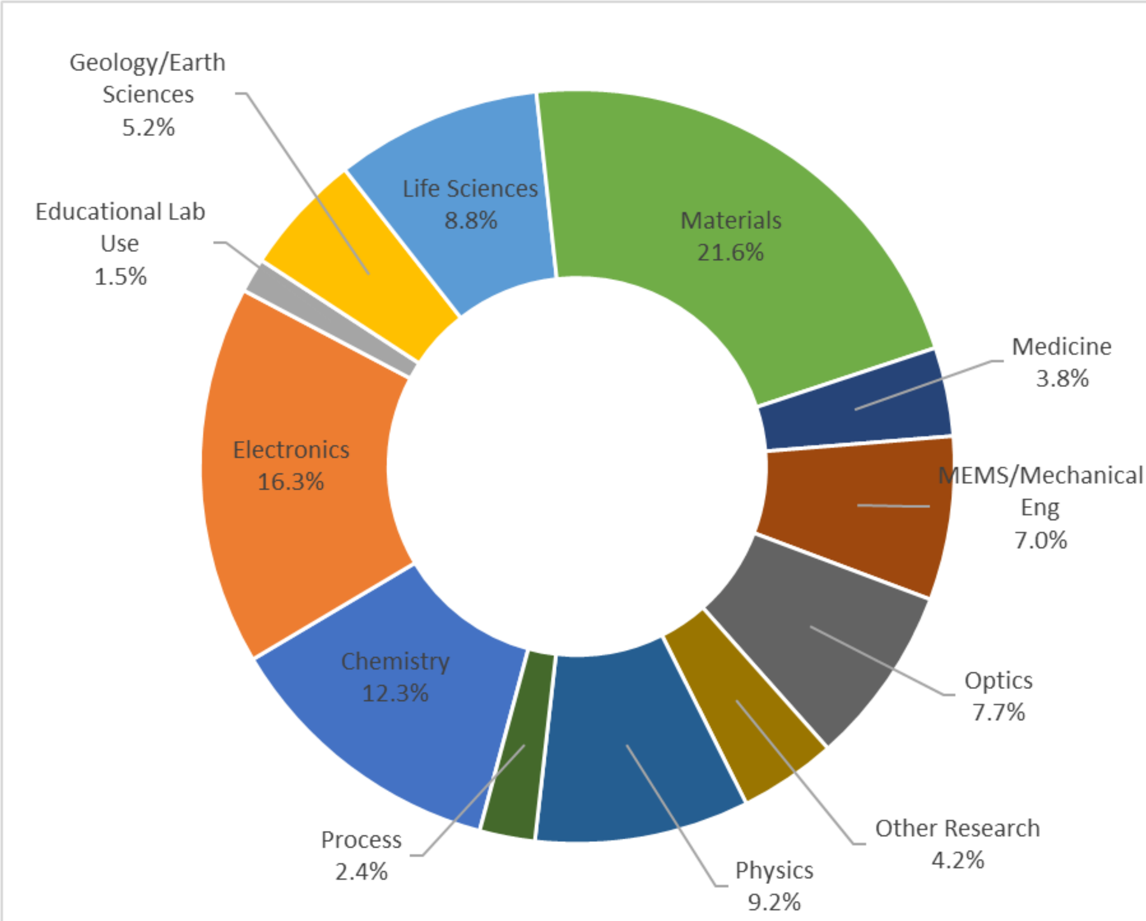


Figure 18: NNCI Usage Hours by Discipline (Year 4)

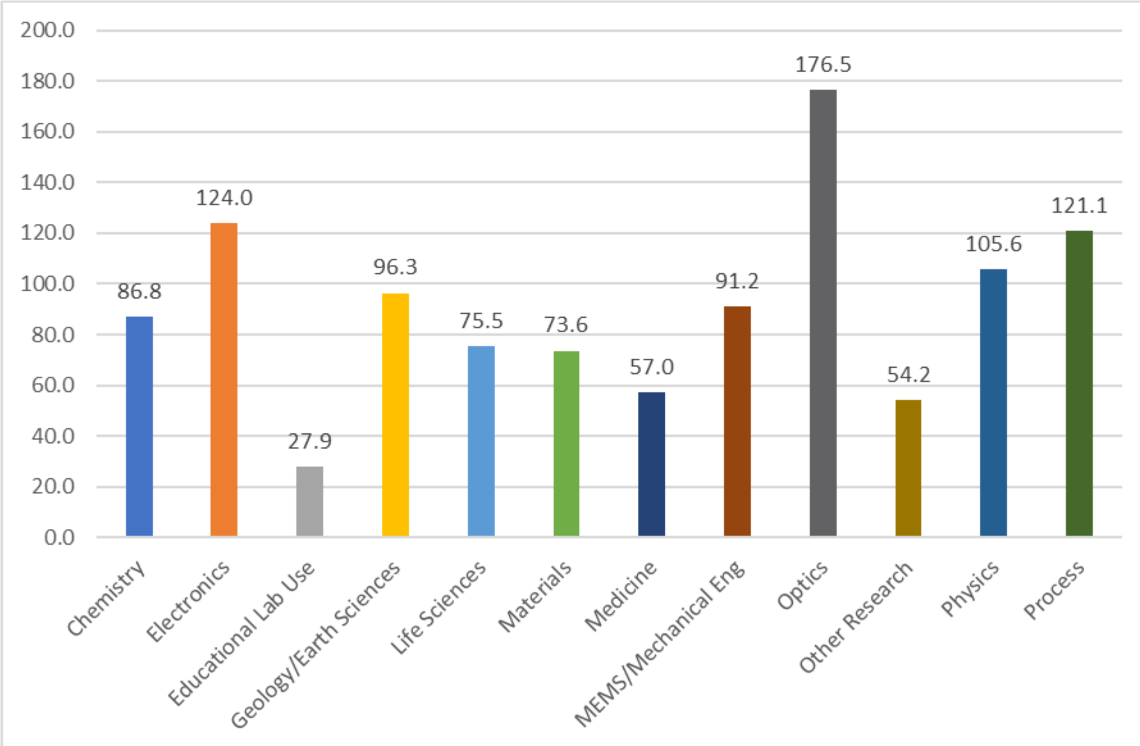


Figure 19: NNCI Hours/User by Discipline (Year 4)

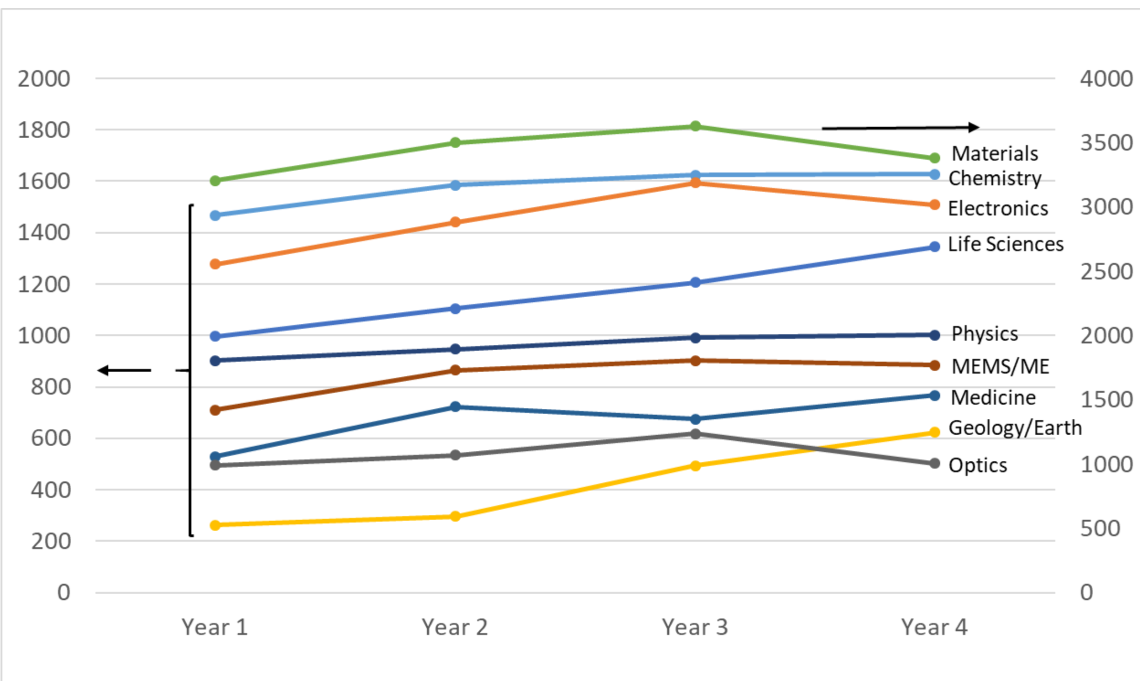


Figure 20: NNCI Yearly Users by Discipline ("Materials" indicated by the right Y-axis for improved clarity.)

Beginning with the Year 1 annual report, and as a matter of convenience, we have defined "traditional" disciplines to include the engineering-related electronics, materials, MEMS, and process development disciplines, whereas "non-traditional" contains everything else (Educational Lab Use is excluded in this tabulation). Table 14 below compares the relative usage breakdown by number of users and hours for each year of NNCI. Using the above definition, the number of users was split evenly between traditional and non-traditional during the first three years, with a measurable shift in the usage hours from traditional to non-traditional during that same time period. However, during Year 4 usage by non-traditional users has increased significantly so that is now the dominant population of users.

Table 14: Usage by Traditional and Non-Traditional Disciplines

	Year 1	Year 2	Year 3	Year 4
# of Users				
Traditional*	5386 (51%)	6063 (50%)	6384 (50%)	5997 (47%)
Non-Traditional**	5262 (49%)	6044 (50%)	6383 (50%)	6750 (53%)
Hours of Usage				
Traditional*	495,215 (55%)	506,393 (54%)	510,180 (51%)	543,838 (48%)
Non-Traditional**	409,935 (45%)	424,855 (46%)	490,992 (49%)	588,980 (52%)

* Electronics, Materials, MEMS/ME, Process

** Chemistry, Physics, Optics, Medicine, Life Sciences, Geo/Earth Sciences, Other

Another measure of non-traditional usage within NNCI is to examine the diversity of users home academic institutions, particularly those that serve under-represented minority populations as defined by the US Dept. of Education.

- As constituted, NNCI sites contain one *Historically Black College and University* (HBCU), North Carolina A&T State Univ. (SENIC), and one *Primarily Black Institution* (PBI), Community College of Philadelphia (MANTH).
- Four other primary sites are recognized as *Emerging Hispanic Serving Institutions* (EHSI, 15+% Hispanic undergraduate students): Univ. Texas-Austin (TNF), Arizona State Univ. (NCI-SW), Univ. California-San Diego (SDNI), and Stanford (nano@stanford).
- During Year 4, external academic users came from 15 *Hispanic Serving Institutions* (HSI, 25+% Hispanic undergraduate students), 20 EHSI, 11 HBCU, 15 *Asian-American and Native American Pacific Islander* institutions (AANAPI), and 1 *Tribal College and Universities* (TCU). Thus, 62 of the 247 (25%) US academic institutions using NNCI facilities serve under-represented populations.
- Examples of these institutions are: Cañada College, Florida International Univ., Hampton Univ., Howard Univ., Morehouse College, Navajo Technical Univ., Tuskegee Univ., and University of Puerto Rico.

More generally, the fraction of users from non-research academic institutions (4-year colleges, 2-year colleges, and pre-college) has remained steady through the first four years of NNCI at approximately 1% of all users.

10.3. Publications Information

The publications data shown below (Table 15) was collected by sites for the calendar year 2018. Due to the difficulty in getting compliance from users for this requested information, this should only be considered a lower limit of the actual publications data. In addition, no attempt was made to remove duplicates, where authors might have been from multiple NNCI sites. This represents a nearly 3% increase in total publications compared to Year 3 (2017 publications) and nearly 6% in peer-reviewed Papers (internal and external). Publications reported by each site range from 96 to 753. In addition, due to extra efforts in improving compliance among users and PIs to properly acknowledge NNCI and NSF in publications using the appropriate grant numbers, Figure 21 below shows a significant improvement in this metric.

Table 15: NNCI 2018 Publications

Publication Type (CY 2018)	
Internal User (Site) Papers	2775
External User Papers	357
Internal User Conference Presentations	1160
External User Conference Presentations	124
Books/Book Chapters	41
Patents/Applications/Invention Disclosures	563
Total	**5020**

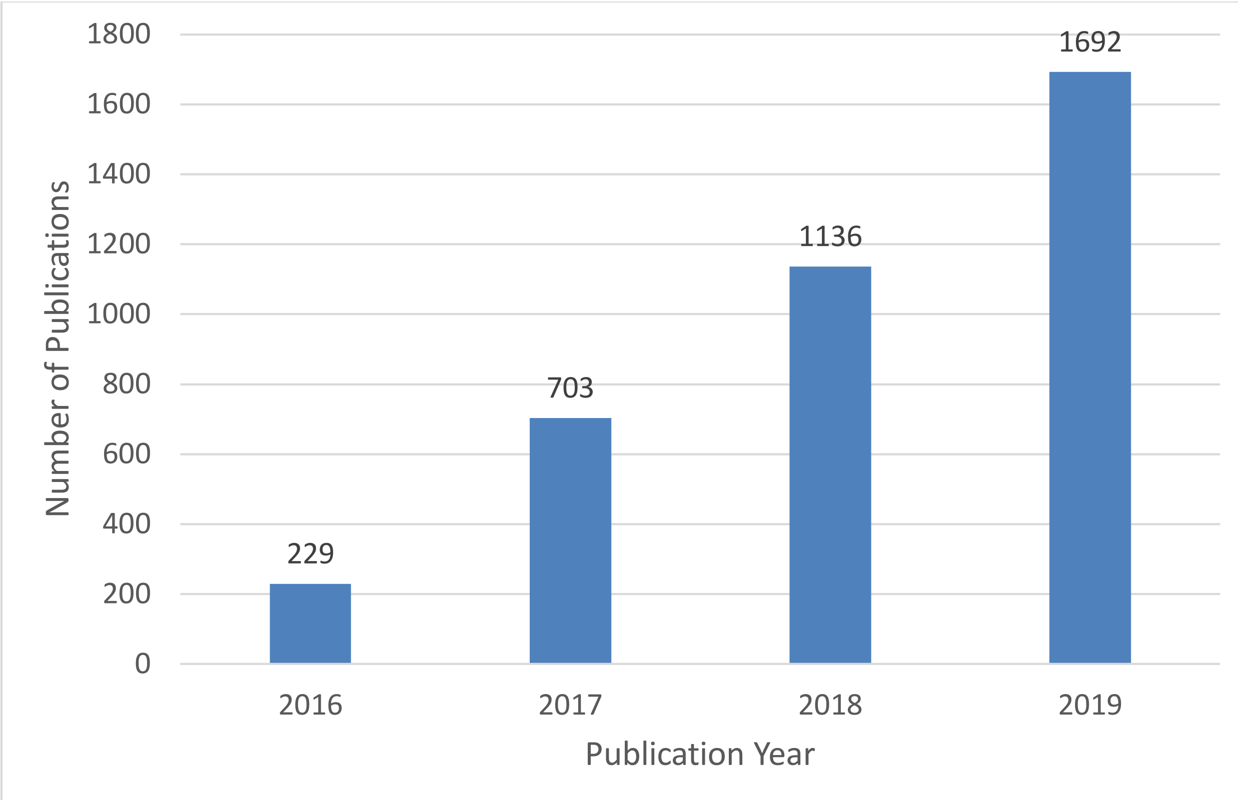


Figure 21: Number of Publications with NSF NNCI Award Numbers based on Google Scholar (NNCI-Award # <u>or</u> ECCS-Award #)

11. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 3 report. Specific information requested included:

1. A brief narrative corresponding to the NNCI Year 4 (Oct. 1, 2018 - Sept. 30, 2019).
    a. Facilities, tools, staff updates during the year
    b. User base – marketing, outreach and support activities, including any specific research strengths or focus of the site
    c. Research highlights and impact – include brief mentions of any significant user accomplishments as well as scholarly and economic impact. Note: Research and education highlight slides are provided as a separate document.
    d. Education and outreach activities summary
    e. Societal and ethical implications activities (if applicable)
    f. Computation activities (if applicable)
2. A listing of all external user institutions for NNCI Year 4, separated as follows: Academic, Small company (<500 employees), Large company, Government, International, Other. See Appendix 13.2 for the complete listing. Due to disclosure limitations, some external users asked that their information not be shared, and the number of these are indicated in the appendix.
3. The number of publications in each category for calendar year 2018. The list of publications may have been part of each site's Year 4 report to NSF, but the data presented here (Section 10.3 above) are only aggregate numbers of publications for the NNCI network.
4. A list of site-site or network-wide activity, including proposals, facility operations, education/SEI programs, staff interactions, or other events. This is provided in Section 9 above.

In addition, the user statistics for NNCI Year 4 (Oct. 2018-Sept. 2019) were collected from the sites and used by the Coordinating Office to generate both the aggregate network user activity described in Sections 10.1 and 10.2 above, as well as the individual site usage information shown after each site narrative below.

The reports below are presented as provided by the sites, with only minor editing for format.

11.1. Center for Nanoscale Systems (CNS)

Facility, Tools, and Staff Updates

This has been a very productive fourth year for the Center for Nanoscale Systems. Pi Westervelt and co-PI Wilson, the operational director of the center, have been continuing the assessment, revamping, and augmentation of the tools and instrumentation available at CNS for advancing Nano and Quantum science.

This year we have not added new permanent staff; but have expanded our instrumental research capabilities. We have expanded the capabilities available to the user base, both in the nanofab and the other core instrumentation focused areas of the lab. The new tools and instrumentation include: **Imaging and Analysis:** Leicia Nonlinear Confocal Microscopy System (FLIM); Hitachi 7800 120kV TEM; JEOL 7900 Analytical SEM; new VitraBot Cryoplunge System; **Nanofabrication:** Oxford PECVD System; Allwin RTP furnace; PVD E-beam evaporator; Film-Sense Wafer scan ellipsometer. Moreover we are installing an Elionix High-Speed E-beam Lithography tool this winter to add bandwidth and allow production of large area structures. These listed new tools expand our analysis and processing capabilities for a wide variety of advanced materials. Importantly several of these tools were leased adding flexibility to our tool evolution process. **High-end Instrumentation:** We have also taken the delivery of the ***"Harvard Quantum Imager"***, an Hitachi 300 keV aberration-corrected electron microscope, which has an ultra-high resolution energy filter and the capability of imaging magnetic materials with atomic-resolution. This system was funded internally by the University and will be open for community use in early February 2020. We were also awarded an NIH Shared Instrumentation Grant for the purchase of a high-resolution microCT system, the Zeiss Xradia 620 Versa, which was delivered last summer. The system is operational and already in use. Finally, we have also commissioned the building of a Low Energy Electron Microscope (LEEM) system, funded with NSF MRI support which will be delivered early next year. **Staffing:** We have lost two staff members this year: a scan-probe spectroscopist was offered a faculty appointment in Europe and an optical lithographer whose husband accepted a faculty position at UCLA. One position has already been replaced, while the other is a current open search.

User Base

CNS this year began an outreach to increase the usage by start-ups via direct interaction and partnership with technology incubators in the Cambridge area. This effort has more than doubled the usage by start-ups this fiscal year. PI Westervelt and co-PI Wilson have also continued cultivating a cooperative, synergetic relationship with the STC for Integrated Quantum Materials and beyond. For example, CNS co-organized a *Quantum Engineering Symposium* at NanoTech 2019. The symposium highlighted NNCI-supported work in Quantum Optics and Quantum information systems. We have expanded and enlisted several new participants in the CNS scholars' program. This activity is focused on giving young researchers access to CNS expertise and instrumentation, particularly researchers from underrepresented groups and from minority serving institutions. The new participants were mostly from Howard University, Smith College, and others. In addition, we have supported a few new international academic users. All these users are engaged in activities in quantum engineering and translational bioscience. We have continued our partnership with Harvard Catalyst, a federally sponsored translational biosciences initiative to train non-traditional life science researchers in an array of techniques available at CNS. Their funding is designed to support the innovative application of light and electron microscopy, nanoscale fabrication, and nanoscale analysis technologies for big ideas that will advance clinical healthcare. Again, as last year, these projects have helped greatly increase the number of *"non-traditional"* users at CNS particularly in the life sciences and in several new emerging biomedical areas.

Research Highlights and Impact

Below are titles of some of the ongoing research prevalent in the Center which is highlighted. We have selected engaging work representing a wide cross-section of the work focused within the NSF's 10 Big Ideas.

Quantum Leap Technologies: Quantum Engineering: ***Photon-mediated interactions between quantum emitters in a diamond nanocavity.; R.E. Evans, R. E.; Bhaskar, M. K.; Sukachev, D. D.; Nguyen, C. T.; Sipahigil, A.; Burek, M. J.; Machielse, B.; Zhang, G. H.; Zibrov, A. S.; Bielejec, E.; Park, H.; Loncar, M.; Lukin, M. D.;*** Department of Physics, Harvard University, Institute for Quantum Information and Matter and Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology, John A. Paulson School of Engineering and Applied Sciences, Harvard University, Sandia National Laboratories, Department of Chemistry and Chemical Biology, Harvard University; Photon-mediated interactions between quantum systems are essential for realizing quantum networks and scalable quantum information processing. The Loncar and Lukin groups have demonstrated such interactions between pairs of silicon-vacancy (SiV) color centers coupled to a diamond nanophotonic cavity. When the optical transitions of the two-color centers are tuned into resonance, the coupling to the common cavity mode results in a coherent interaction between them, leading to spectrally resolved superradiant and subradiant states. They use the electronic spin degrees of freedom of the SiV centers to control these optically mediated interactions. Such controlled interactions will be crucial in developing cavity-mediated quantum gates between spin qubits and for realizing scalable quantum network nodes. (*Reference: Science **362**, 662-665, 2018*);

NanoPhotonics/ Integrated Optics based Photonic Circuits: ***Broadband electro-optic frequency comb generation in a lithium niobate microring resonator; Mian Zhang, Brandon Buscaino, Cheng Wang, Amirhassan Shams-Ansari, Christian Reimer, Rongrong Zhu, Joseph M. Kajn, and Marko Loncar;*** John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA; HyperLight Corporation, Cambridge, MA, USA; Edward L. Ginzton Laboratory, Department of Electrical Engineering, Stanford University, Stanford, CA, USA; Department of Electronic Engineering and State Key Laboratory of Terahertz and Millimeter Waves, City University of Hong Kong, Hong Kong, China; Department of Electrical Engineering and Computer Science, Howard University, Washington, DC, USA; The Electromagnetics Academy at Zhejiang University, College of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China; Optical frequency combs consist of equally spaced discrete optical frequency components and are essential tools for optical communication, precision metrology, timing and spectroscopy. Here the Loncar team has realized an integrated EO comb generator in a thin-film lithium niobate photonic platform that features a large EO response, ultralow optical loss and highly co-localized microwave and optical fields, while enabling dispersion engineering. Their measured EO comb spans more frequencies than the entire telecommunications L-band (over 900 comb lines spaced about 10 gigahertz apart), and they show that future dispersion engineering can enable octave-spanning combs. Furthermore, they demonstrate the high tolerance of our comb generator to modulation frequency detuning, with frequency spacing finely controllable over seven orders of magnitude (10 hertz to 100 megahertz), and they use this feature to generate dual-frequency combs in a single resonator. Their results show that integrated EO comb generators are capable of generating wide and stable comb spectra. Their excellent reconfigurability is a powerful complement to integrated Kerr combs, enabling applications ranging from spectroscopy to optical communications. *(Reference Nature Volume:568 Issue:7752, Pg373 April 18, 2019)*

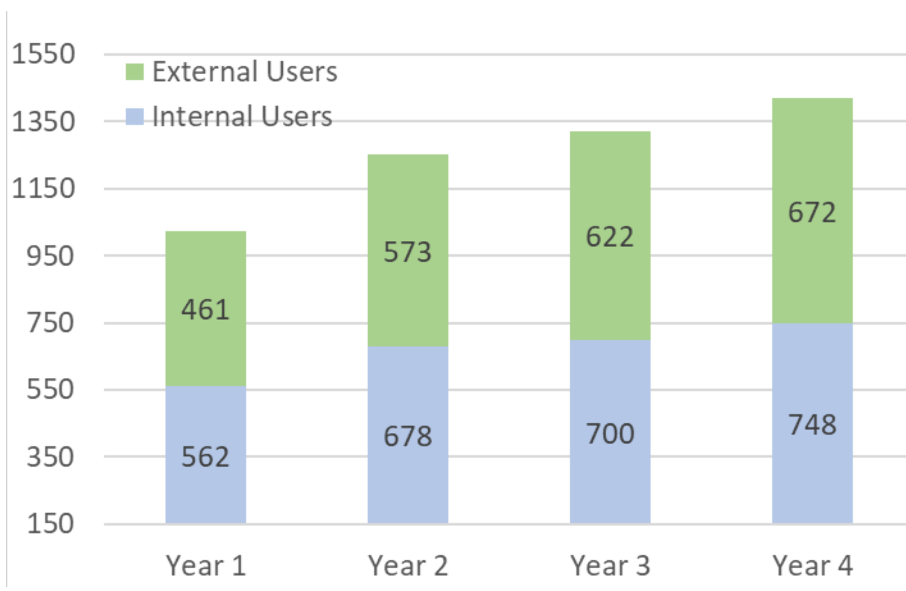
Understanding the Rules of Life: Neuroscience/Electrophysiology: ***A nanoelectrode array for obtaining intracellular recordings from thousands of connected neurons:*** **Jeffrey Abbott, Tianyang Ye, Keith Krenek, Rona S. Gertner, Steven Ban, Youbin Kim, Ling Qin, Wenxuan Wu, Hongkun Park, and Donhee Ham.** John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA; Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA, USA; Department of Physics, Harvard University, Cambridge, MA, USA; Current electrophysiological or optical techniques cannot reliably perform simultaneous intracellular recordings from more than a few tens of neurons. The Ham group developed a nanoelectrode array that can simultaneously obtain intracellular recordings from thousands of connected mammalian neurons in vitro. The array consists of 4,096 platinum-black electrodes with nanoscale roughness fabricated on top of a silicon chip that monolithically integrates 4,096 microscale amplifiers, configurable into pseudocurrent-clamp mode (for concurrent current injection and voltage recording) or into pseudovoltage-clamp mode (for concurrent voltage application and current recording). We used the array in pseudovoltage-clamp mode to measure the effects of drugs on ion-channel currents. In pseudocurrent-clamp mode, the array intracellularly recorded action potentials and postsynaptic potentials from thousands of neurons. The team mapped over 300 excitatory and inhibitory synaptic connections from more than 1,700 neurons that were intracellularly recorded for 19 min. This high-throughput intracellular-recording technology could benefit functional connectome mapping, electrophysiological screening and other functional interrogations of neuronal networks. *(Reference Nature Biomed Eng 23 September 2019, doi:10.1038/s41551-019-0455-7)*

Education and Outreach Activities

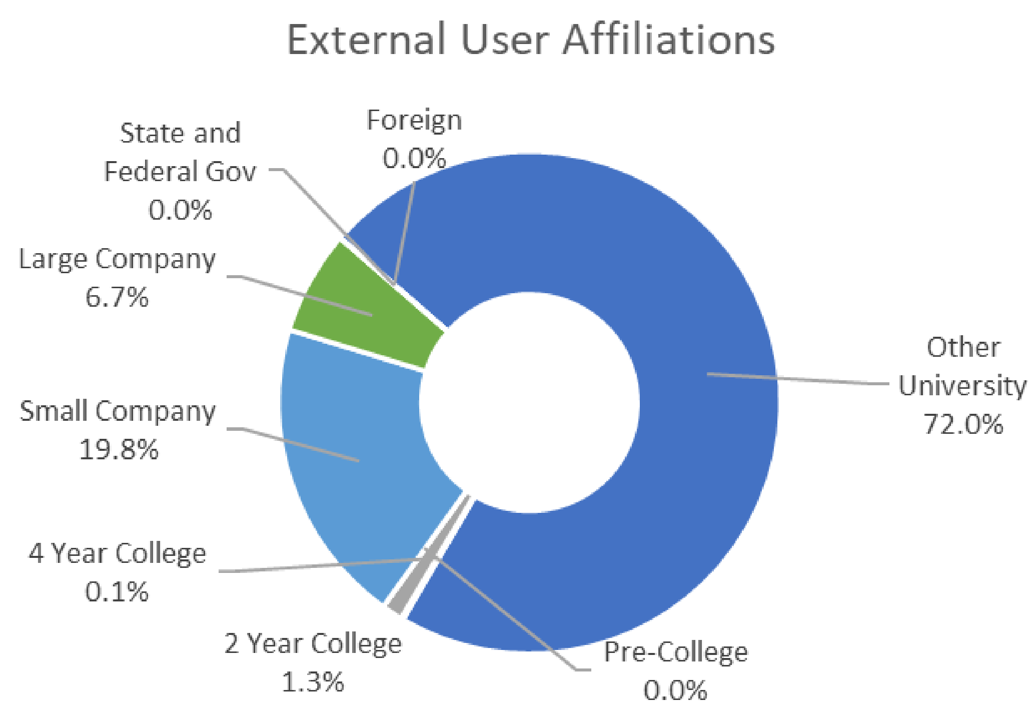
This year's REU and REV students were again chosen using a joint Harvard website hosting potential research projects campus wide. PI Westervelt and co-PI Wilson again used the STC college network and several other vehicles to ensure a diverse candidate pool. PI Wilson again recruited both at the NSBE and CARRMS meetings, events geared toward STEM development in the African-American community. We also continued our recruiting activities at the National Society of Black Physicists (NSBP) annual meeting. We as noted selected 3 Research Experience for Veterans (REV) interns, two of which are being supported doing continued work in the current academic year. Most of these students were selected from a pool at BunkerHill Community College. BHCC has a very vibrant STEM focused directed at VETs. As part of our traditional REU program, this year we again solicited summer research projects from the entire CNS user base, (both internal and external). The goal, to foster new strong interactions between staff and research groups. As noted we continued an outreach which has resulted in a substantial increase in usage from local start-ups. We also held a start-up "Boot Camp" this past spring as a vehicle to teach the userbase the promise and pitfall of Start-ups. The goal being to bring together Entrepreneurs, Incubator and Venture Capital folks, IP folks, students and post-docs to allow an open dialog on creation of start-ups. The focus was to demystify the process and educate our userbase on strategies and pitfalls when starting a technology business. This event was open to the entire NNCI network.

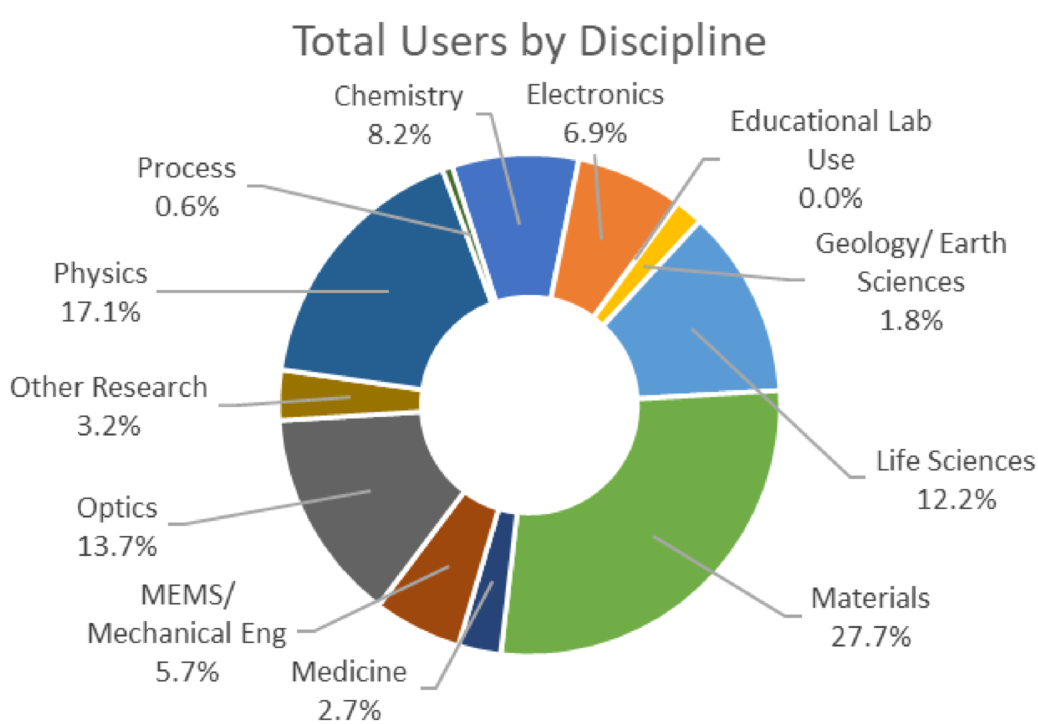
CNS Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	1,023	1,251	1,322	1,420
Internal Cumulative Users	562	678	700	748
External Cumulative Users	461 (45%)	573 (46%)	622 (47%)	672 (47%)
Total Hours	174,710	181,826	185,288	204,221
Internal Hours	124,256	133,020	126,662	117,615
External Hours	50,454 (29%)	48,806 (27%)	58,626 (32%)	86,607 (42%)
Average Monthly Users	511	514	538	565
Average External Monthly Users	201 (39%)	196 (38%)	218 (40%)	250 (44%)
New Users Trained	415	404	452	483
New External Users Trained	196 (47%)	200 (50%)	233 (52%)	240 (50%)
Hours/User (Internal)	221	196	181	157
Hours/User (External)	109	85	94	129



CNS Year 4 User Distribution





11.2. Cornell Nanoscale Science and Technology Facility (CNF)

Facility, Tools, and Staff Updates

CNF serves as a nanofabrication-focused open resource to scientists and engineers with emphasis on providing complex integration capabilities. This is made possible by an expertly-staffed user program providing rapid, affordable, hands-on 24/7 open access to advanced nanofabrication tools.

The following tools, processes, facilities and software have been acquired or developed over the past year.

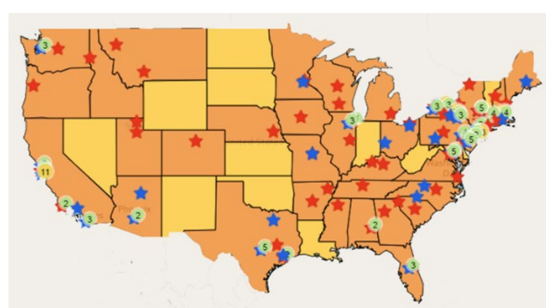
New Tools	New Processes/Software
Keithley 4200A-SCS Semiconductor Parameter Analyzer (installed)	High aspect ratio (HAR) Si nanowires
AJA Orion 8 load locked sputter deposition (installed)	Software utilities for advanced electron beam lithography
Xallent Nanoprobe (installed)	Si etch with no notching, bowing, microtrench and no RIE-lag
New CEE Spin Coat Systems (installed)	Artifact-free SiC inductively coupled plasma etch
Finetech-Flipchip Bonder (installed)	TaN and TiN as well as GaN deep etch,
Nanoscribe Photonic Professional GT2 3D Laser Lithography System (Received award from NSF, MRI program) (delivered and being installed)	HAR etching with hybrid thermal nanoimprint lithography (T-NIL) template
C&D Semiconductor Lift off tool (ordered)	Complete Piezoelectric aluminum nitride process
	Coventor SEMulator (process simulation software),
	JetStream (pattern preparation software)

During this year, Don Tennant, CNF Director of Operations for 14 years, retired. In August 2019 he was replaced by Ron Olson, a former CNF user, who comes to CNF from a long management career at GE Research.

User Base

The CNF user base is distributed widely across nanotechnology areas, with particular concentration in the Life Sciences areas. As part of its strategic plan, CNF has highlighted several areas as Strategic Initiatives over the next decade. These include

- **Heterointegration**
- **Quantum Materials and Devices**
- **2D Materials**
- **Life Sciences**



CNF user geographical distribution. Red=universities, blue=companies

CNF has also recently started an AI in the CleanRoom initiative to use machine learning to improved process control.

After an extensive development process, CNF launched a new, greatly updated website in September 2019 (www.cnf.cornell.edu). As part of that effort, we also introduced a new introductory video featuring testimonials from selected CNF users, and this is also available on the CNF web site.

Research Highlights and Impact

Research reports are provided annually for many projects and are published as "CNF Research Accomplishments" and online at:

https://cnf.cornell.edu/publications/research_accomplishments/2019

Highlights of selected projects are provided separately.

CNF continues to serve as an engine for economic development for small businesses. We supported projects from 67 companies this past year and in the last 4 years, CNF has averaged 2.5 new startup company launches per year; these include Xallent, Esper Biosciences, FloraPulse, Ultramend, Jan BioTech, Heat Inverse, JR2J, White Light Power, Odyssey Semiconductor, GeeGah and Xallent. The CNF has also been an effective resource for the commercialization of nanotechnology. The 169 different companies that have used the CNF during the past decade include 34 startups that have started at CNF and at least 45 other small startup companies and 90 established companies have utilized CNF for major research and development/prototyping.

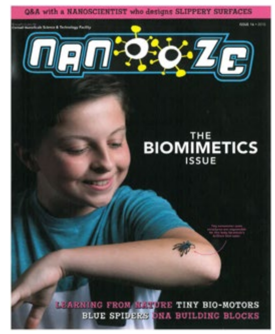
Education and Outreach Activities

CNF continues to actively participate in numerous educational outreach activities, hosting over 150 visits, special events, educational tours and workshops at Cornell and in the greater community. The CNF staff met with over 3000 people including prospective graduate students, middle-school students, new faculty, visiting dignitaries and corporate executives. Major community outreach events include the 4H Career Explorations event in June and the Jr. FIRST LEGO League expo in January. CNF's renovated "demonstration room" allows us to host small groups of students with live demonstrations of nanotechnology concepts. This, coupled with FaceTime tours of the clean room, provide a great experience for visiting school groups.

Research Experience for Undergraduates (REU): CNF was honored to host the network-wide National Nanotechnology Coordinated Infrastructure (NNCI) 2019 REU Convocation for 72 interns. CNF has a demonstrated history of support for undergraduate research initiatives, hosting a Research Experience for Undergraduates program for over 20 years and sponsoring the International Research Experiences for Undergraduates since 2008.

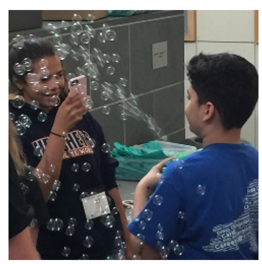
The CNF REU Program accepts undergraduate students from across the United States, exposing them to a state-of-the-art facility and world class Cornell faculty and staff. In addition to five CNF REU students, work was done in collaboration with the Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials (PARADIM) REU Program and their six interns. Over the course of the 10-week summer REU program, participants engaged in shared research discussions, presentations and poster training. Research reports are available at https://www.cnf.cornell.edu/education/reu/2019.

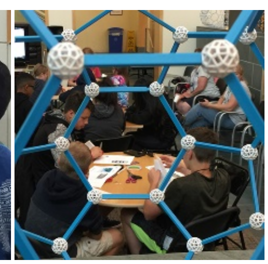
International Research Experience for Undergraduates (iREU): CNF coordinated an NNCI International Research Program for Undergraduates in 2019. A group of six students selected from the prior year (2018) NNCI REU interns from around the US spent the summer in Japan conducting research at the National Institute of Materials Science (NIMS) in Tsukuba, Japan. For 2019 this program was funded jointly by Cornell (CNF) and the NNCI Coordinating Office. This program has demonstrated significant success in developing "globally aware scientists", i.e. students with the demonstrated ability to successfully work in groups across culture, a critical skill for 21st century research. A renewal proposal for the iREU program was submitted to NSF. Research reports are available at https://www.cnf.cornell.edu/education/reu/2019.



Nanooze: CNF produces and distributes Nanooze, a children's science magazine relating to nanotechnology. Nanooze (http://www.nanooze.org/) is both a web-based and printed magazine, with kid-friendly text, topics, and navigation. Nanooze is edited by Cornell Professor Carl Batt, and is distributed to ~1300 classrooms and through many other channels throughout the US. We print 100,000 copies per issue as requests from classroom teachers continue to grow.

TCN – Technology and Characterization at the Nanoscale: CNF offered an introductory short course on nanotechnology semi-annually during the summer and winter recess, so that interested students from universities and industry can easily participate. Under NNCI we are offering TCN free to grad students from external US colleges and universities. Over forty students and scientists registered for the two courses offered this year. The course includes lectures and laboratory demonstrations as well as hands-on equipment sessions. Participants uniformly recommend the course to others.





4-H: CNF teams with 4-H to host STEM activities and to use 4-H as a distribution network for demonstration materials and Nanooze science magazines. We hosted a large campus visit of 4-H members for their "Career Explorations" featuring hands-on STEM nanotechnology activities.

CNF Annual Users' Meeting was held this fall featuring keynote speaker Britton Plourde from Syracuse University who spoke about building Quantum processors, 14 Invited Talks, 63 Student Posters, 29 Company Sponsors, and nearly 180 attendees.

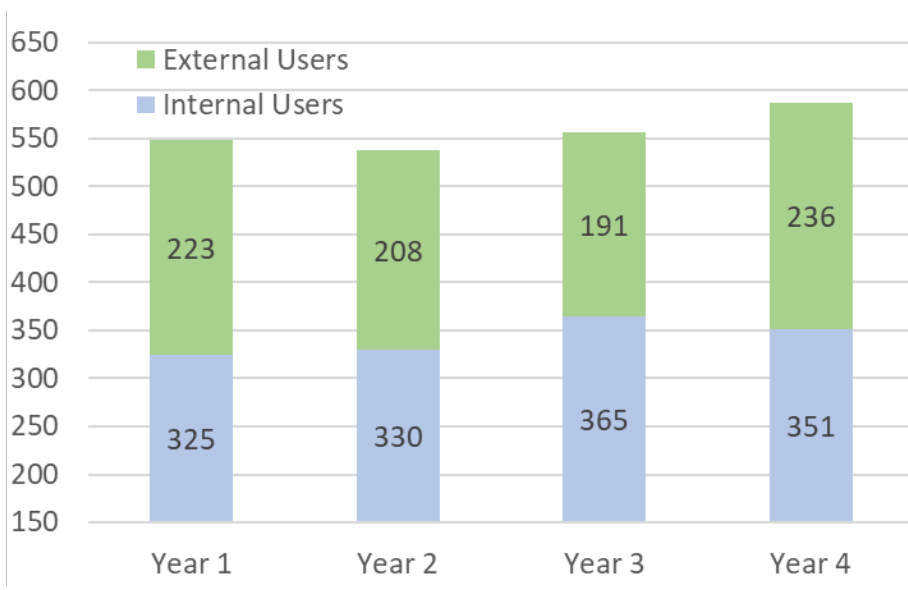
Whetten Memorial Award which recognizes young women scientists whose work and professional lives exemplify *a commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and exuberance for life*, was awarded by CNF to Ph.D. student, Taylor Oeschger. Cindy Harnett (U Kentucky), a former Whetten Memorial Award winner also spoke at the Users' Meeting.

Junior FIRST Lego Expo (~300 attendees) featuring 18 teams of middle school students presenting their displays on a "Mission MOON" theme. CNF sponsored the event, and staff and users served as reviewers.

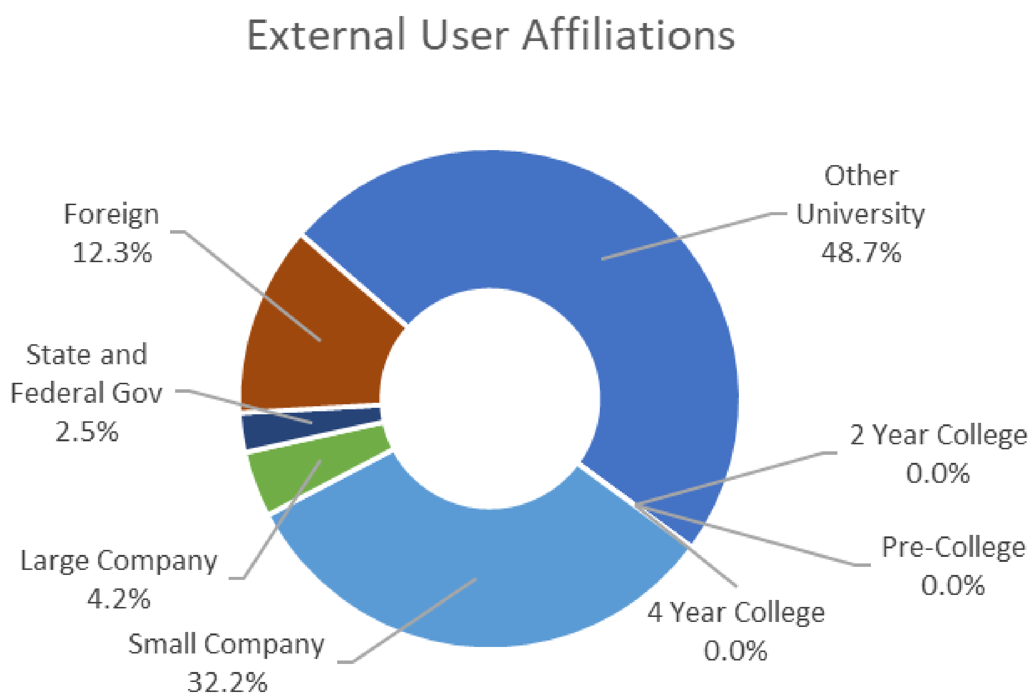
Publications: CNF published two *Nanometer* newsletters (latest at https://www.cnf.cornell.edu/publications/nanometer), an annual *Research Accomplishments (103 reports)*, the REU Research Final Reports, and several promotional brochures. These periodic publications are all available in pdf format on our website.

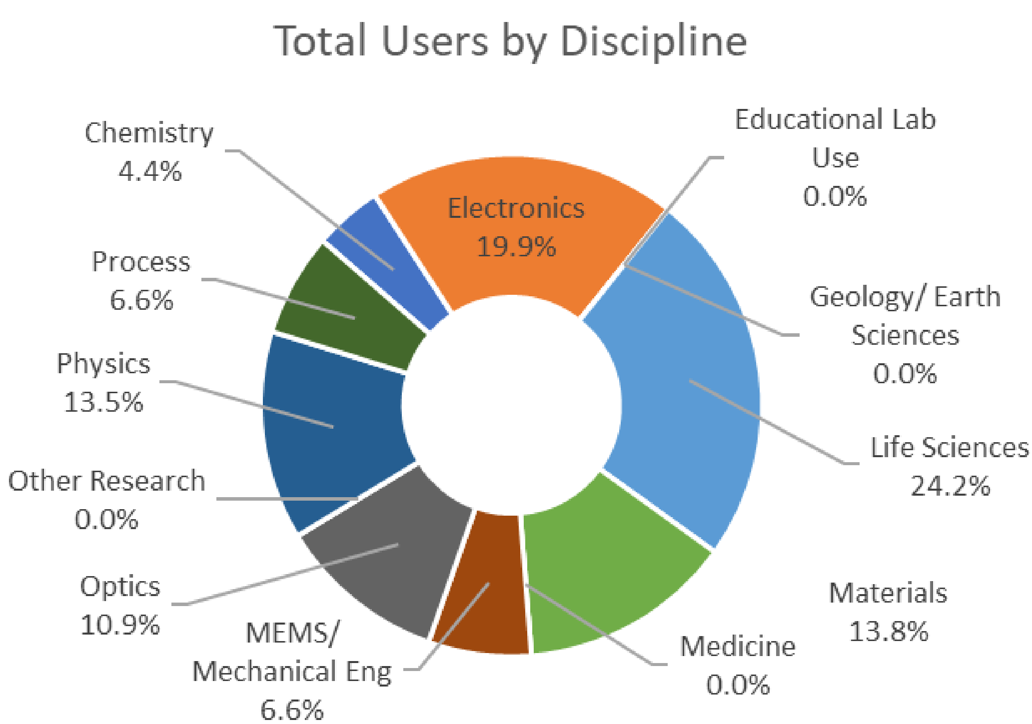
CNF Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	548	538	556	587
Internal Cumulative Users	325	330	365	351
External Cumulative Users	223 (41%)	208 (39%)	191 (34%)	236 (40%)
Total Hours	40,544	45,340	53,680	56,668
Internal Hours	22,965	25,201	31,143	34,627
External Hours	17,579 (43%)	20,139 (44%)	22,537 (42%)	22,041 (39%)
Average Monthly Users	210	204	225	235
Average External Monthly Users	67 (32%)	66 (32%)	68 (30%)	71 (30%)
New Users Trained	131	161	174	208
New External Users Trained	46 (35%)	51 (32%)	42 (24%)	91 (44%)
Hours/User (Internal)	71	76	85	99
Hours/User (External)	79	97	118	93



CNF Year 4 User Distribution





11.3. Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY MMNIN)

Facility, Tools, and Staff Updates

Year 4 was a busy and productive period for our new KY MMNIN NSF NNCI site (i.e. KY Multiscale). Our multidisciplinary high-tech infrastructure, which focuses on advanced multiscale manufacturing, continued to serve a growing user base including high schools, university laboratories, government facilities, startup ventures, and Fortune 100 companies this past year. To illustrate that growth, we point out that during our first 4 years in the NSF NNCI network, our site revenues increased dramatically from $718K to an impressive $1.28M, and our number of external users grew from 70 to 135. This provides hard evidence of the positive impact that NNCI has had on our new site.

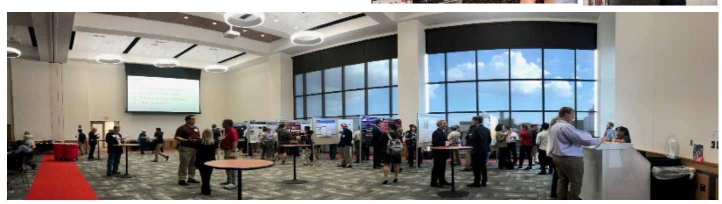
In Year 4, we had numerous facility improvements. At the UK CeNSE core cleanroom, a new Nanoscribe two-photon lithography system was fully installed and made available to all qualified users for both local and remote work. Early users are focused on printable color filters, rapid prototyping of integrated optics, and microfluidics for radiation chemistry studies. A new state-of-the-art Mirwex mini Labo roll-to roll coater was installed at the UofL Conn Energy Center for high precision, high quality lab coating for Li-Ion batteries, flexibles & wearables, optical, medical, and renewable energy research applications. The UofL RPC/AMIST additive manufacturing core facility installed a new metal sintering manufacturing system from Farsoon Technologies and a new Microtrac S3500 multi-laser particle size analyzer. The newly-installed Talos F200X at the UK EMC imaging core facility is now operational, complete with SuperX EDS detectors and Gatan dual EELS capabilities. The system is currently achieving resolution of 0.2 nm, though additional improvements will be implemented this coming year, aiming for the system's specification of 0.16 nm. Supporting the materials analysis capabilities of the EMC facility is the newly acquired Xenocs Xeuss 2.0 SAXS/WAXS system for x-ray scattering materials analysis. Being able to simultaneously perform WAXS has advantages for polymer research. UK EMC relocated a Thermo Scientific K-Alpha XPS system which includes a FIB attachment for performing depth profiles, allowing the user to mill into the top layers of the sample. UK EMC also acquired an array of sample preparation equipment geared toward supporting research in the life sciences and medicine: a Leica EM AFS2 freeze substitution/low temperature embedding system, a Leica EM UC6 microtome, a Leica EM ICE high pressure freezer, and a Thermo Scientific Vitrobot. The UofL Micro/Nano Technology Center (MNTC) purchased a new sputter coater from Ted Pella. Finally, in Year 4 we started the requisition process for purchasing a new SEM at the UofL MNTC for imaging down to the single nanometer scale. We expect to finalize this acquisition in January of 2020.

Year 4 welcomed 4 new staff members to our team: a support engineer, Mike Martin, for the UofL MNTC/Huson core facility, 2 PostDoctoral Associates, Chuang Qu and Dilan Ratnayake for the KY Multiscale UofL Site, and a new coordinator for the KY Multiscale UK site, Jillian Cramer. Additionally, KY Multiscale UofL and UK sites have targeted to date 16 new faculty hires in areas related to our advanced multiscale manufacturing NNCI theme.

In Year 4, our NNCI site won a very large NSF MRI award for a new state-of-the-art manufacturing tool, which will be located in our core facility. This custom tool will directly benefit KY Multiscale users. UofL Endowed Prof. Dan Popa received $1.5M for the development of a Multiscale Additive Manufacturing Instrument with an Integrated 3D Printing and Robotic Assembly. This "NEXUS" system will strategically combine fused deposition modeling (FDM), aerosol jet printing, ultrasonic metal additive manufacturing, fiber weaving, pick and place, annealing, and inspection in a single autonomous system. The Nexus system will be used for the automated fabrication of smart AM components, microsystems, microrobots, distributed sensors/actuators, soft robots, and wearables. This tool will be housed at KY Multiscale.

<u>User Base</u>

Our signature outreach event in Year 4 was our annual *<u>KY Nano + AM Symposium</u>*, which focuses on the intersection of nanotechnology and additive/advanced manufacturing (AM). This was the second year for the well-attended regional conference. The two-day event consisted of parallel technical and business sessions, several joint keynote presentations by national renowned speakers, poster presentations, sponsorship opportunities, food and refreshments, core facility tours, and a valuable evening networking reception. Local dignitaries included the mayor of Louisville and the president of UofL. This annual conference included an Industry Outreach Day where potential industrial users were invited to tour our core facilities. The goal of our annual Nano+AM Symposium is to bring together researchers in the Nano+AM space to discuss new findings, share results, discuss applications, debate the future, and network with one another. The 2019 KY Nano+AM Symposium venue was conveniently located on UofL campus enabling all KY Multiscale Core Facility users to participate. It was held on July 31 – August 1, 2019. The symposium brought together over 150 participants from industry and academia.



In year 4, we continued to expand our marketing effort of our NNCI site by engaging an online marketing company, Constant Contact, to continue to develop and distribute our KY Multiscale Nano+AM monthly newsletter and email campaign to a growing number of industry and academia recipients. Our newsletter includes important information about our site's activities and initiatives (new capabilities, new research results, upcoming conference and seminar opportunities, workshops we host, undergraduate research opportunities, etc). Our newsletter is distributed to over 2200 recipients nationally. We are now able to develop professional surveys and keep valuable statistics and continually improve our content and distribution.

The University of Kentucky launched its NNCI-funded seed grant program in 2019. The program aims to stimulate small-scope research projects both internally and from external academic institutions. The program provides up to $2,000 over 6 months for free access to the University's NNCI-affiliated research cores.

KY Multiscale hosted a workshop limited to 50 participants on Vacuum Science and Design. The workshop was developed and presented by Kurt J. Lesker Company. The event was very successful (per exit surveys assessment) and had full attendance.

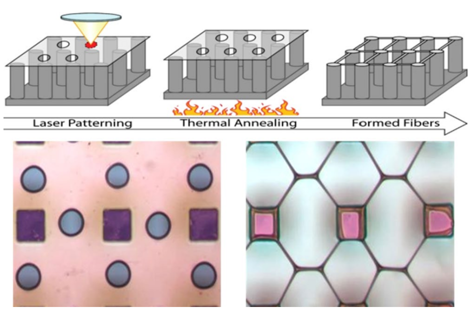
KY Multiscale was proud to learn that Curt McKenna, research engineer at the UofL MNTC, won the 2019 NNCI Outstanding Staff Member Award. Mr. McKenna received his award in person during the evening reception at the Annual NNCI Conference hosted at Harvard University. This annual conference was also attended by 8 other KY Multiscale personnel.

2019 NNCI Staff Awards (Curt McKenna – 2nd from left)

Results from usage data in Year 4 continue to be very positive and revenue continues to increase for our KY Multiscale core facilities.

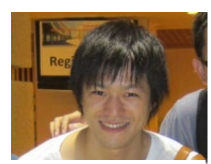
<u>Research Highlights and Impact</u>

In this section, we highlight a successful research collaboration involving a key international partner. Prof. Robert Cohn of the UofL ECE Department designed a new type of lithography that leverages photolithographic exposures to direct the self-assembly of suspended polymer micro/nano-structures, as shown in the figure. This research was developed with partial support from UofL's NSF NNCI and REU awards, as well as from Cornell's IRES NSF award and Japan's National Institute for Materials Science (NIMS). The method offers dramatic increases in production throughput and arbitrary patterning of suspended, flexible polymer nanofibers and related high-aspect ratio structures. The method is compatible with roll-to-roll manufacturing and systems and mass production wafer steppers (though additional research is underway to lower the exposure threshold to that of existing 193 nm steppers). The method offers a manufacturable approach to including a plane of flexible suspended MEMS structures in mass produced integrated circuits, with applications to micromechanical actuation, guiding of light and templates for microfluidics channels and highly customized tissue scaffolds.



Photolithographic exposures to direct the self-assembly of suspended polymer micro/nano-structures.

Dr. Cohn developed this technology with the help of Hiroya Abe, a visiting PhD student from Tohoku University as part of the NNCI's exchange program with Japan. Hiroya continued to perform studies on this technology when he returned to Japan. In October 2018, Hiroya completed his PhD in Chemistry and joined the Advanced Institute for Materials Research (AIMR) at Tohoku University, which is part of Japan's World Premier International Research Centers (WPI). There Dr. Abe will continue this research and his collaboration with our NNCI site.

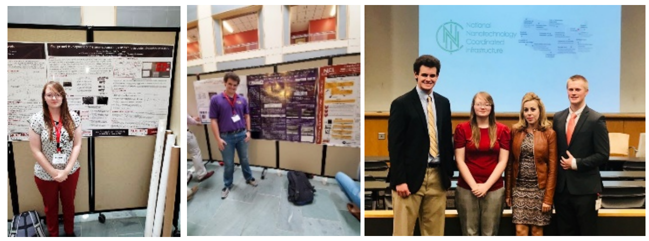


Hiroya Abe, KY MMNIN Intern from Japan

<u>Education and Outreach Activities</u>

KY Multiscale continued to promote and engage the public about Nanotechnology in Year 4 by organizing and participating in numerous outreach events locally. For example, KY Multiscale participated in MAKER FAIRE LOUISVILLE, a gathering of engineers, scientists, artists, and crafters showcasing their hobbies, experiments, and projects. For National Nanotechnology Day, KY Multiscale participated and won first prize on the NNCI Image Contest, “Plenty of Beauty at the Bottom”. Contestant Sarah K Lami’s Nanoscribed “Moon City in the Nano Universe” SEM Image, was chosen as the NNCI Nano Image Competition winner for the “Most Unique Capability” category. In addition to participating in this network-wide activity, KY Multiscale ran our first internal Nano SEM Competition in honor of Nanotechnology Day. We received numerous submissions and selected 3 winners. All contestants’ SEM images will be professionally framed and displayed permanently in our Shumaker Research Building, home of the UofL Micro/Nano Technology Center.

Participants from KY Multiscale’s REU program Mariah Hall, Zane Ronau, and Kevin Tobin, traveled to the NNCI Convocation 2019 at Cornell University to present their summer research results and network with their peers. This was a wonderful culmination of their summer research experience.



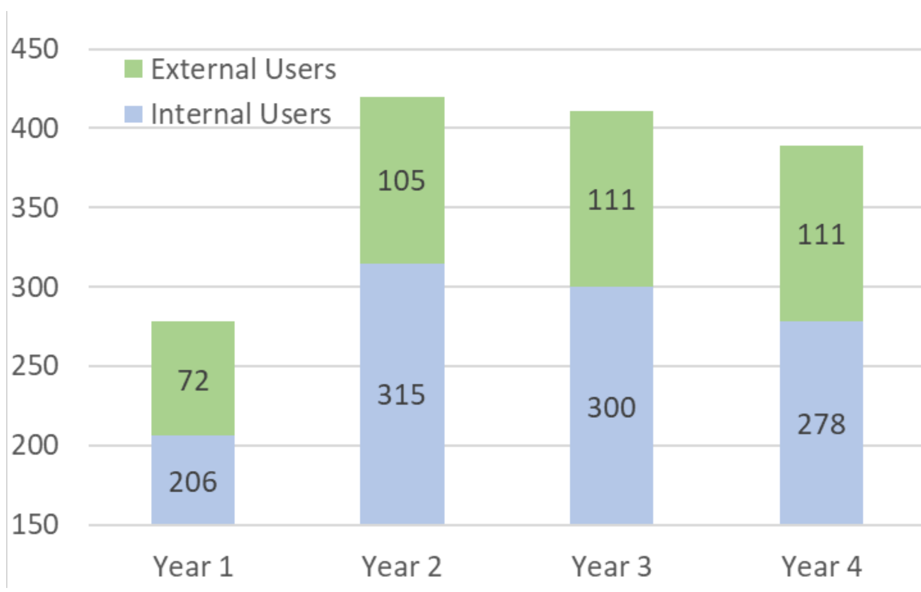
KY Multiscale REU Participants at the 2019 NNCU Convocation - Mariah Hall, Kevin Tobin and Zane Ronau along with our nano-coordinator Ana Sanchez

In year 4, KY Multiscale started a nanotechnology collaboration with Yale University called “Bulldogs in the Bluegrass”. This program provided a summer internship opportunity for a Yale undergraduate to work on research at the UofL MNTC cleanroom. Ross Parish, a sophomore Mechanical Engineering student from Yale, participated this past year. The goal of Bulldogs in the Bluegrass, sponsored by Yale in Kentucky, Inc., is to employ hardworking Yale students in meaningful internship positions, introduce these students to the assets and leadership of the Louisville community, provide benefit to local employers and enhance the community as a whole. KY Multiscale is planning to continue this workforce development effort in the summer of 2020 and expand its participants.

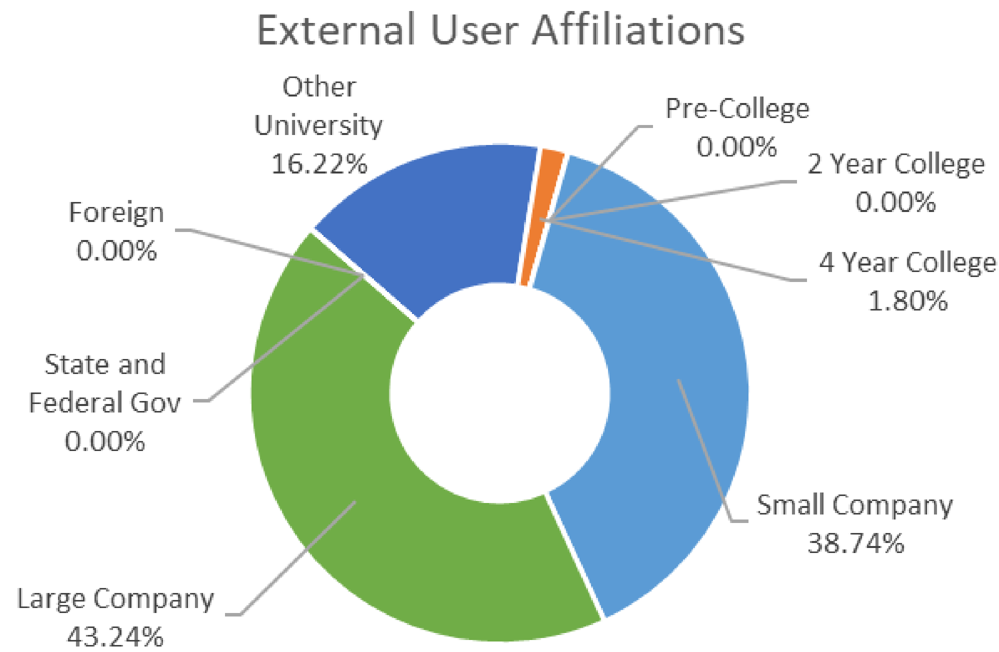
In year 4, approximately 4,500 people attended a variety of KY Multiscale outreach and educational events including: UK and UofL engineering day, Girls Rule STEM Summit, MNTC Engineering Expo, AMCC Promise Zone for Appalachia HS, KY Multiscale seminar series, Vacuum Technology and AFM workshops.

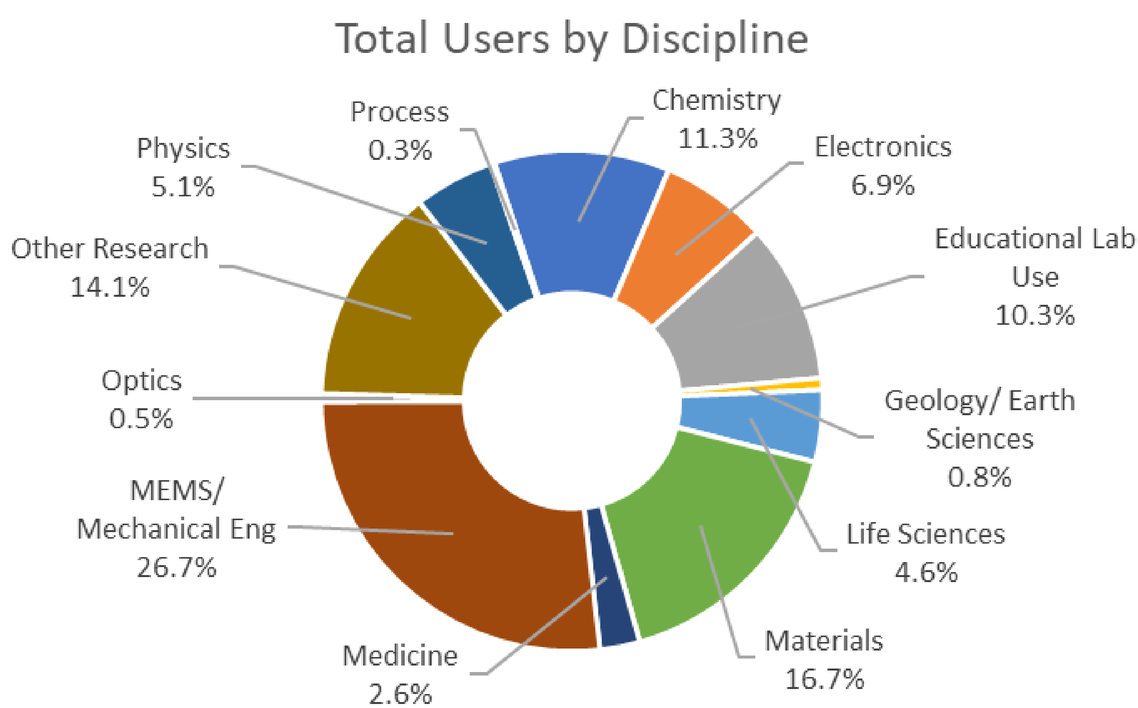
KY MMNIN Site Statistics

Yearly User Data Comparison				
	Year 1	Year 2	Year 3	Year 4
Total Cumulative Users	278	420	411	389
Internal Cumulative Users	206	315	300	278
External Cumulative Users	72 (26%)	105 (25%)	111 (27%)	111 (29%)
Total Hours	14,629	17,151	17,301	15,651
Internal Hours	9,726	12,166	10,960	11,869
External Hours	4,903 (34%)	4,986 (29%)	6,341 (37%)	3,782 (24%)
Average Monthly Users	104	141	120	140
Average External Monthly Users	22 (21%)	25 (18%)	25 (21%)	25 (18%)
New Users Trained	111	251	164	223
New External Users Trained	26 (23%)	43 (17%)	28 (17%)	22 (10%)
Hours/User (Internal)	47	39	37	43
Hours/User (External)	68	47	57	34



KY MMNIN Year 4 User Distribution





11.4. Mid-Atlantic Nanotechnology Hub (MANTH)

MANTH celebrated the fifth anniversary of its opening of the Singh Center for Nanotechnology in 2019, a milestone that coincided with our 4th year of participation in the NNCI. These events motivated us to do 2 things: to look back to see our progress as an access point to nanoscience and nanotechnology for the Mid-Atlantic and larger community, and to look forward so that we may understand how we can continue to provide leadership in the nano arena.

The substantial growth in external users, and robust equipment acquisition - within the past year and since the inception of the NNCI - are summarized in the sections below. We also expanded our educational outreach with our partner CCP and with other academic institutions in the region, outlined below as well.

In order to plan our future course, our senior staff, with the help of our External Advisory Board, developed a strategic plan for the next 5 years. We coalesced our priorities into 3 nano-relevant pillars: *Education, Research + Innovation, and Engagement*. These pillars shape how we will organize our node and will guide us in setting success metrics and implementation strategies as the nanotechnology research of our users continues to evolve in exciting new directions.

<u>Facility, Tools, and Staff Updates</u>

The 2018-2019 timeframe has been an extraordinarily busy one for MANTH in terms of acquiring, installing, and providing training for new research equipment. MANTH added several significant new pieces of equipment to our fabrication and our characterization facilities. These capital investments included $9.2M for electron microscopy, $400k for scanning probe enhancements, and over $1.5M for cleanroom equipment, totaling **$11M** in the past year. We also welcomed a new member of our staff, Technical Director Dr. Darrah Johnson-McDaniel, who runs our new Cryo-TEM facility. Tools we installed in the past year include:

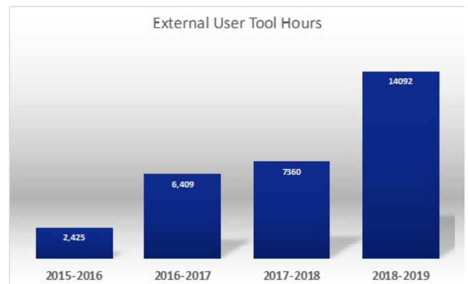
MANTH Krios TEM

1. A Thermo Scientific Krios G3i Cryo Transmission Electron Microscope (Cryo-TEM) with a Gatan Energy Filter, and a K3 Direct Electron Detector Camera and Phase Plate. Cryo-Electron Microscopy has become a new standard for structure determination of various biological molecules and cellular processes. This method not only allows us to achieve atomic-level resolution information about various proteins, but also reveals details on the protein-ligand, protein-protein and protein-lipid interactions.
2. Tescan S8000X Plasma Focused Ion Beam-Scanning Electron Microscope (Plasma FIB-SEM). The plasma source can operate at up to 1 µA enabling large volume cross-sectioning (~1 mm x 1 mm) of a wide variety of materials, from MEMS devices to mouse brains.
3. The SMI-manufactured metal-organic chemical vapor deposition system is a dual chamber CVD system with four sources, devoted to synthesizing 2D materials. The system is composed of two chambers, both of which can operate up to 1200C: the horizontal hot walled chamber with 2 " diameter wafer holding capacity in a quartz tube chamber; and

the vertical cold-walled chamber capable of holding 4" diameter wafers. The tool is used to grow sulfides, selenides and tellurides of molybdenum and tungsten to begin with and will be transitioned to explore more novel and exotic quantum materials such as indium, tantalum and niobium-based chalcogenides as well as elemental selenium and tellurium.

User Base

MANTH served approximately 700 unique users over the past NNCI year. In particular, our external user base has flourished since the beginning of the program. The graph on the upper right shows the number of external users at MANTH in each NNCI year. Since year 1, that number has more than doubled to 279 users in year 4. In addition, the fraction of external users has grown from 26% to 39% of our total user population.



MANTH external user growth in number and hours.

The graph on the lower right implies that our external users are working in our laboratories on increasingly complex projects. The number of tool hours external users have consumed has increased dramatically from about 2000 hours in Year 1 to 14,000 hours in Year 4.

Research Highlights and Impact

MANTH and its users have played an increasingly important role in exploring the nanotechnological aspects of several of NSF's 10 Big Ideas. A small selection of these activities are highlighted below.

QUANTUM LEAP AND CONVERGENCE ACTIVITIES

MANTH's researchers are active in many ***Quantum Leap*** projects. We recently hosted the symposium *Enabling Quantum Leap: Achieving Room-Temperature Quantum Logic through Improved Low-Dimensional Materials.* This NSF-Funded workshop at MANTH explored the needs and challenges involved in ensuring the advancement of quantum logic with improved low-dimensional materials operating at room temperature. Attendees from NSF and 17 Universities participated in the 1½ day meeting.

Attendees of the NSF sponsored Enabling Quantum Symposium at MANTH.

MANTH academic users were the recipients of 2 recent Research Advanced by Interdisciplinary Science and Engineering (RAISE) Engineering Quantum Integrated Platforms for Quantum Communication (EQuIP) grants. Both $750k RAISE-EQuiP Grants are interdisciplinary in nature and are 3-years duration.

- *Integrated Higher-Dimensional Quantum Photonic Platform.* A collaboration between Penn Engineering (Liang Feng and Ritesh Agarwal) and Stevens Institute of Technology

(Stefan Strauf), this grant funds the fabrication of nanophotonic devices with unique materials that are essential in advancing quantum communications research.

- *Chip-Scale Quantum Memories for Practical Quantum Communication Networks*. This collaboration between Penn Engineering (Lee Bassett and Firooz Aflatouni) and Brown University (Rashid Zia) leverages modern capabilities in materials science, nanofabrication, signal processing, and integrated systems-on-a-chip to harness the computational power and sensitivity of quantum-coherent systems for practical applications.

RULES OF LIFE AND WINDOWS ON THE UNIVERSE: NIH/NCATS MICROFLUIDICS IN SPACE

This collaboration between Penn Engineering (Dan Huh) and Children's Hospital of Philadelphia (Scott Worthen) investigates a little-known fact about space travel: astronauts often get sick with colds and lung infections during their time away - much more frequently than on Earth. Recruitment of the immune system to battle disease in space can be observed through microfluidically-enabled organs on a chip, fabricated at MANTH and launched to the International Space Station (ISS). The goal is to improve the ability to protect astronauts during long voyages to the Moon, Mars, and beyond. The figure below-left shows the packaged device in Zero-G on the ISS.

MANTH fabricated microfluidic device for lung infection studies floating in the ISS.

RULES OF LIFE: NON-TRADITIONAL USERS AT MANTH USE TWO-DIMENSIONAL Ti_3C_2 MXENE FOR HIGH-RESOLUTION NEURAL INTERFACES

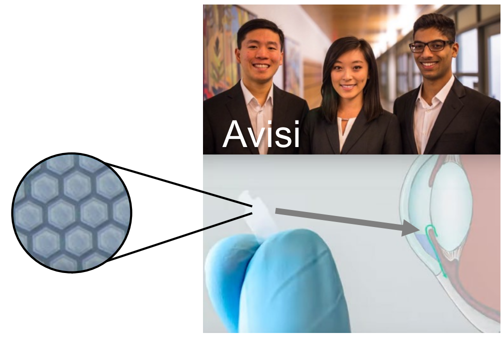
High-resolution neural interfaces are essential tools for studying and modulating neural circuits underlying brain function and disease. Because electrodes are miniaturized to achieve higher spatial resolution and channel count, maintaining low impedance and high signal quality becomes a significant challenge. Nanostructured materials can address this challenge because they combine high electrical conductivity with mechanical flexibility and can interact with biological systems on a molecular scale.

Two-dimensional Ti_3C_2 MXene possesses a combination of remarkably high volumetric capacitance, electrical conductivity, surface functionality, and processability in aqueous dispersions distinct among carbon-based nanomaterials. A high-throughput microfabrication process for constructing these neuroelectronic devices has been demonstrated with microelectrodes exhibiting a 4-fold reduction in interface impedance. These results indicate that Ti_3C_2 MXene microelectrodes have the potential to become a powerful platform technology for high-resolution biological interfaces.

The researchers, led by Penn Department of Neurology Professor Flavia Vitale, include those from Penn Departments of Bioengineering, Penn Department of Neurosurgery, from Drexel University. This work was published in ACS Nano.

IMPACT – SEED GRANT INNOVATORS

Innovation Seed Grant Competition is designed to encourage the Mid-Atlantic region's brightest minds to design or prototype innovative technology through the use of nanotechnology equipment. Up to $3,000 individual grants in laboratory/equipment time to be used in the MANTH laboratories. In last year's round of the Innovation Seed Grant, 11 finalists were awarded $20k. These companies raised **$4.3** million in venture capital since then.



Avisi Technologies Innovation Seed

Among the most successful of these Seed Grant companies, Avisi Technologies, is developing porous, nanostructured membranes created at MANTH, to be used to control the damaging effects of fluid pressure in the eyes of glaucoma patients.

Our 2019 cohort of 7 startup companies was selected in two stages, first on technical merit based on the input of a panel of MANTH technical staff members, and then on the potential commercial impact based on the selection of 6 panelists drawn from the Philadelphia startup community. Grants totaling $18.5k of tool access were awarded; so far **$2.2** million additional venture capital was raised by these companies.

<u>Education and Outreach Activities</u>

MANTH partner, the Community College of Philadelphia, launched 2 courses aimed at students who are interested in advanced fabrication and nanotech technician careers. The first, *Additive Manufacturing* (ASET 140, Lecture and Lab) is running in Fall 2019 with 8 students enrolled. It makes use of the additive manufacturing laboratories at Penn. The other course is running in Spring 2020: *Intro to Nanotechnology* (ASET 201), which will include hands-on fabrication and characterization projects in MANTH labs.

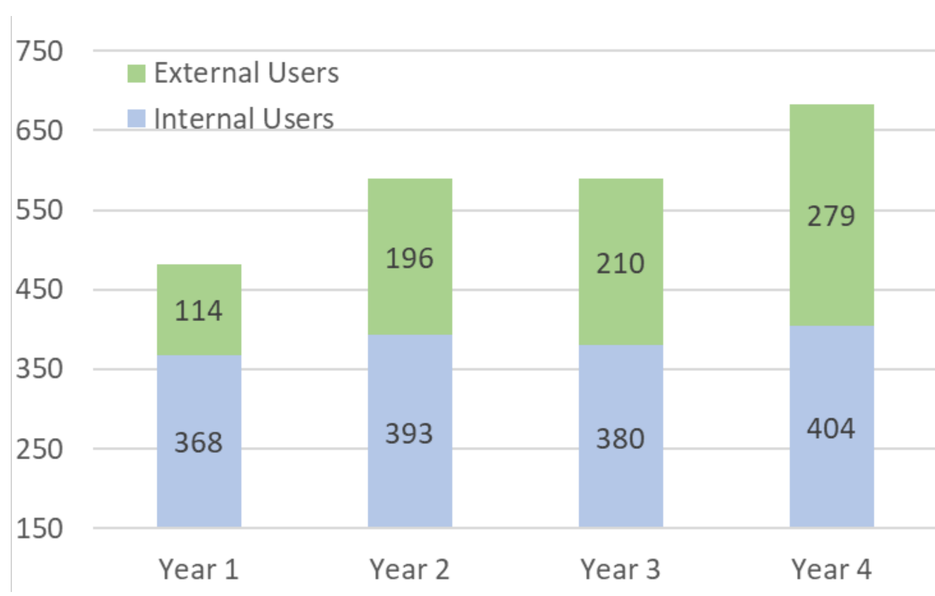
MANTH has developed a program for undergraduate students from local colleges and universities that provides these students with a hands-on opportunity to fabricate and characterize micro and nano-scale structures, using the tools in the MANTH cleanroom facility. Seven STEM students and their instructor from Swarthmore College participated last year. This year, we expanded the program so that **47 students** from 3 local colleges and universities participated, including the women's college Bryn Mawr. We plan to reach other institutes in the near future, including students from Jefferson University and the Community College of Philadelphia.

Undergraduates from local college Bryn Mawr using the MANTH fab.

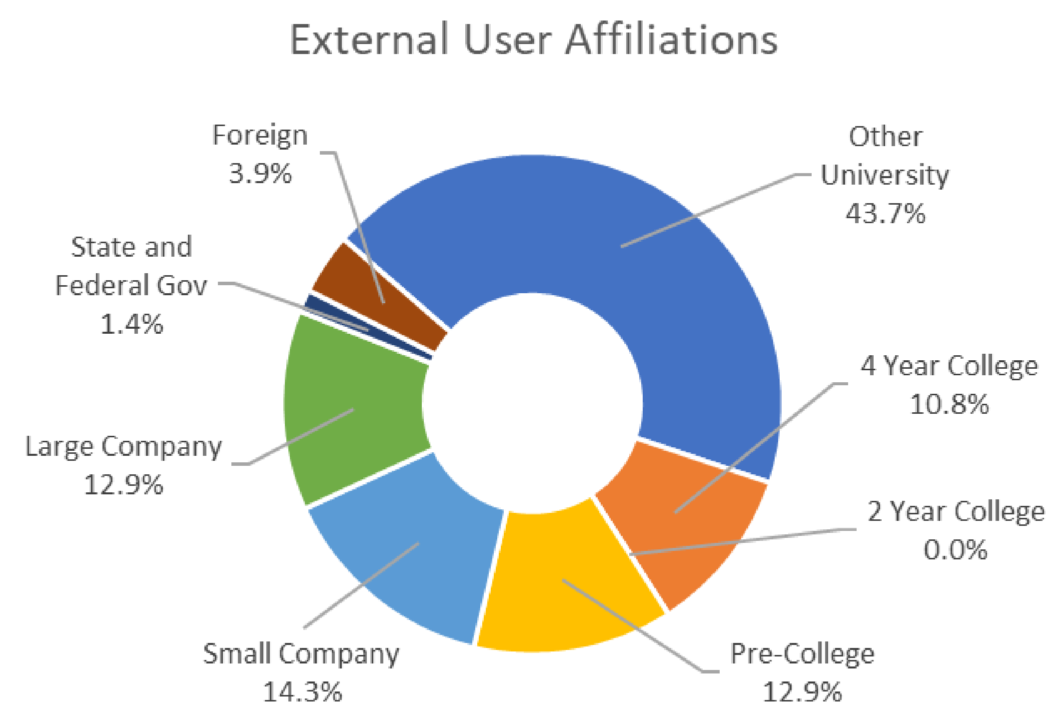
MANTH was host to 6 REU students last Summer. We also developed a 3-week Summer nanotech program for 34 high school students – the *Engineering Summer Academy at Penn: Nanotechnology*. Our *Nanoday@Penn* program in October 2019 brought 104 high school students to MANTH for a full day of demonstrations and talks.

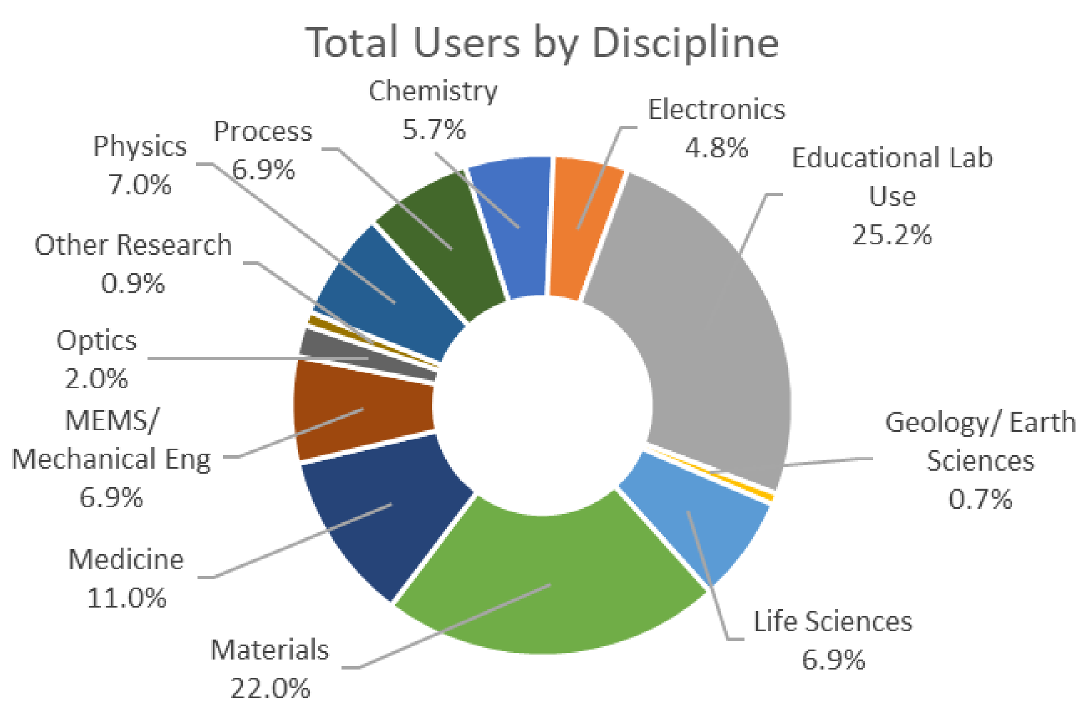
MANTH Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	482	589	590	683
Internal Cumulative Users	368	393	380	404
External Cumulative Users	114 (24%)	196 (33%)	210 (36%)	279 (41%)
Total Hours	36,970	37,933	34,796	56,849
Internal Hours	34,545	31,542	27,436	43,673
External Hours	2,425 (7%)	6,409 (17%)	7,360 (21%)	13,176 (23%)
Average Monthly Users	171	194	186	210
Average External Monthly Users	29 (17%)	44 (23%)	45 (24%)	61 (29%)
New Users Trained	270	339	270	418
New External Users Trained	73 (27%)	138 (41%)	104 (39%)	203 (49%)
Hours/User (Internal)	94	80	72	108
Hours/User (External)	21	33	35	47



MANTH Year 4 User Distribution





11.5. Midwest Nanotechnology Infrastructure Corridor (MINIC)

Facility, Tools, and Staff Updates

MINIC received nearly $400K in funding from university sources to improve nanoscale processing capabilities through upgrades and expanded capabilities:

- Upgrade of the JEOL 6700 field emission SEM computer to Windows 10. This involved replacing the computer and several control boards, and will extend the life of the SEM for years.
- We acquired Genisys ProSEM software which analyzes SEM image files, providing fast, consistent feature measurements for process calibration and monitoring tasks.
- We also obtained a software upgrades for Genesys Beamer software: TRACER is an add-on package that extends the capabilities of the BEAMER software used for electron beam lithography.
- We upgraded the stage motors on Vistec EBPG5000+ electron beam lithography tool to replace the older, less reliable stage control motors.
- An Atomic Layer Deposition (ALD) of oxide films has been funded and is currently in acquisition. This will complement our other two ALD systems.

Staffing—Gary Olin retired in July 2019 after 15 years of service. Gary worked as a maintenance staff, supervisor and facilities support coordinator. His duties have been re-assigned to other staff.

User Base

MINIC staff employed newsletters, tours, company visits, and presentations at conferences to reach new users during the past year.

- *Communications.* MINIC produces a quarterly newsletter on activities at the Nano Center and related facilities to all current users. In addition, we send an annual "What's New at the Nano Center" New Year's email update to everyone in our contact list (about 1200 unique names).
- *Conference Exhibits and Talks.* In October MINIC presented an invited talk on nanomaterials in medicine to about 40 industry representatives at the MedFUSE Conference held in Minneapolis and gave a talk to the engineering staff at Skywater Technology (Bloomington MN), a local semiconductor foundry, about MINIC's capabilities and collaboration. Each April the University of Minnesota holds its highly regarded Design of Medical Devices (DMD) conference, to which MINIC contributes an exhibit which allows us to contact potential users and provide tours.
- *Supporting External Researchers.* In the fall of 2018 MINIC instituted a new user recruitment program called *Explore Nano.* The program waived the first $2000 of lab use fees by new external academic or industrial users. Six applicants were accepted into the Explore Nano program, representing staff from a large company (General Mills), entrepreneurs from start-ups, and independent inventors.

Research Strengths: Since its inception, MINIC has emphasized growing its user base by cultivating three focused areas of research support. The first area is in two dimensional (2-D) materials, forming and characterizing samples of graphene, MoS_2, WSe_2, and phosphorene. The second area is in microelectronic device packaging, for which we partner with the advanced facilities at North Dakota State University. The third focus area supports the biological applications of nanotechnology, specifically making and analyzing nanoparticles and applying these materials to drug delivery and cell analysis. These focus areas, in additional to our historic strengths in micro- and nanoscale device fabrication, form the core of MINIC's research activities.

<u>Research Highlights and Impact</u>

- Steve Campbell and his graduate student Nez Izquierdo developed the first known process for depositing the 2D material Black Phosphorus directly on silicon without exfoliation. Single crystals 100 µm in length have been demonstrated: "Deposition of Surface Passivated Black Phosphorus Thin Films", Izquierdo, et. al., *ACS Nano* 13(6) pp. 7091-7099 (2019).
- Topological insulators are predicted to convert charge into non-equilibrium spin density efficiently, promising a path for ultralow power and fast magnetic-based storage and computational devices. This work has shown that BiSe films grown directly on Si not only have exceptionally high conversion efficiency, devices made from these films operate at room temperature. "Room-temperature high spin–orbit torque due to quantum confinement in sputtered BixSe(1–x) films", Mahendra, et. al., Nature Materials, 17, 800-807, 2018.
- MINIC staff scientist J. Marti worked with research and clinical staff at the Mayo Clinic (Rochester MN) to develop an improved method to mark the location of biopsied tissue in patients. The improved marker must be small and easy to insert, biocompatible, bright under ultrasound imaging, and durable for the span of the patient's treatment. MINIC's Nanomaterials Lab contributed several candidate materials for *in vitro* testing, contributing to a paper from the group at Mayo: "The Development of an Effective Bacterial Single-Cell Lysis Method Suitable for Whole Genome Amplification in Microfluidic Platforms", Liu, et. al. Micromachines, 9, 367, 2018.
- MINIC supported the development of a new class of lipid nanoparticles by Dynation LLC (St. Paul MN), an SBIR-funded start-up biotech company. Over the past year, Dynation has used MINIC's lab s to expand its product applications to include nanoparticles for dermal delivery of ibuprofen, cannabidiol, and other pharmaceutical/nutriceutical compounds.
- MINIC enabled the development of a wireless biosensor using ungated graphene transistors as the active element. The process was transferred to Boston Scientific who further developed it in the MINIC facilities as a breath sensor for early stage noninvasive disease detection. In mid-2019, the process has been transferred to Skywater Technologies, a local 200 mm fab, which will carry out volume manufacturing of the device.

<u>Education and Outreach Activities</u>

Over the past year, MINIC outreach staff completed 21 educational outreach events, both on campus and at remote sites. Educational outreach highlights include:

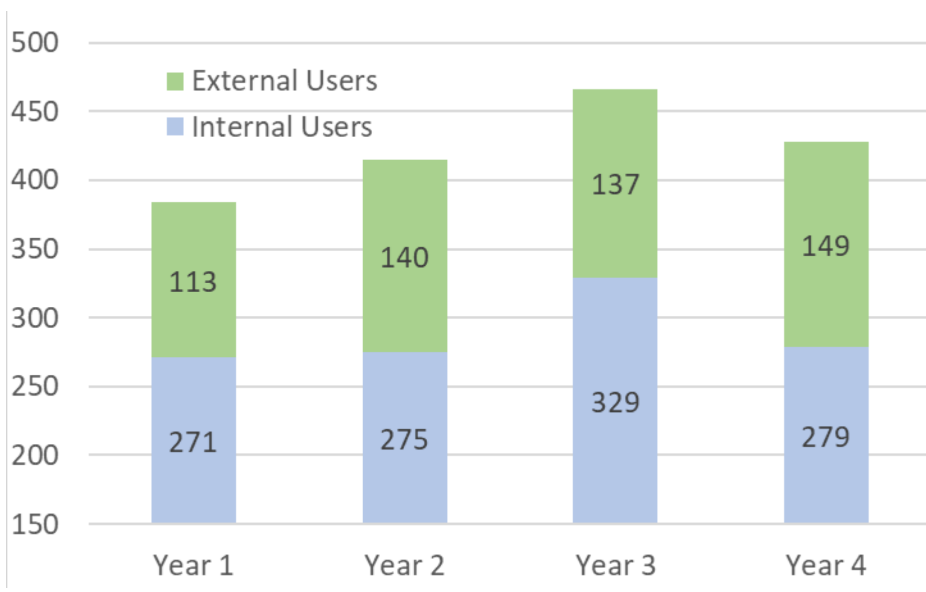
- *Programs for summer camps and visiting K-12 school groups.* Classes on nanotechnology and photolithography were presented to twelve visiting groups, reaching over 280 students in grades 8-12. MINIC provided two nanotechnology programs for the Eureka SciGirls summer camp, dedicated to attracting girls in grades 8-10 to STEM fields.
- *Programs for undergrads and grad students*. MINIC staff traveled to four regional colleges to present overviews of nanoscience and the work of MINIC's nanotechnology labs, reaching over 200 undergrads and their professors with an invitation to work with us. In June of this year, MINIC organized two short courses dedicated to 2-D materials and to applications of nanotechnology to biology and medicine. These short courses were open to undergrads, grad students, and faculty from UMN as well as other institutions, and attracted almost 200 participants.
- *Programs for K-12 Teachers*. MINIC staffed an exhibit at the annual convention of the Minnesota Science Teachers Association, sharing information on our educational offerings with the approximately 350 attending science teachers at grades 7 and up.
- *Science festivals*. MINC staff presented three hands-on Intro to Nano programs to 100 students in grades 5 and 6 as part of a STEM education event produced by Success Beyond the Classroom, a local nonprofit dedicated to expanding elementary students' curiosity and confidence in STEM fields.

In all, over 1600 students were impacted by MINC's education and outreach efforts during year 4.

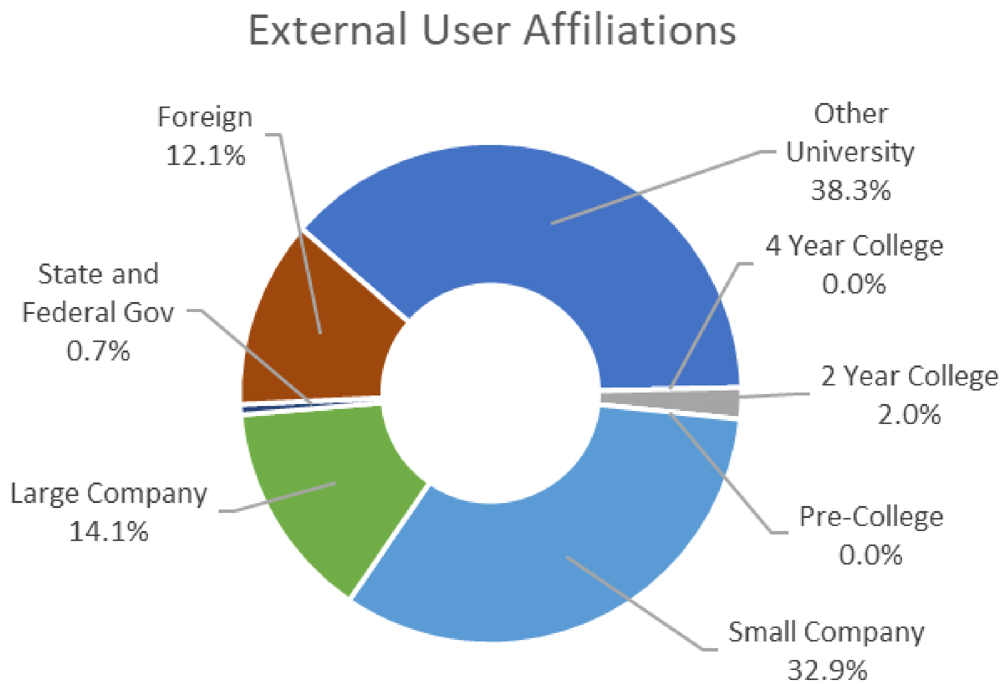
In addition, MINIC supports the Northern Nano Lab Alliance. In September we hosted a meeting of NNLA members. Several new academic institutions were added, including Minnesota State Mankato, University of Colorado at Boulder, and the University of Wisconsin at Madison. This brings the total of participants to 10 institutions: University of Minnesota, North Dakota State University, Rose Hulman Institute of Technology, Minnesota State Mankato, University of Iowa, Iowa State University, Michigan Tech University, South Dakota State University, University of Colorado at Boulder, and University of Wisconsin at Madison. Each school made a presentation about their facilities, research capabilities, user base, faculty research fields, institutional support, and problems/issues they face. Most sites continue to struggle with inadequate staff support and low user base. As part of the meeting attendees toured MNC facilities and met process and maintenance staff for individual discussions of specific areas of interest regarding equipment operation and maintenance, best practices, training, safety, vendors, and other relevant topics.

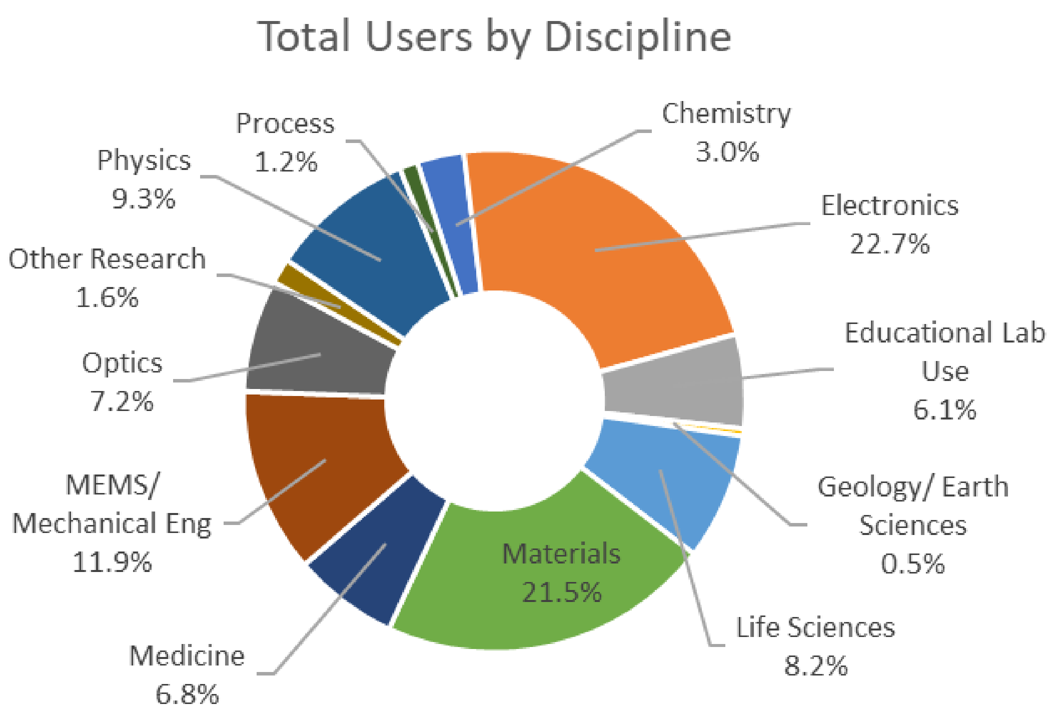
MINIC Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	384	415	466	428
Internal Cumulative Users	271	275	329	279
External Cumulative Users	113 (29%)	140 (34%)	137 (29%)	149 (35%)
Total Hours	27,002	26,443	26,851	27,782
Internal Hours	20,495	19,733	21,324	17,780
External Hours	6,507 (24%)	6,710 (25%)	5,527 (21%)	10,002 (36%)
Average Monthly Users	156	156	161	161
Average External Monthly Users	26 (17%)	33 (21%)	30 (18%)	37 (23%)
New Users Trained	151	150	189	136
New External Users Trained	57 (38%)	59 (39%)	48 (25%)	45 (33%)
Hours/User (Internal)	76	72	65	64
Hours/User (External)	58	48	40	67



MINIC Year 4 User Distribution





11.6. Montana Nanotechnology Facility (MONT)

MONT Facilities include: Montana Microfabrication Facility (MMF), Imaging and Chemical Analysis Lab (ICAL), Center for Biofilm Engineering (CBE), Mass Spectrometry, Metabolomics, Proteomics, Facility (MSMP), and transmission electron facility (TEM); Partner site with the Science Education Resource Center (SERC) at Carleton College.

Facility, Tools, and Staff Updates

The **Montana Microfabrication Facility (MMF)** completed its Cobleigh Hall cleanroom expansion to support microfluidics and soft lithography activities. This expansion supports MONT users who are developing new tools and techniques to study neural development, disease diagnosis, separation and detection of genetic material and proteins, and propagation of bacteria and viruses at the single cell level. Fit-out of that space with new equipment is underway. The MMF also took delivery of a new e-beam evaporator with capability for ion-assisted and glancing angle deposition. The **Imaging and Chemical Analysis Laboratory (ICAL)** installed a new atomic force microscope (Oxford Instruments Asylum Research) capable of nanometer resolution mapping of piezoelectric, magnetic, conductive and viscoelastic material surface properties. Year 4 also saw continued increased use of a new cryogenic stage for SEM imaging of biomaterials, and the nanoAuger instrument for detailed elemental analysis of surfaces.

New Tools in Y4 of the NNCI Project

Major new instruments are now available to users of MONT, funded with grants from the NSF MRI program, the Murdock Charitable Trust, internal MSU funds, and NNCI.

- EvoVac (Angstrom Engineering) e-beam evaporator with ion-assist and GLAD stage
- Cypher S AFM (Oxford Instruments Asylum Research)
- Awarded NSF MRI for **200 keV cryo-TEM** (NSF #1828765).

EvoVac e-beam evaporator in MMF

MONT is cooperating with **Georgia Tech of SENIC** to link its SUMS facility management software to MONT facilities.

Staff Updates

Dr. Manjula Nandasiri, ICAL manager, has taken a position with Arconic, Inc.; Elif Roehm has taken the role of User Liaison for ICAL. Dr. Phil Himmer, MMF's Founding Manager, has relocated to **nano@stanford**. MMF has hired Dr. Andy Lingley from **NNI/University of Washington**, as the new MMF Manager. Betsey Pitts (CBE Microscopy Manager) has retired; the CBE/Microscopy User Liaison is now Heidi Smith. It is a testament to the skills of these technical staff contributors that they were recruited to excellent new opportunities. We are pleased to be working with these new, talented staff members to support our users.

User Base

Facility usage continues to increase. MONT served 184 users in Y4, up from 158 in Y3 and following a four-year growth trend of 13.8% annual rate of increase. External users were 27% of total users, and growing at an average annual rate of 22%, over four years.

Marketing, Outreach and Support Activities

MONT held its **annual User's Meeting** on May 13, 2019. This year's meeting focused on "looking forward" to identify user's research directions and how MONT can best serve those needs. The half-day meeting also included facility updates, presentations by industrial and academic users and a poster session. Fifty-one people attended the meeting including eight representatives from local industry. MONT also continued monthly **"brown bag" lunch meetings** to visit with users about processes, equipment issues and capabilities users would like in the future. Users from both academia and industry have attended.

MONT awarded 11 **user grants to seed new projects** in Y4.

Mike Miller of Resodyn™ Acoustic Mixers, a small company based in Butte, MT, is conducting research to eliminate solvents from materials processes.

Sarah Mondl of AdvR, Inc.; developing sputtered SiO2 Films for Nonlinear Integrated Optics Devices.

NanoCoatings, Inc. a small business in Rapid City, SD, is developing advanced coating and materials technology development, including solid state batteries.

Chris Arrasmith of Revibro Optics was awarded a user grant to work on Bond Recipe Development. This was supported by The Murdock Charitable Trust and MONT.

David Joswiak, University of Washington (Astronomy Dept), received a user grant to characterize interplanetary dust particles (IDPs) using unique instrumentation available in ICAL.

Dr. Scott Wade, Swinburne University of Technology, Australia, is investigating microbial corrosion and sulfate reducing bacteria, with follow-on proposals to NASA and ONR.

Dr. Robert Peterson, Dept. of Entomology is investigating metazoan extremophiles (beetles) thriving in extreme temperatures and environments of Yellowstone National Park. Their adaptations could result in patents and engineering inspiration for nanomaterials.

Dr. Wan-Yuan Kuo, Dept. of Health and Human Development, is working on structural analyses for innovating value-added food products with small enterprises. Follow-on proposals are anticipated to NSF-CAREER and USDA-NIFA.

Dr. Roland Hatzenpichler, Chemistry and Biochemistry Department, is working on design and fabrication of a PDMS-based chip used to study the chemotactic behavior of bacteria. Results will be used to apply for DOE Early Career Program.

Dr. Chelsea Heveran, Mechanical & Industrial Engineering Department, is investigating improvement of the freeze-thaw resistance of cement by incorporating structural toughening mechanisms biomimetic of bone.

Dr. Yaofa Li, Mechanical & Industrial Engineering, is using pore-scale flow interactions of water and oil in a micromodel microfluidic device. This work is preliminary for proposals to NSF and ACS.

Research Highlights and Impact

Highlight slides for ten of our user projects are provided separately.

Scholarly Impact: During 2018, MONT researchers produced 41 journal papers, 53 proceedings papers and presentations, 1 book chapter, and 1 patent. These 96 products represent a 14% increase compared to 2017.

Example publications include: Hochstein et. al., who used MONT facilities for their ***PNAS*** paper (115:2120-2125, 2018) on "Structural studies of Acidianus tailed spindle virus reveal a structural paradigm used in the assembly of spindle- shaped viruses"; Trevor J. Gahl and Anja Kunze published, "Force-Mediating Magnetic Nanoparticles to Engineer Neuronal Cell Function" in ***Frontiers in Neuroscience*** (12:299, 2018); The Muson-McGee et. al. article, "A virus or more in (nearly) every cell: ubiquitous networks of virus-host interactions in extreme environments" (12:1706-1714, 2018) in ***ISME Journal*** has been **cited 21 times already** (Google Scholar); Jay et. al. published "Marsarchaeota are an aerobic archaeal lineage abundant in geothermal iron oxide microbial mats" (3:732-740, 2018) in ***Nature Microbiololgy;*** this article **has already been cited 12 times** (Google Scholar).

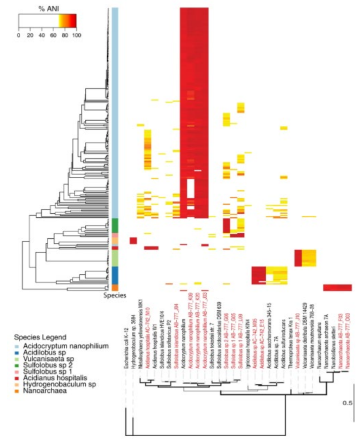


Fig.1 from "A virus or more in (nearly) every cell..."

MONT users had several outstanding accomplishments during the reporting period.

Dr. Anja Kunze, Department of Electrical and Computer Engineering, won a CAREER award (NSF# 1846271, Biol & Envir Inter of Nano Mat). Kunze's work is focused on engineering neuronal networks and exploring neuronal cell morphology in neurodegenerative diseases.

Dr. Stephanie McCalla, MSU department of Chemical and Biological Engineering, was also awarded an NSF CAREER grant (NSF# 1847245, Cellular & Biochem Engineering). McCalla's research is focused on biosensors and working toward affordable applications of this technology.

Dr. McCalla in lab with her student.

Dr. Erik Grumstrup, MSU department of Chemistry and Biochemistry, earned a Presidential Early Career Award for Scientists and Engineers (PECASE). The Grumstrup lab works toward understanding the optical, electronic, and chemical properties of materials important for advancing technology.

Economic Impact: During Y4, MONT served the needs of 35 industrial partners. Notable successes for our industrial users included $5.5M in active SBIR Awards.

Phase I (9 active)

- Agile Focus Designs, NSF IIP 1819493;
- Glacigen Materials, Inc., DOE DE-SC0018595 and DOE DE-SC0017698;
- Sustainable Bioproducts, LLC, NASA 80NSSC18P2141;
- AdvR, Inc., NASA 80NSSC18P2010 and DOE DE-SC0019566
- NanoValent Pharmaceuticals, Inc., DHHS R44CA233128
- NanoCoatings Inc., DOD W56HZV-18-C-0104

- Resodyne, Inc., DOD FA9101-19-P-0018

Phase II (6 active)

- Revibro Optics, NSF 1831287;
- Resodyn Corp., DOD W911QY-18-C-0231 & DOE DE-SC0017698;
- AdvR, Inc., NASA 80NSSC18C0030.
- Sustainable Bioproducts, LLC, EPA EP-D-16-007;
- NanoCoatings Inc., DOD N68335-18-C-0221

UTRS, American Chemet and others successfully parlay MONT usage to attract additional significant government and private investment to develop processes and products.

Education and Outreach Activities

MONT PI David Mogk co-authored the *Science* review article "Natural, incidental, and engineered nanomaterials and their impacts on the Earth system." This invited review grew out of an NSF-sponsored workshop Mogk hosted with lead-author Michael Hochella from **NanoEarth** in 2018, and included collaboration with **NCI-SW**. A companion educational website was developed at the **Science Education Resource Center (SERC)** to encourage inclusion of nanoscience in Earth and Environmental Sciences courses across the curriculum. Expanded webpages on "What", "Why", and "How" to teach nanoscience have been developed; all presentations from the 2017 and 2018 Goldschmidt Workshops and the NanoEarth 2018 workshop are posted for community use; and most importantly, an online annotated bibliography of over 500 references has been developed, based on recommendations from experts who attended these workshops, and organized by topic so that these studies can be readily included in current Earth and Environmental Science coursework. This bibliography includes up-to-date scientific results as well as references that pertain to societal issues, impacts on human health, environmental remediation of toxic substances, and ethical considerations. The "Topics" web resources can be accessed at: https://serc.carleton.edu/msu_nanotech/nano_topics.html

Modern Earth, from a nanoperspective.

Michael F. Hochella Jr. et al. Science 2019;363:eaau8299

In Y4, on-site outreach and education included a weeklong course for secondary science teachers in photovoltaics (teachers came from Missouri, Wisconsin, Massachusetts, and New Jersey), well-attended webinars, academic seminars, and Family Science Day attracting more than 600 people.

Societal and Ethical Implications Activities

Continued work with Carlton College's SERC includes an online resource collection of journal articles and books related to ethics in nanotechnology/science, and societal issues related to nanoscience. These references can be accessed at:

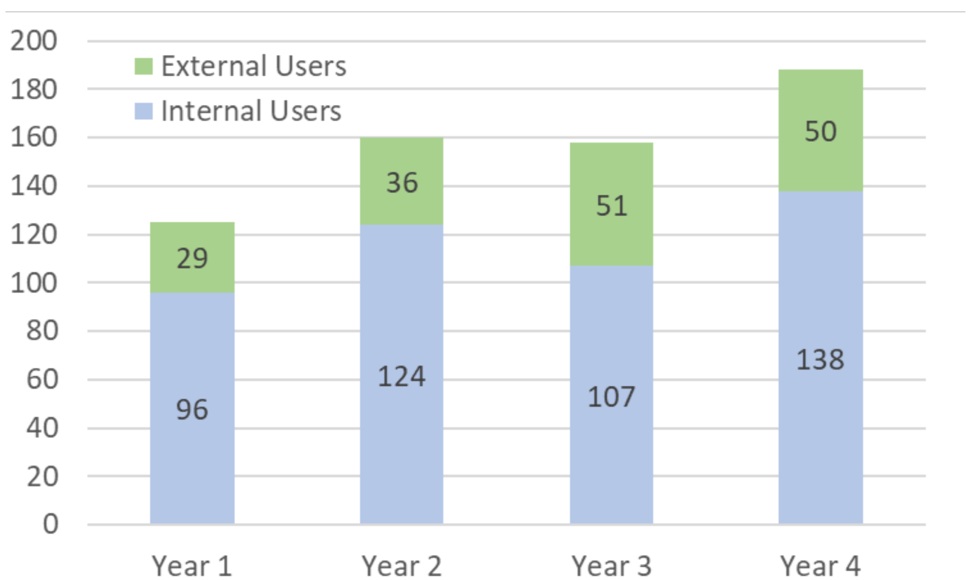
https://serc.carleton.edu/msu_nanotech/ethics.html

Metrics: Visitors to the SEI webpages are on the rise in Y4. The Professionalism webpages that deal with ethics and misconduct of researchers has had 1383 page-views. The Ethics and Nanoscience page has had 263 page-views since its launch on December 8, 2018, and the

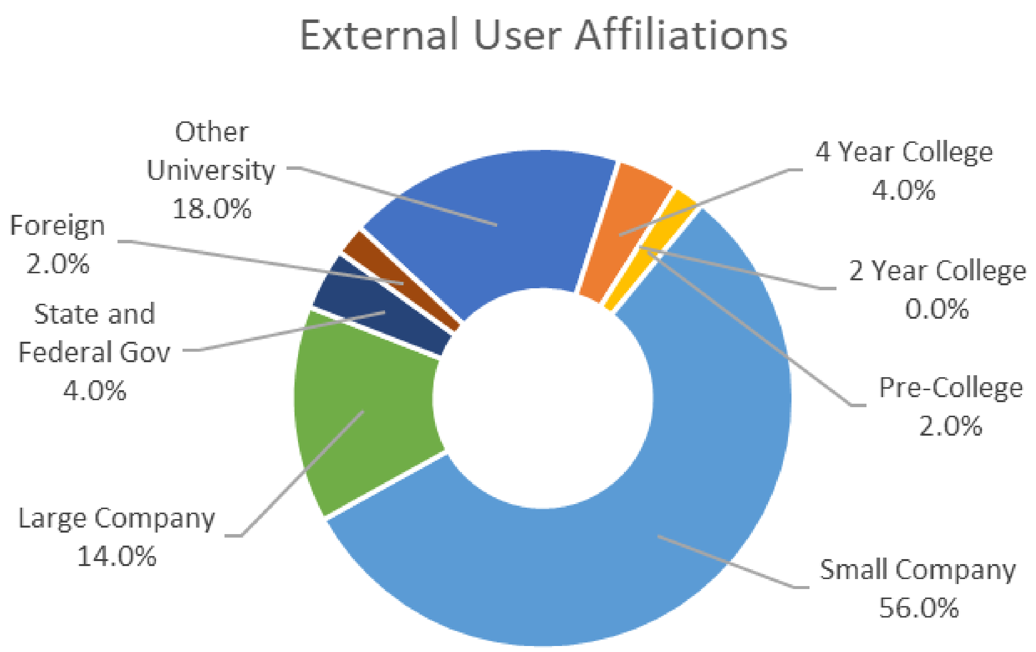
Nanoscience Topics in Earth Science resource collection has had over 912 visitors since its launch on the same day.

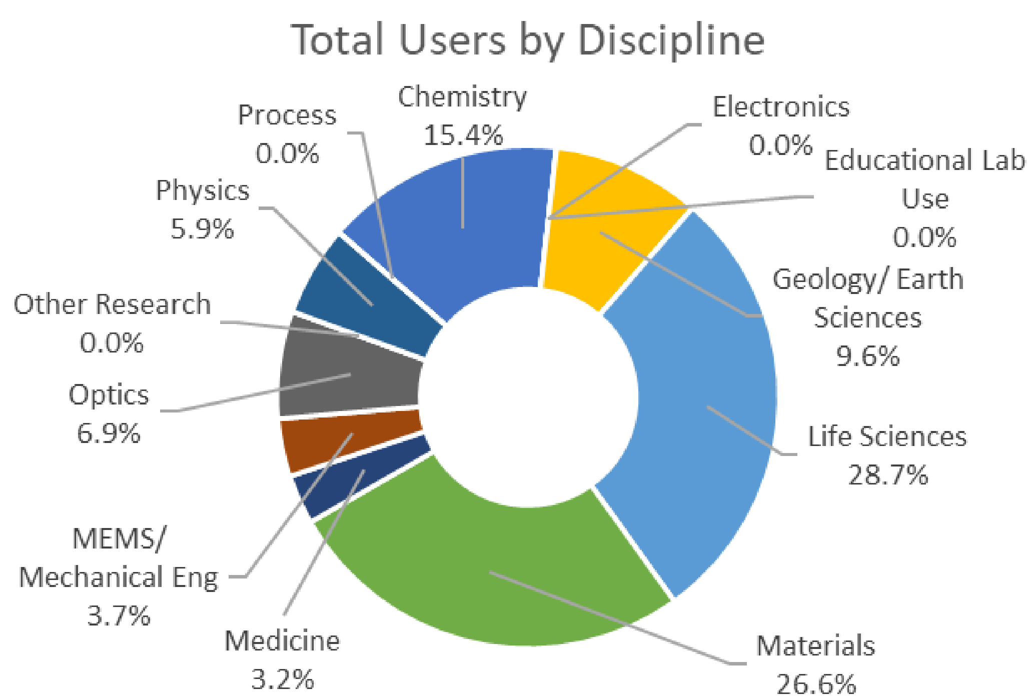
MONT Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	125	160	158	188
Internal Cumulative Users	96	124	107	138
External Cumulative Users	29 (23%)	36 (23%)	51 (32%)	50 (27%)
Total Hours	3,599	4,713	5,420	6,398
Internal Hours	2,842	3,901	4,541	5,332
External Hours	747 (21%)	812 (17%)	879 (16%)	1,066 (17%)
Average Monthly Users	46	51	43	62
Average External Monthly Users	8 (17%)	10 (20%)	7 (17%)	10 (16%)
New Users Trained	36	58	58	76
New External Users Trained	1 (3%)	9 (16%)	8 (14%)	6 (8%)
Hours/User (Internal)	30	31	42	39
Hours/User (External)	26	23	17	21



MONT Year 4 User Distribution





11.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

Facility, Tools, and Staff Updates

Helios FIB for the creation of ultra-thin TEM lamella with sub-nm damage layers.

The ASU Research Office (OKED) recognizes the importance of investing in equipment in high demand by both our internal and external users. For Year 4, OKED has approved $2.6M for a new Heliox G4UX focused ion beam tool from ThermoFisher Scientific. The Helios G4 UX dual beam focused ion beam instrument with cryogenic stage is a state-of-the-art dual beam FIB. Our current FIB capabilities can produce TEM samples, but the quality is too low to be optimal for our suite of aberration corrected S/TEM instruments. The new FIB will provide thinner samples with less surface amorphization. The Helios also has state-of-the-art SEM imaging capabilities and analytical capabilities for serial imaging and sectioning of the sample and 3D image reconstruction. The cryo-stage will allow the analysis of polymer and biological samples.

User Base

New for Year 4, the NCI-SW has implemented a seed funding program to increase the external user base of the site. Academic users not affiliated with ASU can apply for up to $5,000 in laboratory fees to offset the costs of using the ASU Nanofab and/or Eyring Materials Center. Interested users submit a short proposal that is reviewed by the Governance Boards of the NanoFab or EMC. To date we have made two awards to faculty and their students from the University of Arizona and the University of Nevada, Las Vegas.

During Year 4 the NCI-SW organized two multi-day workshops focused on the theory and practice of new and existing tools managed by the Eyring Materials Center (EMC) core facility. To support the growing body of users interested in cryogenic electron microscopy a CryoEM Workshop was held on the ASU campus from 11-14 December 2018. In total, 25 participants from 18 institutions were introduced to the concepts and applications of cryogenic electron microscopy through hands-on experiences including sample preparation, TEM operation, data collection and analysis. Complementing the CryoEM Workshop is the CHREM Winter School hosted 7-11 January, 2019. The Winter School combines theoretical classes with hands on sessions for scientists and engineers familiar with TEM but who need more advanced training.

Research Highlights and Impact

Intel is Hiring Manufacturing Technicians

Intel is hiring technicians with certificate and two-year degrees through online ads such as this.

The economic impact of the NCI-SW can be quantified through a collaboration with Rio Salado College. We host advanced laboratory curriculum for students enrolled in their two-year 62 credit AAS degree in Nanotechnology which contains an 18 credit Certificate of Completion. The stackable credentials offer options to students at different preparation levels. ***Since its launch in Spring 2017, more than 34 students have enrolled in the AAS Nanotechnology program and eight have already graduated, with two being offered jobs by Intel and one by Microchip.***

We impact regional economic development by supporting the needs of the small business community. Our longtime external user, Laser Components DG, Inc., has continued to expand with a ground-breaking ceremony for their new building on 25 April 2019. The new building will be used primarily for product test and packaging. LC-DG will continue locating two full-time staff members in the ASU NanoFab for R&D purposes. In the 16 years that LC-DG has been a small business user of the ASU NanoFab and EMC <u>*they have grown from a single employee to 30 full time staff*</u>.

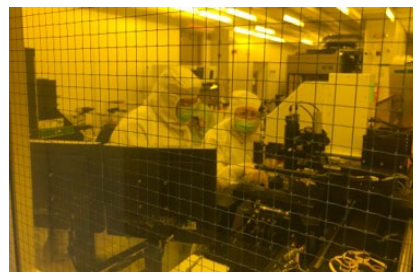
New facility for LC-DG Inc.

The NCI-SW provides general R&D micro- and nano-fabrication support across a range of disciplines. We place emphasis on reaching out to the medical/health communities as well as to researchers in the geological sciences. Summaries of user projects are presented in the research highlight slides.

<u>Education and Outreach Activities</u>

The NCI-SW E&O team lead by Dr. Ray Tsui conducted the following activities during Year 4.

(i) *Labs for Rio Salado College Students* - The number of labs taken at ASU by students from RSC increased from 12 to 17. The labs were conducted by the Eyring Materials Center and the NanoFab of the NCI-SW, and encompass a variety of topics in cleanroom safety, micro- and nanofabrication, and material characterization.



Students from Rio Salado College being trained on a lithography tool.

(ii) *Research Experiences for Undergraduates and Teachers* - The NCI-SW selected two community college students for the 2019 REU program. Both were female with one being Hispanic. In addition, a faculty member from Rio Salado College participated in our 2019 Research Experiences for Teachers program. To continue our efforts to support non-traditional nano-communities, the two REU students worked on projects associated with life sciences and environmental science research within NCI-SW.

(iii) *Remote Access to Equipment* - We continue to offer remote access (RA) to a desktop SEM over a web-based connection as a no-cost resource in education and outreach. The RA feature was used in 11 events where students at the remote locations had hands-on experiences imaging various samples at the micro- and nanoscale. Eight of the RA sessions were conducted with K-14 schools nationwide, one of which was part of a coast-to-coast, multi-site event during the 2018 National Nanotechnology Day.

(iv) *Lab Tours and Public Events* - As in years past, the NCI-SW was involved in two major public outreach events. In the first one, held in February 2019, we were part of ASU's annual open house called "Open Door." Hands-on activities included the use of an optical microscope to view patterned wafers and real-time remote access to the SEM to image micro- and nanoscale structures. There were almost 350 visitors to the exhibit. A random sample of participants were surveyed to determine their demographics and their interest in the NCI-SW activities. The second major event was "Geeks Night Out" held in March 2019 by the City of Tempe in which the main campus of

ASU is located. This is a signature event of the Arizona SciTech Festival, and once again we shared an exhibit with RSC. NCI-SW offered similar activities as in Open Door, and RSC demonstrated 3-D printing. Geeks Night Out is typically a family-friendly event with participants of all ages visiting the exhibit.

Two young visitors learn how to use a microscope during Geeks Night Out.

(v) *Introduction to Nanotechnology Workshop* - Two half-day workshops were coordinated by our partners at Science Foundation Az, as part of the annual Arizona SciTech Festival. The morning session was designed for K-8 educators and attracted 10 educators from six school districts. The afternoon session was targeted to high school teachers who took part in hands-on activities to engage and inform their students about the concept of nano-particles.

(vi) *Newsletters, Webinars and Social Media* – We host a series of webinars that are archived on our web site. The webinars last approximately one hour, and recent topics have included compact free electron laser technology, strategies to build nano-technology program enrollments, new silicon carbide nano-materials, and nano-biotechnology enabled healthcare. We produce newsletters emailed to a distribution list of over 2,000 addresses. The e-newsletters profile center news and highlight activities at the research partner centers. They also include a section in which one of our graduate student researchers explains their project and why it is important, using language that is accessible to the public. The newsletter also promotes upcoming outreach events, webinars and networking opportunities. The newsletter "open" rate was 28%, higher than the 14-18% open rate typical for e-newsletters of this type showing the excellent reach of the newsletters. Our Twitter account currently has 518 followers.

Societal and Ethical Implications Activities

Last year we reported an example of work that Dr Jameson Wetmore and his colleagues do in the NCI-SW SEI User Facility. They hosted Christopher Scott, Associate Director of the Center for Medical Ethics and Health Policy at Baylor College of Medicine, who was looking for ways to involve stakeholders in thinking about the future of genome editing technologies. His visit convinced him of **the importance of the methods developed at ASU and he asked three SEI faculty to be included on the R01 NIH grant**. We're happy to report that the NIH awarded that grant and NCI-SW SEI User facility faculty members have been working closely with Prof. Scott to run stakeholder engagement activities on this important emerging topic.

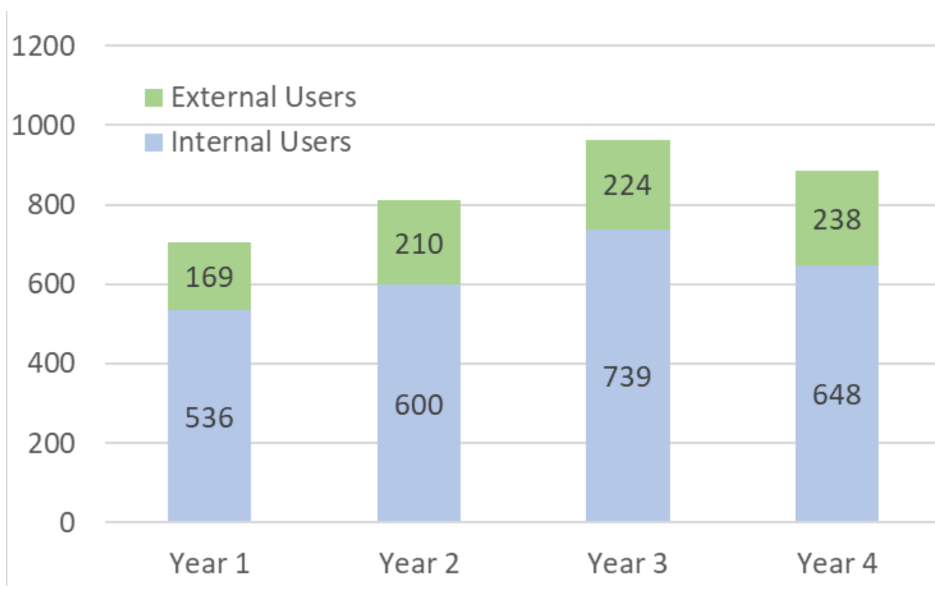
The SEI user facility sponsored the 4^{th} version of Science Outside the Lab (SOtL) focused on nano-technology in June 2019. We were able to take 15 graduate student scientists and engineers from eight different NNCI universities. Over the course of the week they met with policymakers to better understand how science influences policy and how policy influences science.

Computation Activities

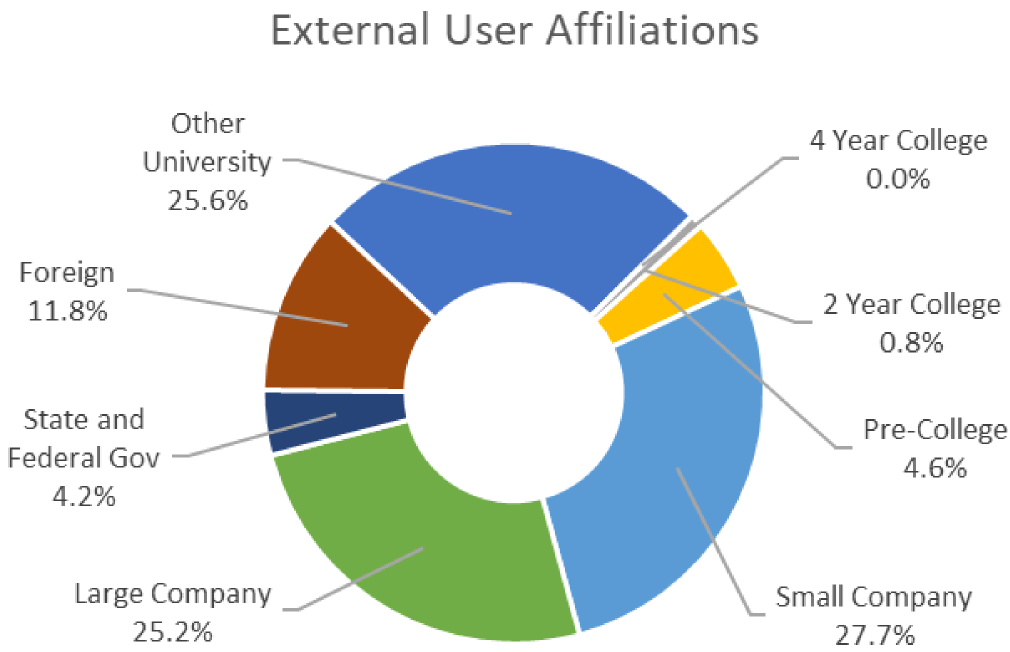
Dr. Dragica Vasileska is coordinating the computational activity for the NCI-SW and has been a long-time contributor and user of the NCN's nanoHUB. She has tallied 5,197 new simulation users on nanoHUB for calendar year 2018 and her content materials have been accessed by 111,207 users in the last 12 months. Prof. Vasileska has been involved in the development of several computational modules, including a tool to calculate the phonon-limited mobility in GaN/AlGaN nanowires which was published (V. N. Kumar and D. Vasileska, "Phonon-limited Mobility Modeling of Gallium Nitride Nanowires," Journal of Applied Physics 125, 114301 (2019)), and a 2D diffusion-reaction simulator (PVRD-FASP) for HgCdTe solar cells (A. Shaikh et al., "PVRD-FASP: A Unified 2D Solver for Modeling Carrier and Defect Transport in Photovoltaic Devices," IEEE J. Photovoltaics 9, pp1602 – 1613 (2019)).

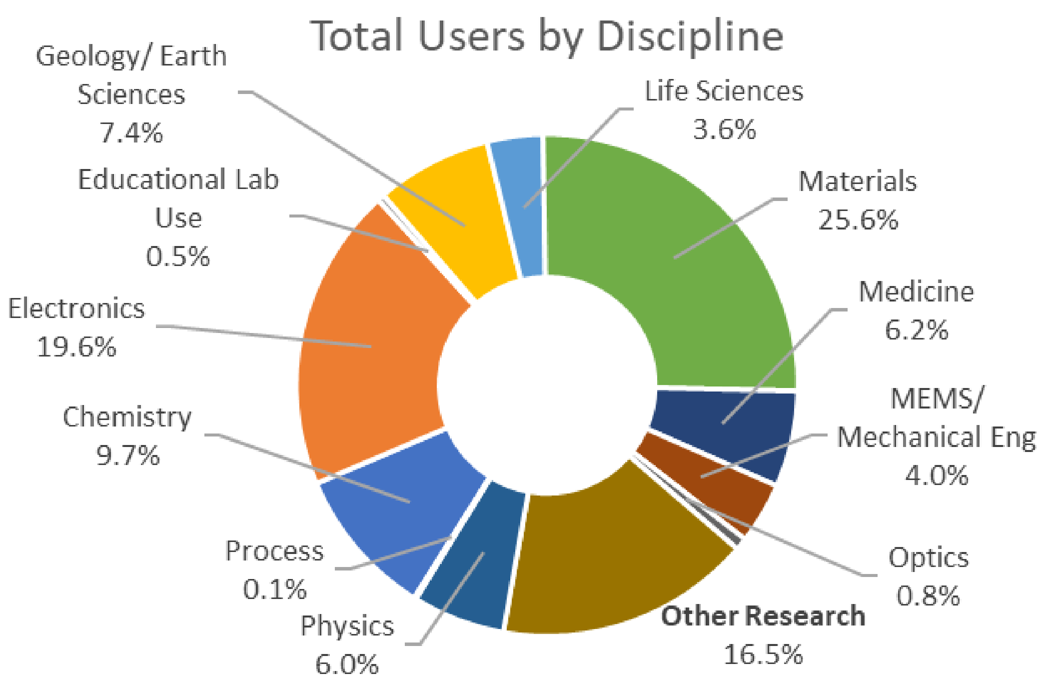
NCI-SW Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	705	810	963	886
Internal Cumulative Users	536	600	739	648
External Cumulative Users	169 (24%)	210 (26%)	224 (23%)	238 (27%)
Total Hours	43,098	49,370	46,647	50,630
Internal Hours	32,883	38,270	37,954	37,996
External Hours	10,215 (24%)	11,100 (22%)	8,693 (19%)	12,834 (25%)
Average Monthly Users	271	313	284	312
Average External Monthly Users	43 (16%)	49 (16%)	47 (17%)	56 (18%)
New Users Trained	275	333	675	700
New External Users Trained	47 (17%)	53 (16%)	102 (15%)	143 (20%)
Hours/User (Internal)	61	64	51	58
Hours/User (External)	60	53	39	54



NCI-SW Year 4 User Distribution





11.8. Nebraska Nanoscale Facility (NNF)

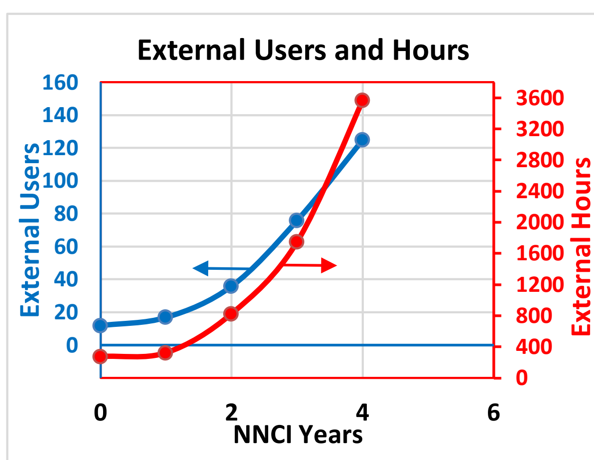
The *aim* of the Nebraska Nanoscale Facility (NNF) is to be an internationally recognized center of excellence for nanoscience, and a NNCI research hub for integrated fabrication, characterization and education in nanotechnology for the western region of the United States Midwest. NNF builds upon the established Central Facilities of the Nebraska Center for Materials and Nanoscience (NCMN) to promote nanoscience and nanotechnology research and educational outreach activities in Nebraska and throughout the region. The NNF provides open and affordable access to state-of-the-art facilities, expertise, training and services in nanoscience, nanotechnology, materials science and engineering to users from academia, industries and government labs.

Facility, Tools and Staff Updates

Facilities Updates: The enhancement of our NNF facilities has proceeded in the last year through funds received from the University of Nebraska, U.S. Army Research Office and NSF-NNCI. Following is a list of major acquisitions. ***New Tools and Capabilities:*** The Nanoengineering Facility recently added a new ZEISS Laser Confocal Scanning Microcope, EnvisionTEC 3D-Bioplotter 3D printer for tissue engineering research and a cell-culture laboratory. The Nanofabrication Cleanroom Facility purchased a second Ion Beam Milling and Deposition system, Intlvac nanoquest-II, and a Laurell WS-650-23B spin coater. The spin coater will accommodate up to ø150mm wafers and 5" × 5" (127mm × 127mm) substrates/masks, and features a maximum rotational speed of 12,000 RPM, which will largely enhance the capability of wafer processing at the nanofab facility. A Turbovac i Cart pump station and a 4" Sample Table for the HEX Deposition system with rotation and heating up to 300°C were added to the Nanomaterials and Thin Film Facility. An AR200 Laser measurement sensor from Acuity with computer and software for TEM sample thickness measurements was purchased by the Electron Nanoscopy Instrumentation Facility. A new Instron mechanical testing system was added to the NNF Shared Facilities. ***Staff Update:*** New staff members supported by NNF and the University of Nebraska include: NNF Coordinator and User Contact: Jacob John, Research Technologists: Anand Sarella and Andrei Sokolov, Program Associate: Samone Behrendt, and Engineering Associate: Zach Sun. Part-time support has been provided to Drs. B. Balasubramanian and W. Zhang to establish new XPS and high-field instrumentation.

User Base

A significant increase of the external user base from academia and industry is shown in the figure. It is in large part the result of proactive efforts by the NNF:NNCI-supported technical staff: Drs. Jacob John, Anand Sarella and Andrei Sokolov. ***Outreach to New Regional Users:*** The Facility Coordinator Dr. Jacob John has reached out to more than 170 companies located in Nebraska, Kansas, Missouri, Oklahoma, Colorado, South Dakota and Iowa and as a result, more than 60 companies visited the NNF for tours and discussions so far and around 50 of them have become NNF users. Some of the companies



that have recently visited NNF include Bosch Security Systems, Garner Industries, Toray CMA, Mitsubishi, TMCO, Nebraska Boilers, Snyder Industries, Royal Engineered Composites, Quantified AG, Vishay Dale Electronics, and Teledyne ISCO. The Facility Coordinator visited several universities and companies in South Dakota, Kansas, Missouri, and Oklahoma and these visits generated new external users and increased usage of the NNF. The NNF provides remote services for users who are located far away from our facility or have difficulty in making frequent trips to our site. More than 95% of our external users are remote users.

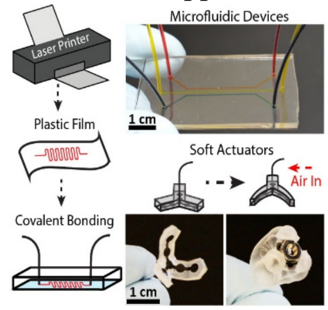
NNF Seed Grant for External Users: More than 25 external users benefited from the NNF Seed Grant/Free usage program for external users in the fourth year. The Seed grant program/Free usage program enabled external faculty members and students who lacked funding resources to access the NNF facilities and expertise and generate data for grant submissions and publications. The users who benefited are from Kansas, Oklahoma, Utah, South Dakota and Nebraska. The users who benefited include minorities and women. Several smaller companies and companies run by minorities benefited from the Free usage/Seed grant program. The NNF Facilities Seed Grant program aims to provide resources to industries, start-up companies, and students from 4- and 2-year colleges and universities for facilitating development of new nanotechnology enabled products, proof-of-concept development that involves characterization of nanomaterials, fabrication of devices and testing that require access to the instrumentation facilities.

Nanotech Minicourse for External Users: The 3-day Minicourse was held on May 13-15, 2019, had 25 external participants, all benefited from the lectures and hands-on operational experience provided by our Facility Specialists. The external users from other universities and companies were able to receive hands-on training on instruments of their choice at no cost. A survey was given at the end of the minicourse and a summary of responses showed 100% strongly agreed that they understood what work could be done using NNF and how to become a user after the event.
Nanotech Lab Course for Internal Users: This one-credit hour per semester course provides students with an introductory, but yet comprehensive view into the large variety of the instruments available at the NNF.

User Accomplishments: Ten spinoff companies were established over the years by the faculty and student users of the NNF. They are Rare Earth Salts, LNK Chemsolutions, Rieke Metals, Vajra Instruments, J. A. Woollam Co., Ground Fluor Pharma, Ossient, Inc., Photonic Solutions, Inc., Nanofiber Co., and Surface Integrity.

<u>Research Highlights and Impact</u>

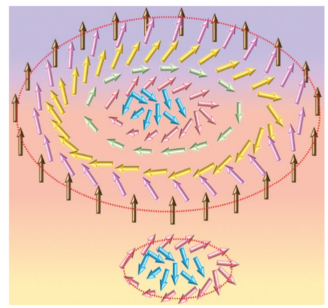
The Nebraska Center for Materials and Nanoscience, together with NNF, were able to obtain approval from the university administration to initiate a cluster-hiring process in quantum materials and technologies (QMT). These new faculty, along with several present faculty, will form a strong research group in the NSF Big Idea: Quantum Leap. The NNF supports and facilitates major sponsored research programs such as NSF MRSEC, NIST-SRC: Center for Nanoferroic Devices, NSF/DOD, NSF DOE projects and several others. The faculty users are primarily focused in the research areas such as polarization and spin phenomena in nanoscale structures, high-energy magnets, earth-abundant materials, spintronic devices, nanoferroic devices, nanomagnetics, functional nanostructures, laser processing, solar cells, nanomaterials for energy, complex nano-hybrid materials, nanophotonics, metamaterials, nanocrystals, graphene nanostructures, oxide films and interfaces,



nanomachines, nanobiology, nano-biosystems, sensors and devices, catalysis, metal-organic frameworks, etc.

Recent Scientific Achievements:

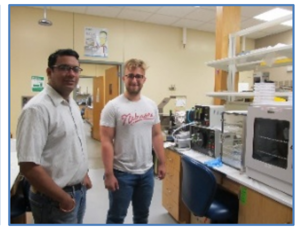
- NNF User S. Morin and his colleagues have developed a method which strengthens the bonding between plastics and silicones. It offers new possibilities for fabricating fluid-carrying channels that are commonly used to direct the motion of soft robotic components. The invention can drive movement in soft robotics and enable chemical analyses on microscopic scales. The developed technique facilitated a simple and scalable procedure that is capable of covalently laminating a variety of commodity ("off-the-shelf") thermoplastic sheets to silicone rubber films. When combined with laser printing, the nonbonding sites can be "printed" onto the thermoplastic sheets, enabling the direct fabrication of microfluidic systems for actuation and liquid handling applications (*Advanced Materials 30, 1705333 (2018))*.
- NNF Director David Sellmyer and B. Balasubramanian have reported the formation of skyrmions just 13 nanometers wide – what seems to be the smallest possible size in the material. Researchers had previously created skyrmions with a diameter of about 50 nanometers. The anomalous behavior shown by the 13 nm particle is size-dependent and suppressed in the smallest nanoparticles (9.7 nm), and this suppression is interpreted as a confinement effect that leads to a truncation of the skyrmion structure. Because creating and moving a skyrmion demands far less energy than aligning those polarized groups of atoms, researchers see the magnetic spiral as an appealing alternative for digital storage (*Nanoscale 10, 9504 (2018)*).



***Economic Impacts*:** The NNF critically supports all research in materials and nanoscience at the Univ. of Nebraska. The related annual research expenditures are \$22.8 M in FY 2018, leading to an estimated \$137 M in economic activity. NNF also supports the Manufacturing economic sector of Nebraska's economy which, at \$12.9 B, is third in the state's gross domestic product after Government (\$14.8 B) and Finance/Insurance (\$13.3 B). The NNCI grant enables NNF to provide critical resources necessary for many companies, smaller universities and colleges in the Midwest region. The NNF supported more than 60 regional institutions in 7 states in the Midwest region during the 4th NNCI year in terms of R&D, innovation, product development and testing, quality control, solving and identifying problems in product lines and identifying reasons of product failures in the field, etc. For example, a small company that makes agricultural equipment located in Nebraska was having problems due to failure of one of their products in the field. They approached the NNF and we ran a few tests on the failing product and identified the cause of failures. The test saved that product and the company rectified the problem. There are many such examples. Access to NNF enables the companies to improve manufacturing processes, facilitate R&D programs, and develop or test new products. NNF resources and seed grants enables smaller companies to obtain SBIR and other grants, which results in business expansion, and more jobs. The NNF facilitates the awards of several federal and state research grants for faculties and students in small colleges and universities in the region and enables successful completion of such projects by providing full access to the NNF capabilities and resources.

Education and Outreach Activities

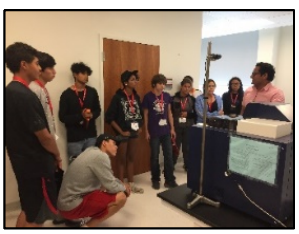
***REU programs*:** Individual students and Professor/Student pairs worked in research labs for 10 weeks during the summer (2 professors/5 students) focused on nanoscience areas. Two students from this program have been chosen to travel to Japan as part of the NNCI summer exchange program and one received a Barry Goldwater Scholarship award. We also hosted a visiting Japanese student for 10 weeks that was part of the NNCI REU prog. NNF supported the summer CREST REU prog. between California State Univ. -San Bernardino and the Univ. of Nebraska MRSEC.



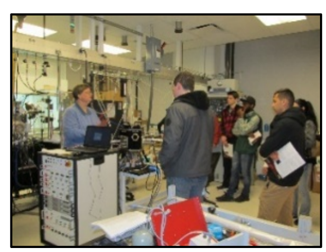
***High School Intern Program*:** NNF hosted a STEM summer prog. for 12 high school interns in June-August 2019. Faculty from Chem., Phy. and Eng. provided opportunities for high school students to work in their research labs for 10 weeks with the help of a graduate student mentor.

K-12 Diversity Programs for Title 1 Schools: (1) After-School and Summer Nano Camps for hundreds of diverse elementary and middle school student populations and 1st generation, college-bound high school girls. (2) Using nanoscience curriculum developed in partnership with the 4-H program and utilizing the Remote Assess Instruments for Nanotechnology (RAIN) network, 190 diverse elementary students, in 14 different schools were introduced remotely to nano equipment analysis, nanoscientists, and new products.

***Teacher Conferences/Workshops*:** NNF trained hundreds of K-12 teachers with STEM/Nano-related information at teacher science fairs and conferences, and workshops, and through online educational videos, and lesson plans.



Rural Workforce Development: Information and hands-on activities were presented to 70 junior high girls from three small rural schools about nanolight technology, graphene, and nanocomposites topics at a community college in the region. ***NNF Special Events*:** 1. NanoDays, a nationwide festival of educational progs. about nanoscale sci. and eng. was held at our local mall and attended by 400 students and general public. 2. Student Conferences included the Conference for Undergrad. Women in Physical Sciences, WoPhyS, where NNF partnered with MRSEC to bring together outstanding student researchers in Physics from across the US. Neb. 3. NNF hosted tours for over 500 K-16 students, teachers, faculty, and parents. ***Traveling Nanoscience Exhibit*:**

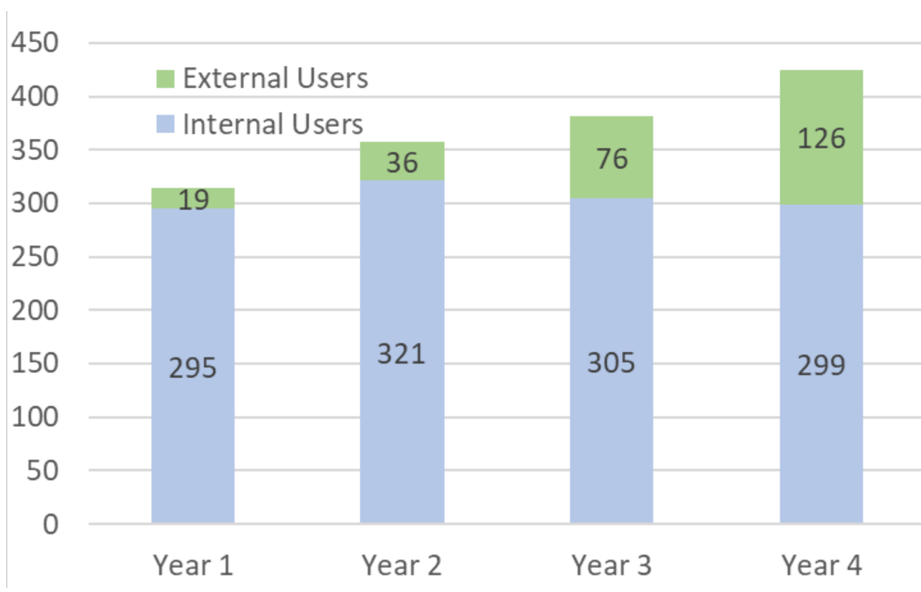


Our 400-sq.-ft. hands-on exhibit was viewed by over 14,000 people in two museums in Iowa, one community college and one tribal K-12 public school (teacher/student workshop included) this past year. Three tribal community colleges are scheduled for 2019-2020 targeting rural, underrepresented students.

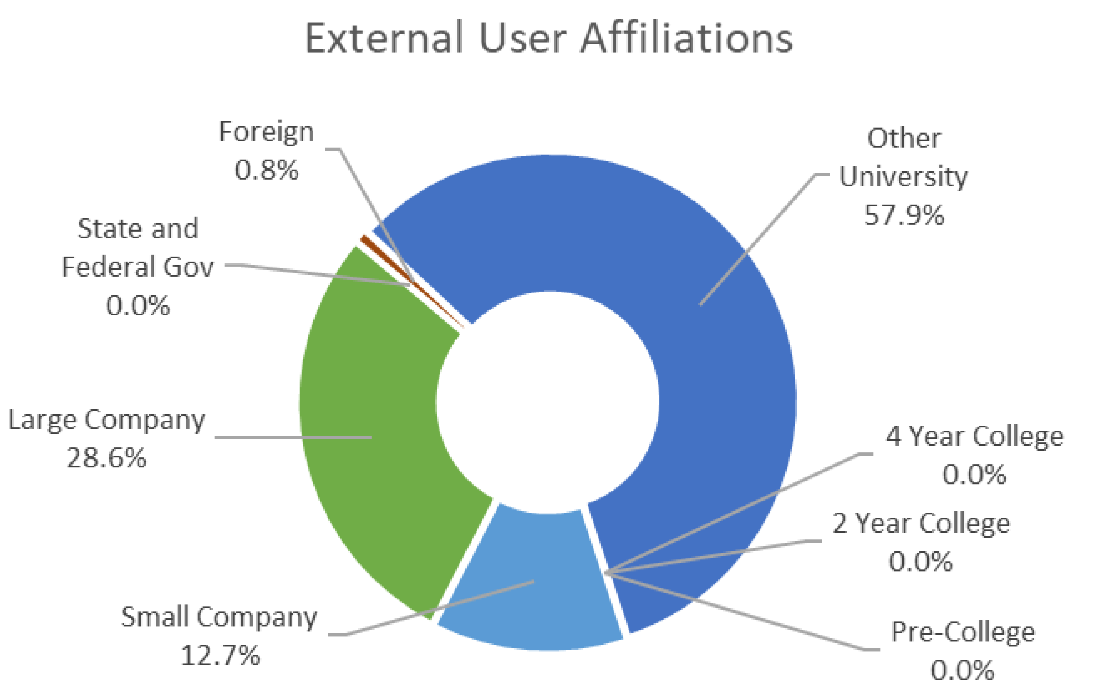
Workforce Development**:** NNF hosted a half-day tour for a 10 undergraduate student cohort from Central Community College. We regularly provide tours and training to hundreds of undergraduate and graduate students in these facilities. ***Assessment Activities:*** NNF conducted exit surveys of participants in the various REU programs, including individual students, Professor-Student Pairs, NNCI Japanese REU and the CREST REU. The High School Interns were also assessed after their work in nanoscience labs in the summer. NNF evaluated efforts to promote nanoscience among diverse, underrepresented groups, by surveying participants at the completion of After School programs, Summer Nano Camps, the WoPhyS conference, the NanoDays event, workforce development efforts to middle school girls in northeast Nebraska, and at some Traveling Nanoscience Exhibit venues.

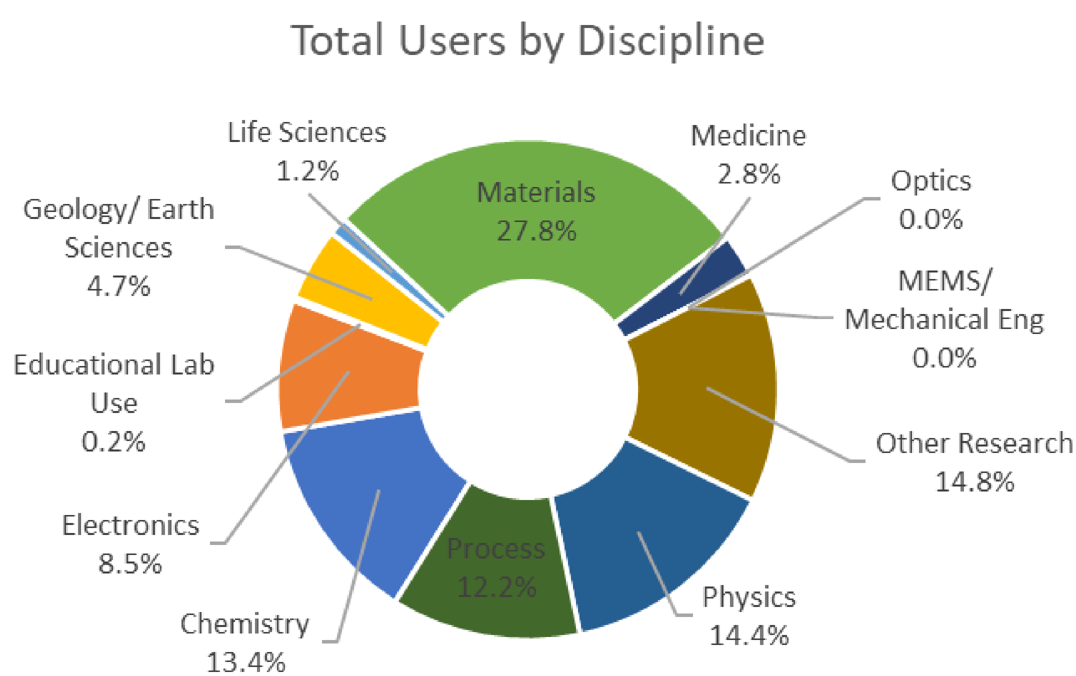
NNF Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	314	357	381	425
Internal Cumulative Users	295	321	305	299
External Cumulative Users	19 (6%)	36 (10%)	76 (20%)	126 (30%)
Total Hours	23,445	20,102	24,008	31,037
Internal Hours	23,123	19,278	22,260	27,468
External Hours	322 (1%)	824 (4%)	1,748 (7%)	3,569 (11%)
Average Monthly Users	40	120	132	137
Average External Monthly Users	3 (8%)	7 (6%)	19 (15%)	18 (13%)
New Users Trained	47	54	124	98
New External Users Trained	0 (0%)	1 (2%)	6 (5%)	7 (7%)
Hours/User (Internal)	78	60	73	92
Hours/User (External)	17	23	23	28



NNF Year 4 User Distribution





11.9. NNCI Site @ Stanford (nano@stanford)

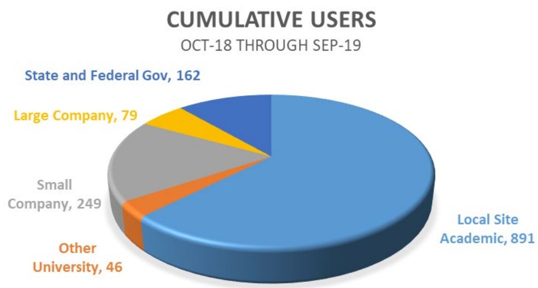
Facility, Tools, and Staff Updates

The NNCI Site @ Stanford University provides access to world-leading facilities and expertise in nanoscale science and engineering for internal users and for external users from academic, industrial, and government labs. Furthermore, we seek to develop and propagate a national model for educational practices that will help students and visitors become knowledgeable and proficient users of the facilities.

Stanford's facilities offer a comprehensive array of advanced nanofabrication and nanocharacterization tools, including resources that are not routinely available at shared nanofacilities, such as an MOCVD laboratory that can deposit films of GaAs or GaN; a JEOL e-beam lithography tool that can inscribe sub-10-nm features over 8-inch wafers; a Cameca NanoSIMS that combines the high mass resolution, isotopic identification, and sub-ppm sensitivity of conventional SIMS with 50-nm spatial resolution; and a unique scanning SQUID microscope with world-leading spin sensitivity. The facilities occupy ~30,000 sq. ft. of space including 16,000 sq. ft, of cleanrooms. They offer state-of-the-art equipment as well as processes developed by scientists who work at the cutting edge of nanoscience. Close to forty expert staff members maintain the instruments, teach users to operate them, and consult with users to optimize processes for their applications. The NNCI Site @ Stanford provides access to the ***Stanford Nano Shared Facilities (SNSF)***, the ***Stanford Nanofabrication Facility (SNF)***, the ***Stanford Mineral Analysis Facility (MAF)*** and the ***Stanford ICP-MS/TIMS Facility***. **New capabilities**: During this reporting period we added several new capabilities to our offerings, including a Keyence 3D imaging system that enables inspection of fabricated structures that are increasingly three-dimensional and more system level, a Xplore microcompounder and extruder to enable researchers to build structures out of new materials and material mixtures, a Durham Magneto Optics ML3 MicroWriter direct write system that allows the user to do "mask-less" photolithography, a Bruker Dimension ICON AFM and a Quorum PP3010 cryo preparation system, which is as highly automated, easy-to-use, column-mounted, gas-cooled cryo preparation system which was installed on our FEI Helio FIB/SEM. **Personnel**: Dr. Phil Himmer joined SNF as a Senior Member of the Technical Staff, Graham Ewing joined SNF as a Lab Operations Engineer, Kasia Krow-Lucal as a Lab Services Administrator, Tai Kim joined SNF as an Accounting Assistant. Dr. Roy Kim joined SNSF as the manager of the Transmission Electron Microscopy Laboratory Manager, Grant Shao joined SNSF as the Cleanroom Operations Engineer, and Justine Dachille joined SNSF as the External User Coordinator.

User Base

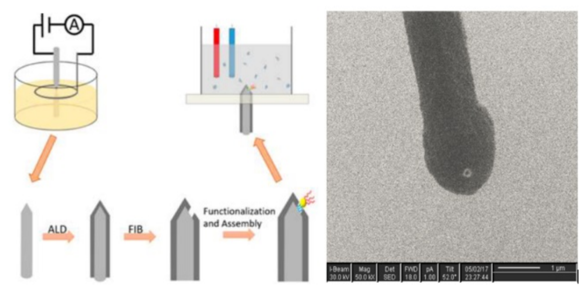
Between October 2018 and September 2019, the NNCI Site @ Stanford University served a total of 1,427 users: 891 internal users, 328 industrial users, 162 state and federal government users,



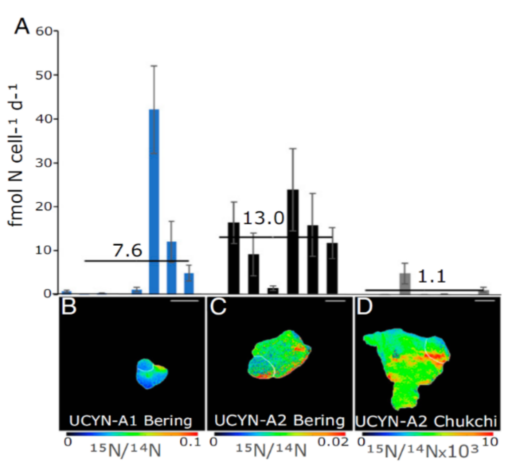
and 46 external academic users. Billed user fees during this time accumulated to about $7M of which about $3.8M was collected from external users. During calendar year 2018 we captured 309 journal publications, 59 conference publications, 5 patent applications filed, and 8 patents issued. We note here that publications are all self-reported. We estimate the total number of publications to be about three times higher but continue struggling to capture all publications. We have started to work with a team at Stanford Libraries to automate the collection process.

<u>Research Highlights and Impact</u>

ProbiusDx is a Stanford spin-off from the research group of Prof. Howe founded in 2015. The company aims to develop a non-invasive point of care diagnostic technology for detecting and monitoring blood concentrations of antimicrobial drugs. The ability to measure drug concentrations in a patient's blood provides valuable information for individualized optimal dosing, maximal efficacy and reduced potential for undesirable side effects. Designed to mimic the olfactory system, it relies on a nanoscale electrochemical solid-liquid interface to detect the vibronic signatures of the biomolecular matrix, and uses the analytical capability of machine learning to identify the biomarker signatures within the complex matrix. The company uses the NNCI Site @ Stanford to prototype their sensors and has enabled them to successfully complete their Phase I SBIR grants and facilitated the conversion into larger Phase II contracts. A team of researchers from ***UC Santa Cruz, College of William & Mary, Memorial University of Newfoundland, Bigelow Laboratory for Ocean Sciences, and*** Stanford used the NNCI Site @ Stanford to study how symbiotic unicellular cyanobacteria can fix nitrogen in the Arctic Ocean. They used nanoscale secondary ion mass spectrometry (nanoSIMS) to measure 15N2 uptake into



Left: Electrochemical sharpening of the tip of the Pt−Ir wire, coating with an insulating HfO2 film using atomic layer deposition (ALD), etching a small hole in the film using a focused ion beam (FIB), functionalization of the exposed Pt−Ir in the hole, and mounting in hole in PDMS membrane. Right: SEM image of sensor element (Pt-Ir wire) is coated with ALD HfO2 and with a 50nm hole subsequently milled in the oxide with FIB



UCYN-A symbioses fix 15N2 in western Arctic waters. UCYN-A cellspecific 15N2 fixation rates (A) and 15N enrichment (B–D) from nanoSIMS measurements after incubating natural populations in seawater with 15N2. Bars of the same color (A) represent rates measured in individual symbioses (UCYN-A with host alga) from a single station and lineage (noted in underlying cell image). (Scale bar, 2 μm.) Averages are shown by a horizontal black line. Error bars are the SD of the cell-specific rate between the host and UCYN-A.

UCYN-A/haptophyte symbiosis and found that UCYN-A strains identical to low-latitude strains are fixing N2 in the Bering and Chukchi Seas, at rates comparable to subtropical waters. These results show definitively that cyanobacterial N2 fixation is not constrained to subtropical waters, challenging paradigms and models of global N2 fixation. The Arctic is particularly sensitive to climate change, and N2 fixation may increase in Arctic waters under future climate scenarios.

Education and Outreach Activities

All users of shared nanofacilities must understand the basic concepts of nanoscience, the properties of materials, and the physical principles that underlie fabrication and characterization techniques. *The knowledge of the users, rather than the availability of the instruments, is the rate-limiting factor that controls scientific and technological progress in shared nanofacilities.* Our vision is that Stanford will accelerate progress in nanofacilities nationwide by providing open access to critical information. In collaboration with internal Stanford offices as well as some of the other NNCI nodes, ***we are working to create and assemble a comprehensive online library of just-in-time educational materials that will enable users to acquire foundational knowledge independently and expeditiously before they receive personalized training from an expert staff member***. We added several new modules during this reporting period and are rolling these out more broadly across our facilities.

The NNCI Site @ Stanford is dedicated to ***developing and implementing activities targeted at youth, school teachers, and the general public that will increase their interest, understanding, and involvement in STEM***. These initiatives range from volunteer participation in outreach events to more in-depth workshops that span multiple days. During the reporting period, about 1,300 people were involved in these types of activities with the NNCI Site @ Stanford. We are developing a ***Summer Institute for Middle School Teachers*** (SIMST) program that enables middle school teachers in the local bay area community to learn about nanoscience and how to incorporate the content into their classroom. 15 teachers participated in June 2018. 5 out of the 12 teachers were from Title 1 schools. We continued engaging with the teachers as they implemented their lesson plans and returned to Stanford for a follow-up workshop.

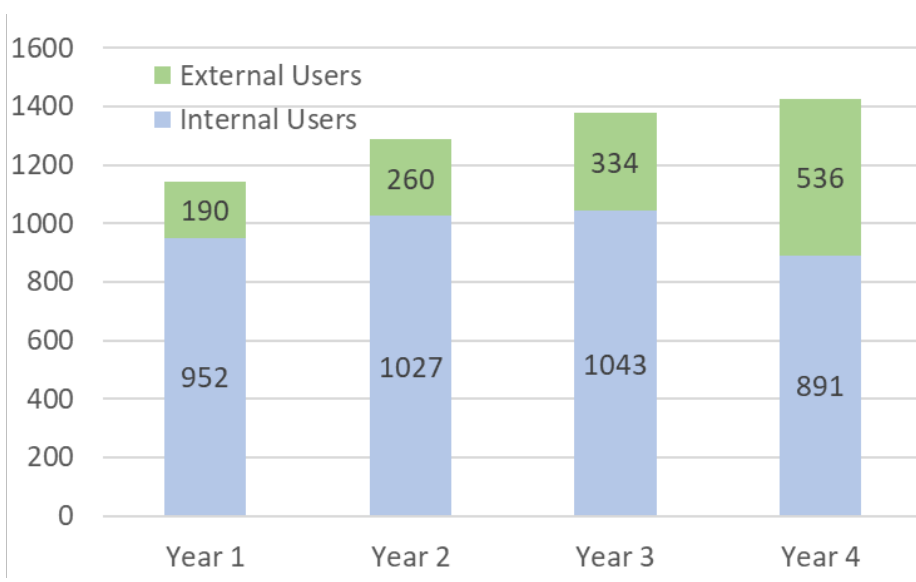
(Left) A group of SIMST teachers learn about AFM during a demo. (Right) Our nanoscience outreach group attends the Bay Area Science Festival at AT&T Park.

Selected partner institutions serving diverse audiences are being supported by Stanford. During this reporting period we have strengthened our partnership with ***California State University, East Bay*** (campus visits, support for fab and characterization, published article in educational journal) and initiated a new partnership with ***Foothill College*** focused on workforce development. ***Notable network activity***: During this reporting period we hosted the ***2018 NNCI Etch Symposium*** (attended by over 100 participants, including almost all NNCI sites as well as other Universities), the ***2018 direct-write Symposium*** (attended by over 120 participants, including participants from 30 different companies and 15 outside academic institutions). The Stanford Site also actively participated in ***National Nanotechnology Days***, the ***USA Science & Engineering Festival***, and several ***NNCI Working Groups*** (including founding of the NNCI Technical Content Development working group led by Dr. Angela Hwang).

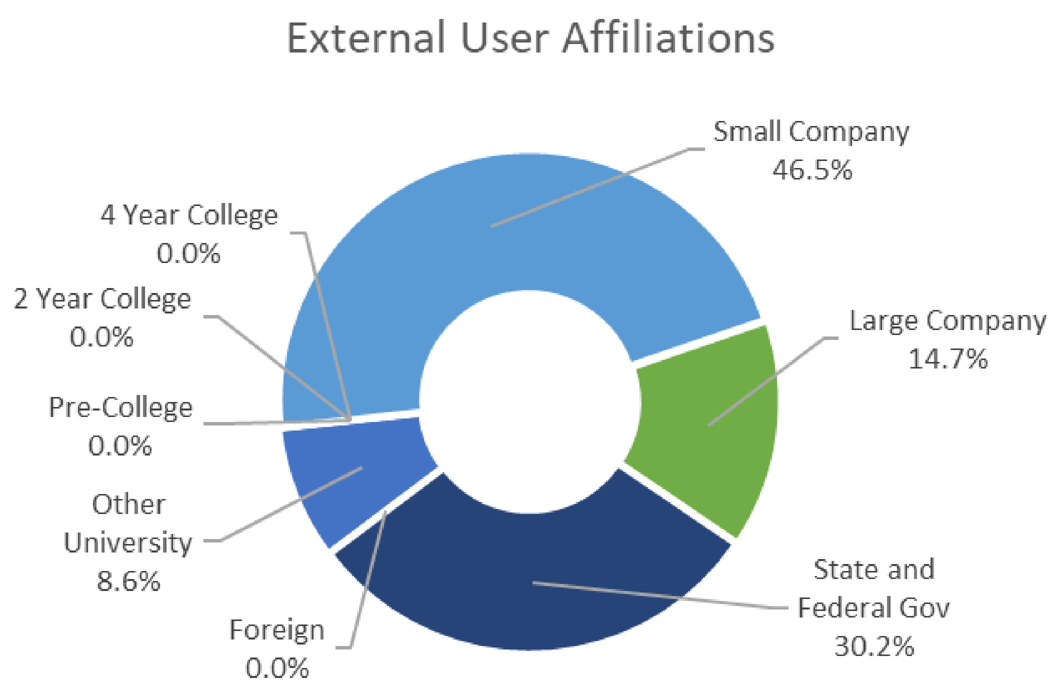
nano@stanford Site Statistics

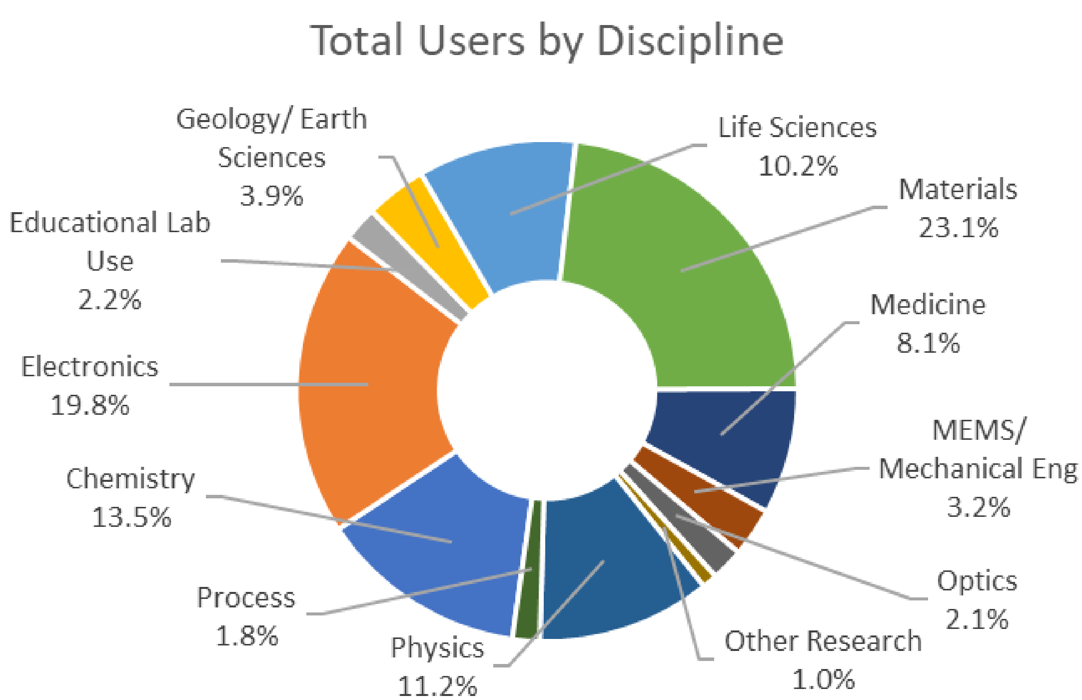
Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 3**
Total Cumulative Users	1,142	1,287	1,377	1,427
Internal Cumulative Users	952	1,027	1,043	891
External Cumulative Users	190 (17%)	260 (20%)	334 (24%)	536* (38%)
Total Hours	113,089	113,193	135,054	119,877
Internal Hours	94,996	91,248	105,083	72,408
External Hours	18,093 (16%)	21,944 (19%)	29,971 (22%)	47,469* (40%)
Average Monthly Users	520	572	601	615
Average External Monthly Users	74 (14%)	92 (16%)	115 (19%)	213* (35%)
New Users Trained	550	579	584	596
New External Users Trained	97 (18%)	143 (25%)	194 (33%)	262 (44%)
Hours/User (Internal)	100	89	101	81
Hours/User (External)	95	84	90	89

*During Year 4 the Stanford site began to categorize users from the SLAC National Lab as federal government users instead of internal users.



nano@stanford Year 4 User Distribution





11.10. Northwest Nanotechnology Infrastructure (NNI)

The Northwest Nanotechnology Infrastructure (NNI) site, the Pacific Northwest node in NSF's NNCI network, includes world-class facilities at the University of Washington (UW) in Seattle, Washington and at Oregon State University (OSU) in Corvallis, Oregon. These publicly-accessible facilities provide researchers and engineers in the region, across the country and around the world, with access to both workhorse and cutting-edge tools, advanced training opportunities, and other specialized resources. Moreover, NNI leverages collaborations with academic, industry, and government partners, such as the Department of Energy's Pacific Northwest National Laboratory (PNNL) in Eastern Washington State, to expand NNI capabilities. By linking together characterization and fabrication capabilities across the Pacific Northwest, NNI streamlines and expands the breadth of equipment and expertise available to scientists with diverse research interest and needs. The increasingly large and distributed user base of NNI facilities includes academic and industrial users as well as nontraditional users in materials science, clean energy and biotechnology. NNI also plays an important role in educating and training the highly skilled workforce of engineers, researchers, and technicians needed by industry. NNI continues to be key to affirming the Pacific Northwest's leadership in nanotechnology research and innovation.

Facility, Tools, and Staff Updates

Infrastructure Investments

The new NanoES building, inaugurated in December 2017 with 45,000 assignable square feet of research space and host of the 2018 NNCI Annual Conference, is now nearly fully occupied by an interdisciplinary assembly of researchers in nanotechnology, molecular engineering, clean energy, and protein design. The NNI Molecular Analysis Facility (MAF) has expanded into the ground floor of NanoES with upgraded TEM and cryoTEM services.

Major New Tools and Capabilities

University of Washington:

- 2 Picosun Atomic Layer Deposition (ALD) systems for a wide range of oxides, nitrides, metals
- Oxford PlasmaPro 100 Cobra chlorine etcher dedicated to PZT
- Two gloveboxes with nitrogen environment for ALD precursor work and PZT synthesis
- FEI Apreo SEM with sTEM offering higher resolution and better charge neutralization; retractable sTEM detector and directional backscatter; EBSD detector will be added in early 2020
- Video rate capability added to Asylum CypherES AFM
- FEI Vitrobot Cryoplunge sample preparation tool for cryoTEM
- Alumnus In situ Nanoindenter (for use in Sirion and Apreo SEM systems)

Oregon State University:

- Temperature-programmed desorption/electron-stimulated desorption (TPD/ESD) system added to Ambient Pressure Surface Characterization Lab
- STM imaging added to Ambient Pressure XPS system
- Ultra-fast laser system for characterization of thin films, funded by an NSF MRI

- Hitachi TM 4000 desktop SEM with EDX added to the Advanced Technology and Manufacturing Institute (ATAMI)

Staff Updates

WNF director Dr. Michael Khbeis stepped down to join Facebook Reality Labs as its new director of operations and was replaced by solar and semiconductor industry veteran Dr. Maria Huffman in mid-July 2019. Shane Patrick acted as Interim Director between December 2018 and July 2019 and will continue as the manager of laboratory operations and safety for WNF. WNF staff engineers, Duane Irish and David Nguyen, also left UW to pursue opportunities in the private sector. WNF has since hired Sarice Jones and Jean Nielsen to fill the open engineering positions. Former WNF industrial user Jason Tauscher joined WNF as manager of business outreach and customer development to help organize and direct remote projects. At NNCI-MONT, former WNF senior engineer and UW alumnus Dr. Andrew Lingley was hired as manager for the Montana Microfabrication Facility. In early 2019, Dr. Lara Gamble, NNI co-PI, became director of the MAF, taking over for long-time director Dave Castner, Professor of Bioengineering and Chemical Engineering at UW, who retired. MAF research scientist Dr. Liam Bradshaw stepped down to join local tech start-up EoSpace (Redmond, WA), but continues to work with the MAF as an industrial user. MAF staff scientist Gerry Hammer retired in 2019. MAF hired Dr. Samantha Young as a research scientist. OSU hired Dr. Rafik Addou to help manage the Ambient Pressure Surface Characterization Laboratory (APSCL). NNI Administrative Coordinator Tosha Missel departed for a new position in the private sector and was recently replaced by Makeda Beck.

User Base

Academic research at NNI spans a wide range of topics including the principal research areas of integrated photonics and quantum devices, advanced energy materials and devices, and bio-nano interfaces and systems. This work is complemented by users from government laboratories and industry, with regional startups and small businesses representing the largest portion of external users.

Even though this year has seen critical staff turnover as well as impacts on WNF operations due to flooring construction and repair activities, there are solid strategic and tactical plans for future growth, namely: increased user-staff interaction to plan for current and future equipment support and acquisition, as well as targeted aging tool replacement; focus on critical research areas, one of which is growth in PZT processing capabilities as well as support for rapid prototyping needs in microfluidics or simpler devices requiring a less stringent cleanroom environment. To that end, we have created a new, full-time position with specific focus on business outreach and customer development, and we are developing plans, jointly with the UW start-up incubator CoMotion, to expand to an adjacent space for hardware innovation and heavy prototyping.

There has been a significant expansion of users for the Ambient Pressure Surface Characterization Lab (APSCL) and we will continue to market the capabilities to academic, industrial, and national laboratory users. A new brochure has been created and we are updating the website to provide more information on the capabilities and highlight data obtained from the AP-XPS/AP-STM system.

Research Highlights and Impact

The past year saw the inauguration of QuantumX, an interdisciplinary group of faculty pioneering the development of quantum-enabled technologies at the UW, and of the Northwest Quantum

Nexus (NQN), a coalition - led by UW, Microsoft, and Pacific Northwest National Labs - of research and industrial organizations in the Pacific Northwest and neighboring regions with the goal of advancing Quantum Information Sciences (QIS) research and developing a QIS-trained workforce. A core focus of the NQN is scalable quantum computing for clean energy, with principal research directions in applications for quantum computing, quantum algorithms, as well as the synthesis and characterization of materials for QIS.

During the current reporting period there has been a significant increase in external use of APXPS/AP-STM capabilities in the APSCL, including users from the National Energy Technologies Laboratory, the University of Arkansas, HP Inc., and Intel. Researchers at the Illinois Institute of Technology and the University of Buffalo are currently scheduling time to use this capability.

ATAMI company Nano3D Systems, LLC creates metallization processes for next-generation microsystems manufacturing. It has recently successfully completed an NSF SBIR Phase II/IIB project and established marketing, distribution and sales in China. UW spin-out Tunoptix, LLC, which develops tunable metasurface optics for machine vision and AR/VR applications, received seed funding from a leading intellectual property commercialization company.

Education and Outreach Activities

NNI continues to support the public's growing interest in nanotechnology through a range of education and outreach activities that impact K-to-gray audiences in the Pacific Northwest. In the past year, NNI activities reached over 16,000 participants through NNI-hosted hands-on activities, campus and lab tours, internships and training positions, REUs and undergraduate research symposia.

- Workforce Development: NNI facilities train undergraduate assistants who gain hands-on laboratory experience. WNF alone employed a record-breaking 34 assistants that included 10 women, 2 Native Americans, and 2 Hispanic or Latino. During the past year, 4 assistants transitioned to work in the facility for industrial clients. MAF employed 3 assistants, all women and one self-identified Latina. OSU had 27 undergraduate researchers in nanotechnology, of which roughly one third identified as female or other underrepresented group in engineering.
- Pre-college, K-to-Gray, and First Nations Outreach: NNI members engage students and educators through interactive nanotechnology activities at local and regional K-12 and community STEM events, with over local 16,000 participants in the past year. The second annual multi-day UW campus visit for students from Paschal Sherman Indian School was hosted. NNI continues to engage with the Puyallup Indian Tribe, including one student (now a UW junior) who works as a lab assistant in the WNF and liaisons with the high school science department for nanotechnology outreach.
- Deployable nanotechnology teaching modules have been assembled based on classroom tested material and refined with student input.
- Assessment: NNI is committed to a process of continuous improvement to ensure its education and outreach activities are effective and provide a meaningful experience. Assessment vehicles were used to evaluate the impact of our outreach activities, collecting 216 individual responses. Participant engagement was assessed to be very high, with an average score of 4.5 (out of a maximum of 5) to the question "this activity was fun."

Participants wanted to learn more (4.4) and agreed that it increased their interest in STEM (4.3).

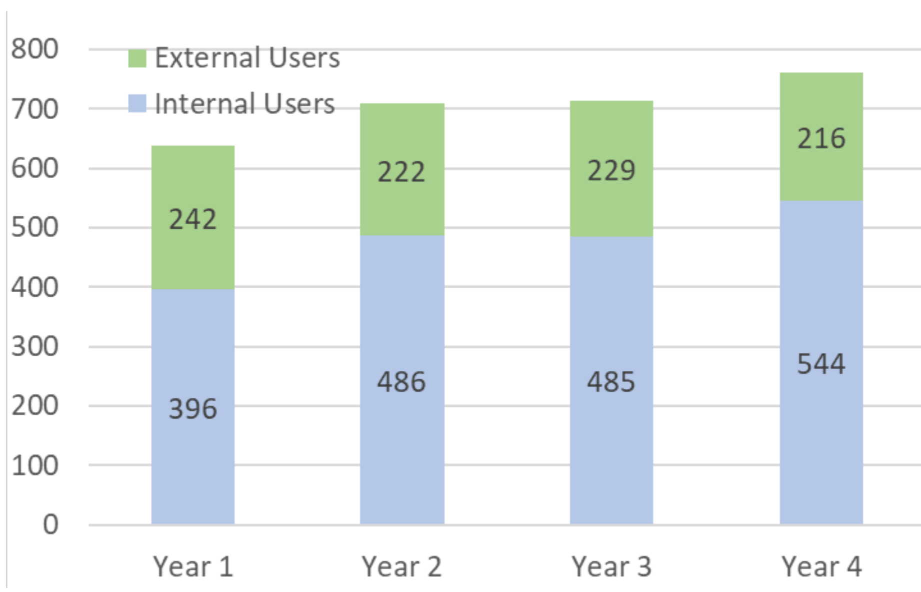
- NNI partnered with the Clean Energy Bridge to Research (CEBR) REU program, and supported 3 additional participants.
- The WNF cleanroom has been integrated with the larger UW curriculum, supporting a number of courses, including the graduate course EE527, Solid State Laboratory Techniques (over 120 NNI staff hours), and EE527-PMP for professional Masters students (over 60 NNI staff hours).
- NNI facilities host a variety of tours for classes (e.g. EE504, Intro to MEMS), professional Masters classes, high school educators, and other visiting groups (including our tribal partner schools).

Societal and Ethical Implications Activities

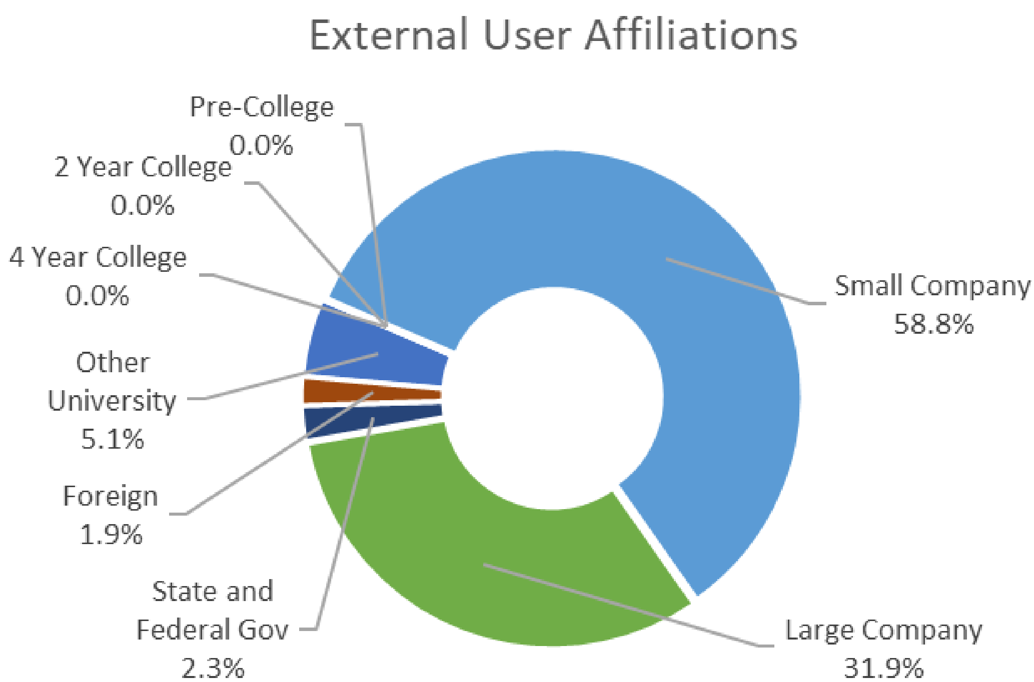
NNI has no funded SEI component, however, co-PI Dan Ratner is a member of the SEI working group and public perception of nanotechnology activities have been integrated into outreach assessment.

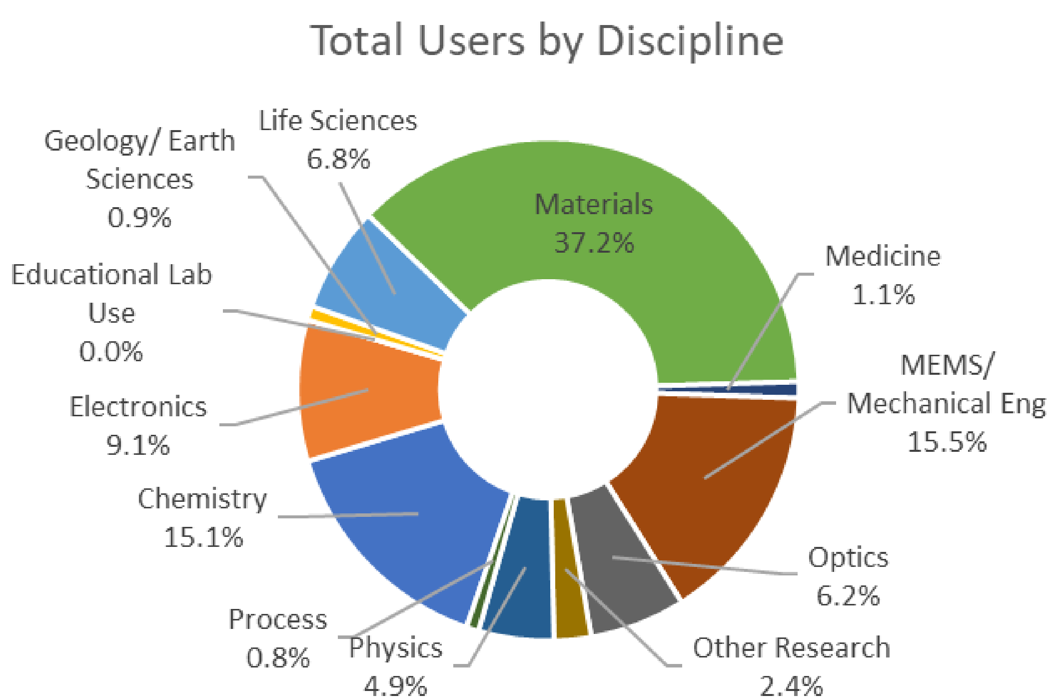
NNI Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	638	708	714	760
Internal Cumulative Users	396	486	485	544
External Cumulative Users	242 (38%)	222 (31%)	229 (32%)	216 (28%)
Total Hours	38,350	46,562	55,925	65,032
Internal Hours	21,822	30,600	27,695	35,564
External Hours	16,528 (43%)	15,962 (34%)	28,230 (50%)	29,468 (45%)
Average Monthly Users	267	277	266	304
Average External Monthly Users	103 (39%)	98 (35%)	93 (35%)	93 (31%)
New Users Trained	126	159	206	134
New External Users Trained	41 (33%)	37 (23%)	57 (28%)	31 (23%)
Hours/User (Internal)	55	63	57	65
Hours/User (External)	68	72	123	136



NNI Year 4 User Distribution





11.11. Research Triangle Nanotechnology Network (RTNN)

<u>Facility, Tools, and Staff Updates</u>

Staff: In Year 4, two new staff members joined NC State's Analytical Instrumentation Facility (AIF). Chris Winkler manages the TEM laboratories, while Aaron Bell is responsible for advancing cryo-electron microscopy capabilities. Professor Shadow Huang also joined AIF as an associate director. **RTNN Ambassadors Program:** This year, we initiated the RTNN Student Ambassadors Program, which is modeled on a similar program at the Cornell Nanofabrication Facility (CNF). The purpose of the program is to engage students in the RTNN's mission to bring nanotechnology tools and expertise to new researchers and the public. Students across the three RTNN institutions are actively engaged as ambassadors. **Tools:** Through university support and by leveraging external funding (such as NSF's MRI program), we have acquired new equipment and upgraded existing equipment to expand RTNN capabilities including a plasma-enhanced atomic layer deposition system that is linked to an electron-beam evaporator (PE-ALD-Evap), 3D X-ray microscope, nano-infrared spectrometer, critical point dryer, TEM, dicing saw, freeze fracture system, and desktop SEM. **Techniques:** Amplitude Modulation – Frequency Modulation using the MFP-3D AFM provides features and benefits of normal tapping mode with nanomechanical property mapping. SiC process blocks are under development for the fabrication of wide bandgap power devices.

PE-ALD-Evap System

<u>User Base</u>

The overarching goal of the RTNN is to build the user base. We make a concerted effort to reach out to users from underrepresented demographic populations, rural areas without access to Research 1 (R1) institutions, non-R1 institutions, and industry. As identified in our proposal, three barriers to engaging new users are distance, cost, and awareness. To address these barriers, we have implemented targeted, innovative programs and activities.

Greater than 50% of current users come from non-traditional disciplines, such as textiles, biology, and agriculture. *Satisfaction*: Unique, IRB-approved surveys collect demographic and satisfaction data from all facility users. Overall, users were very satisfied with their experiences (6.33 ± 1.12, 7=very satisfied). More than 98% of users would return to the lab if further work was necessary.

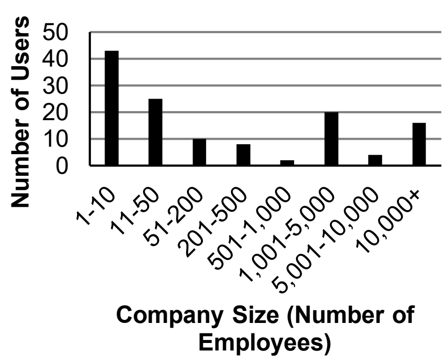
RTNN Kickstarter Program: This program supports use of the facilities by new, non-traditional users by providing free initial access. To date, 70 projects have been selected for over 1,200 hours of use (Year 4: 15 projects, >160 hours use). The majority of participants are from non-R1 colleges/universities (44%), start-ups (27%), and K-12 students/classrooms (9%). **More than forty percent of participants who completed the program continued work in the facilities with their own financial support resulting in >$120,000 in subsequent revenue.** The program brings in new users and provides a pathway to facility sustainability. *Assessment:* Semi-structured interviews have been conducted with 18 participants. Respondents are happy with the program and have indicated they will return. Common themes from respondents were how the program pushed the research project forward and positive interactions with RTNN staff.

Online Coursera Course: "Nanotechnology, A Maker's Course," introduces nanotechnology tools and techniques and shows demonstrations within RTNN facilities. The course targets students who have a high school or higher science background and limited exposure to these facilities. **Since the course launch, over 70,000 people have visited the course website, over 14,000 have enrolled, and over 2,000 have completed the course.** Students hail from more than 155 countries; learners from India (28%) and the United States (18%) account for 46% of total learners. Several participants have engaged with RTNN outside the course (e.g. Kickstarter program, workshops, newsletter subscription). *Assessment:* Overall, students were very satisfied with the course: 6.41 ± 0.56 (7=very satisfied) for course materials; 6.38 ± 0.58 for course instruction, and 6.44 ± 0.73 for multimedia content of the course. Over 90% of respondents noted they were "likely" or "very likely" to recommend the course to others. 78% of respondents noted they had a better knowledge of the capabilities of RTNN's facilities.

Workshops, short courses, symposia: In Year 4, RTNN held 25 technical workshops and short courses (>175 participants) on engaging and relevant topics. The RTNN also helped to plan and execute the Carolina Science Symposium with collaboration from the Joint School of Nanoscience and Nanoengineering (JSNN), an institution in the SENIC NNCI site. This event is student-focused, giving many early career students their first opportunity to present research in a professional setting. We have added a new student-professional networking event that precedes the meeting to give students an additional professional development opportunity and grow their scientific networks. The 2019 symposium had the largest attendance (>125) in event history.

Communication: One of our main methods to disseminate information to stakeholders is via the RTNN website (www.rtnn.org). The website describes RTNN events, programs, and opportunities (e.g. nanotechnology jobs board). It also highlights recent nano-related news and provides an overview of research being pursued by principal faculty. The website has >700 unique visits monthly with >80% of these new visitors to the site. We also maintain two subscription lists to share information and opportunities: one to principal faculty (>100 nanotechnology faculty) and one to other stakeholders (>3,000 subscribers). We have worked diligently to broaden our reach by adding new contacts to our subscribers list and have increased the number by over 36% in the past year. The average "open" rate has increased in the past year (from 27 ± 9 to 38 ± 10%), and we have observed an average of 156 clicks per newsletter.

We are active on multiple social media platforms including Twitter, Facebook, and LinkedIn as a means to promote our activities, events, and opportunities. Facebook was chosen as the main social media platform for RTNN as it reaches a broad range of the public including the professional community, students, and educators. We have seen a 21% increase in Facebook followers and 43% increase in Twitter followers over the past year.



RTNN industry users as a function of company size.

Research Highlights and Impact

Core technical capabilities and expertise span: interfaces, metamaterials, fluidics and heterogeneous integration; nanomaterials for biology and environmental assessment; organic/inorganic 1-D and 2-D nanomaterials; and textile nanoscience and flexible integrated systems. Much of this research is guided by the NSF Big Ideas and other national research priorities.

Scholarly and Economic Impact: Work performed in the RTNN led to >230 publications by our users. In 2018, the RTNN impacted $83 million in research activity, as defined by annual research expenditures, for projects that utilized the facilities. In 2018, the RTNN enabled users to achieve 12 awarded patents, 39 filed patents, and 40 invention disclosures. Our Kickstarter program has given 18 start-ups free access to the facilities, facilitating the success of these nascent business ventures. The figure above demonstrates the tremendous impact we have on small companies; 54% of industry users are from companies with less than 50 employees.

Education and Outreach Activities

Outreach to K-12 Students: In Year 4, we reached over 3,500 students through our outreach programs with >60% of participants from underrepresented groups in STEM. **Immersive lab experiences:** Over 1,700 people visited our facilities in Year 4 to engage in hands-on activities with RTNN tools. **Lesson plans:** We share our lesson plans during educator workshops and other events. Staff members attend the SciREN networking event annually, which brings together researchers and educators from across North Carolina. We also attended the regional National Science Teachers Association conference with an NNCI cohort to share and promote educational opportunities at RTNN and across the network. **Visits to Classrooms and Schools**: RTNN staff traveled to many classrooms and schools (K-Community College) to introduce nanotechnology, interacting with over 250 students. These visits are paired with hands-on activities to engage students. For example, in April 2019, RTNN staff provided an overview lecture on nanotechnology and electron microscopy to all students enrolled in the Intro to Engineering Course at Durham Technical Community College. Students then participated in a lab where they imaged samples they collected using the SEM and designed different types of photomasks. As a result of this program, two students participated in REU experiences at RTNN during the summer, and one student is now working at the Chapel Hill Analytical and Nanofabrication Laboratory. **Girls STEM Day @ Duke:** In May 2019, the RTNN, in partnership with Triangle Women in STEM, Duke's Pratt School of Engineering and Trinity College of Arts and Sciences, Credit Suisse, and IBM, hosted over 140 North Carolina girls and their families. These young women experienced significant hands-on time in the facilities–including use of an SEM–and earned badges in genetics, chemistry of cosmetics, and artificial intelligence/robotics for their work. Parents attended workshops on college funding and supporting their daughters in STEM. **Community College and Teacher Workshops:** 14 participants in our fourth annual two- day workshop for community college educators used tools in the clean room to fabricate a functional LED device. We also held workshops for local K-12 educators introducing the facilities and describing our programs. **Research Experience for Teachers:** Eleven participants in the Atomic Scale Design and Engineering RET Program worked on research projects that heavily utilized RTNN facilities. Educators designed novel lesson plans that include use of RTNN tools and presented their work at the North Carolina Science Teachers Conference in November 2019. **Community Engagement:** We have also organized events at the Chapel Hill Public Library and the Museum of Life and Science. These events provide a means to reach new populations. We bring the portable SEM and other hands-on activities to attract library/museum visitors. **Other:** We hosted many booths at school science nights, participated in numerous North Carolina Science Festival activities, and welcomed tour groups in facilities and remotely.

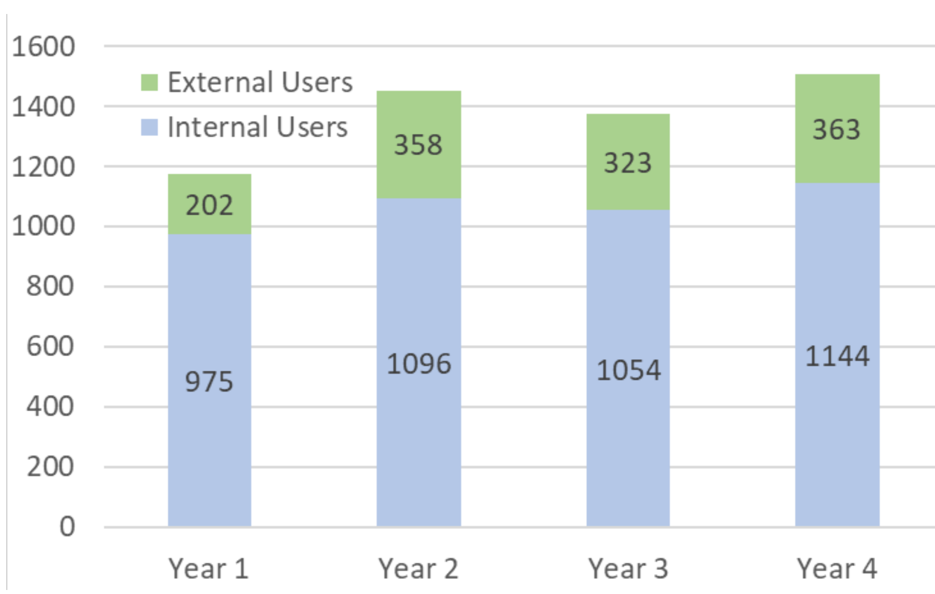
Community college educators at the nanotechnology workshop.

Societal and Ethical Implications Activities

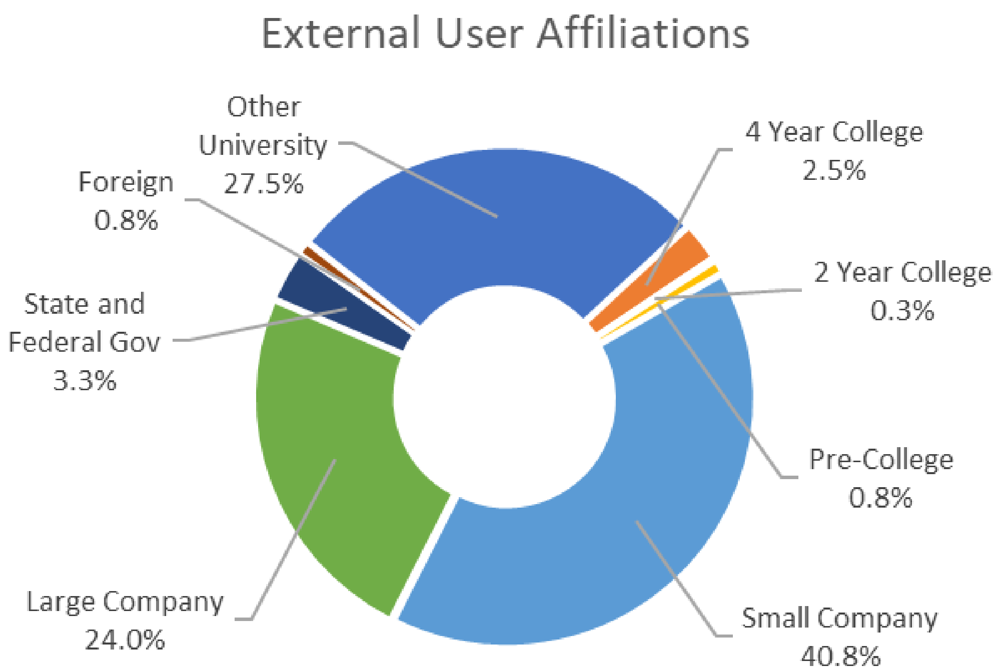
The goal of the SEI program is to leverage the RTNN team and user base to: 1) enhance the instruction and understanding of how humans engage with nanotechnology and 2) study governance involving multiple stakeholder groups**. Deep Assessment:** Surveys were designed and implemented for specific activities (e.g. facility users, Coursera students, Kickstarter participants). This data is used as an iterative tool to improve RTNN facilities and programs, and we are able to discern differences in satisfaction levels across different demographic groups. For example, preliminary data indicates that users from certain disciplines, like physics, experience the facilities differently than other groups. We can now posit research questions that help to better elucidate the reasons for these differences. **Social Media:** We have a cross-platform presence on social media to study how social networks influence nanotechnologists' decision making.

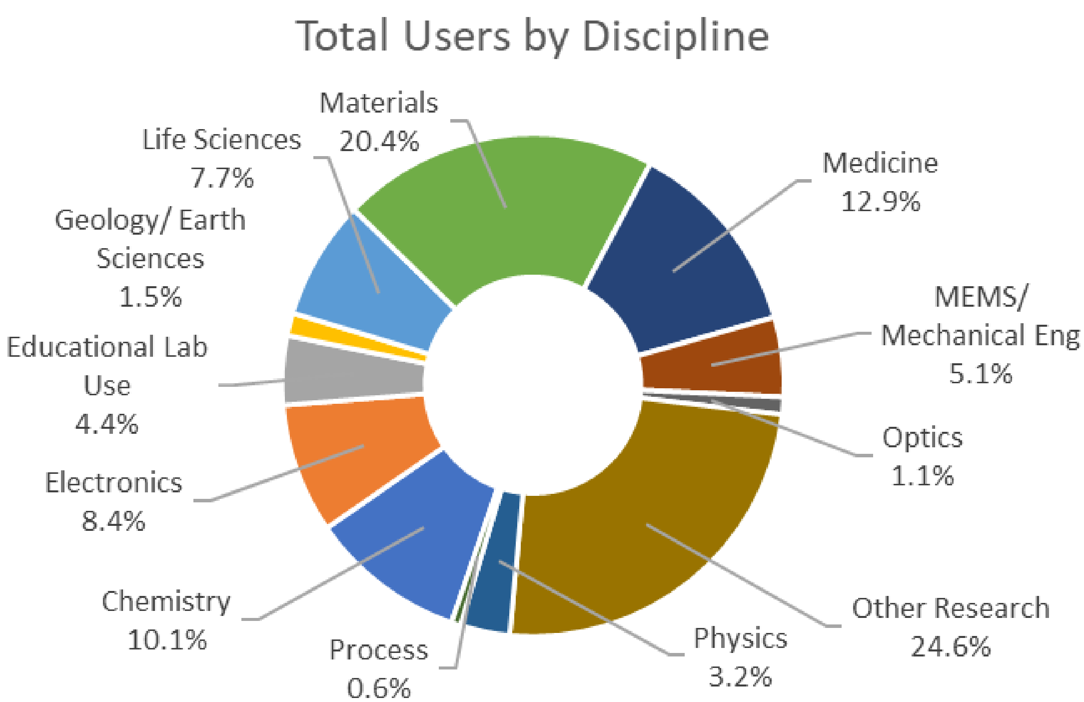
RTNN Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	1,177	1,454	1,377	1,507
Internal Cumulative Users	975	1,096	1,054	1,144
External Cumulative Users	202 (17%)	358 (25%)	323 (23%)	363 (24%)
Total Hours	53,044	51,747	55,684	61,404
Internal Hours	46,908	43,053	46,422	49,685
External Hours	6,136 (12%)	9,694 (17%)	9,263 (17%)	11,719 (19%)
Average Monthly Users	395	422	420	445
Average External Monthly Users	50 (13%)	63 (15%)	71 (17%)	74 (17%)
New Users Trained	433	527	695	627
New External Users Trained	71 (16%)	69 (13%)	82 (12%)	102 (12%)
Hours/User (Internal)	48	39	44	43
Hours/User (External)	30	24	29	32



RTNN Year 4 User Distribution





11.12. San Diego Nanotechnology Infrastructure (SDNI)

Facility, Tools, and Staff Updates

Recognizing the value of SDNI and its commitment to supporting the infrastructure, UCSD's administration has made a major investment in SDNI's expansion by providing approximately $3M towards the purchase of a 200kV Transmission Electron Microscope.

In addition, we have successfully added the CMRR Materials Characterization Facility to SDNI, which greatly strengthens our ability to provide open-access support in the nanomagentics area, as well as our abilities to support research in energy and quantum systems. The new CMRR facility offers an array of state-of-the-art equipment for nanomaterial characterization, including XRD, XPS, Hall effect, UV-Vis, AFM/MFM, SEM, etc. to measure crystal structure, and magnetic, surface, transport, and optical properties. The tools we have acquired or upgraded in the past year include (a) the Talos F200X G2 200 kV FEG Scanning Transmission Electron Microscope (S/TEM) system designed for fast, precise and quantitative characterization of nano-materials, (b) Idonus VPE-150 HF Vapor Etch System, (c) COMPASS Spin Rinse Drier, (d) Oxford Instruments ICP, RIE etchers and PECVD system, and (e) an assortment of general and special purposed tools to support processing and material/device characterization. To summarize, over *$3M investment in tools has been made by the university, and substantial industrial donations valued well over $1M also contributed to the expansion of SDNI's capabilities. No NSF funds has been spent on tool acquisitions while SDNI has been supporting over 80 research projects funded by NSF and other federal agencies.*

User Base

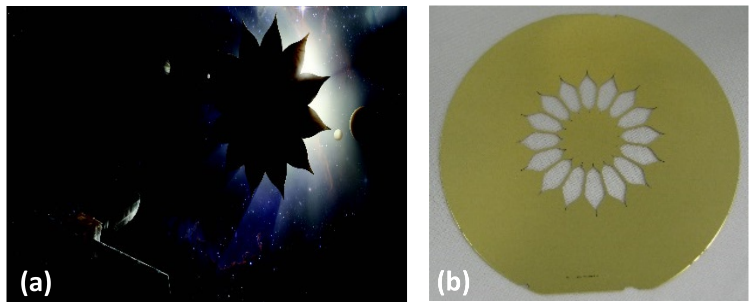
For SDNI, about 20% of its total usage comes from external users of which 88% are company users and the rest are external academic users and government lab users. To improve our ability to satisfy user needs and maximize tool utilization as a 24/7 facility, we have improved our lab management software to allow us to track actual lab utilization in real time. The timely data help us implement strategies to optimize operation and improve equipment utilization efficiency, yielding the marked increase in the reported user hours by approximately 20%. The addition of the CMRR Materials Characterization Facility has also strengthened SDNI's capabilities to support research in quantum devices, energy, and materials.

Since NNCI started, we have observed growing small business users and increasing demands for direct services provided by SDNI staff. In response to these needs, we have strengthened our supports for direct services, which also allows us to expand geographic coverage of our customers. For customers farther than 70 miles from San Diego, direct services often become the attractive and sometimes, only practical mode of operation for SDNI to help these remote users. As a sign of the increasing importance and impact of SDNI on research and industry, our average monthly lab time by small companies has increased by nearly 400%, and the remote utilization has increased by 280% since 2015 when NNCI started. The rapid and continued growth demonstrates SDNI's positive roles in broadening the community's access to nanotechnology and growing the overall economy.

Research Highlights and Impact

SDNI has supported research breakthroughs in many areas, including advanced quantum materials for energy efficient neuromorphic computing. One prominent example is to support development of innovative devices based on charge- and spin-related phenomena. From complex strongly correlated oxides, which exhibit metal-insulator transitions (MIT), scientists have demonstrated *a solid-state neuristor that emulates the complex behavior of biological neurons as the basis of neuromorphic computer*. The work was published in Nature 2019.

Another important scientific contribution of SDNI is that, in collaboration with JPL, *SDNI technical staff have fabricated Starshade masks for detection of earth-like planet by NASA***.** Starshades (or External Occulters) can suppress starlight for high contrast imaging of exoplanets. Starshades masks are designed to enable direct observation by preventing the starlight to enter the observing telescope (see figure).



(a) Artist's rendition of NASA's starshade blocking starlight from a nearby planetary system, enabling imagery of earth-sized planets in the habitable zones around sun-like stars. (b) A starshade prototype fabricated by SDNI staff.

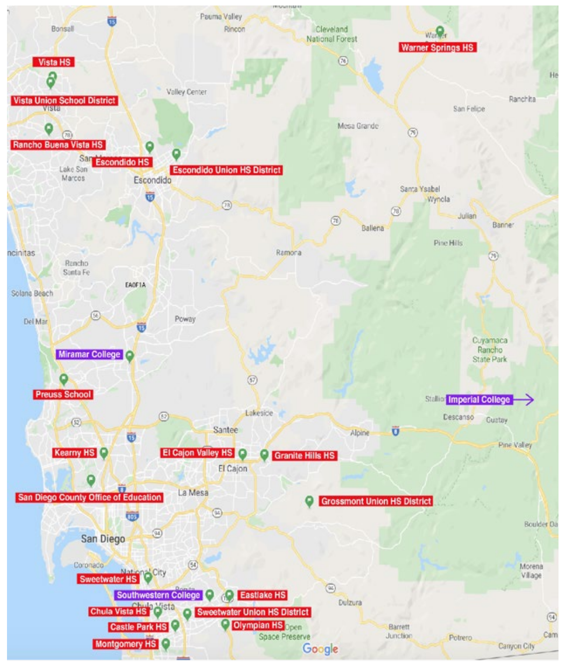
Before manufacture and launch of a full-sized starshade into space, theoretical modeling and ground-based experimental validation with small-scale starshade masks are critical for a successful mission. *SDNI was chosen by JPL/NASA to fabricate small-scale starshade masks to be used at Princeton Starshade Testbed* because of SDNI's fabrication process design which promises advantages over existing approaches.

The small-scale starshade mask is a metal/a-Si thin film structure with flower-like shaped 16 petals fabricated on a 100 mm diameter silicon wafer support. Each petal is an opening in the geometry allowing light to pass through. To fabricate a starshade mask that has > 10^9 light suppression, SDNI staff have successfully overcome three challenges: the critical dimension (CD) control (±100nm), line edge roughness control (< 150 nm RMS), and defects control (pinholes or incursions < 200 sq-microns). SDNI's fabrication approach includes PECVD deposition of low-stress SiO_2 and a-Si films, low-defect metal sputter coating, and high-quality photolithography and dry etch. *The stress-free PECVD films and low stress sputter coated metal films developed by SDNI are critical to the success of device fabrication.* SDNI's unique capability of manufacturing SOI wafers with PECVD stress-free SiO_2 and a-Si films has shortened the prototyping development time and most importantly, provided JPL/NASA a unique opportunity to quantify and reduce polarization effects that cannot be investigated otherwise. Following the success in fabricating the first fully functional starshade mask, JPL/NASA is asking SDNI to produce 16 additional devices to *support the full-scale test in the ground-based system*.

<u>Education and Outreach Activities</u>

SDNI has developed a mission to combine its faculty's intellectual potential with its nano-fabrication and characterization capabilities to become a *Center of Excellence for Nanotechnology education and outreach*. We have been promoting educational equity and facilitating the integration of nanotechnology educational contents to the current California community college and K12 (Next Generation Science Standards-aligned) STEM curricula. Our current pilot efforts are focused in Southern California, specifically San Diego county. San Diego county is the home of 762 public schools which enroll approximately half a million students, with a diversity score of 0.45 and a minority enrollment of 70%. Our initial objectives target the county's 192 high schools representing approximately 173,000 students.

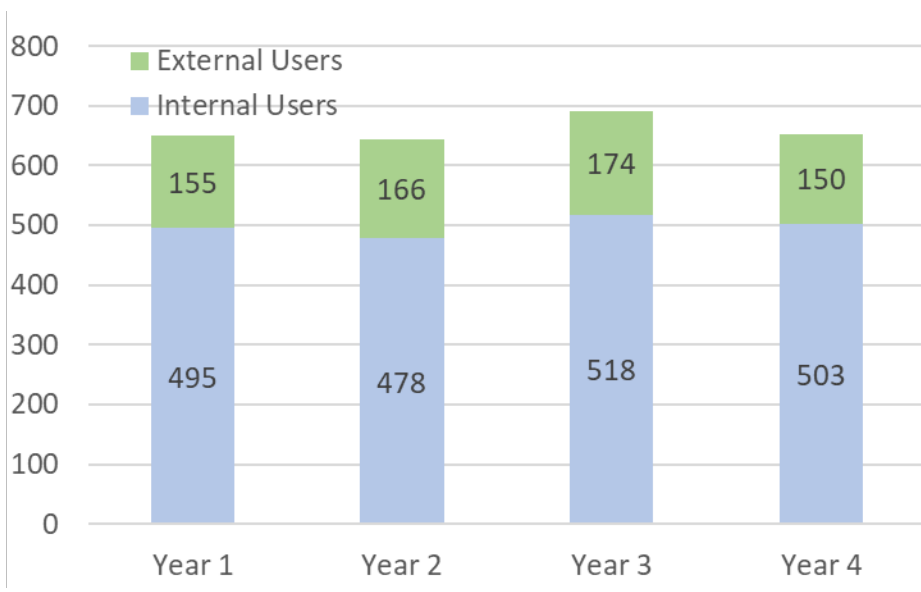
To carry out these missions, we have collaborated with other NNCI sites (e.g. Stanford) and other institutions and networks to optimize nanotechnology education nationwide. Specific efforts and accomplishments include: (a) offering hands-on training in the field of nanofabrication and characterization by leveraging the resources of SDNI's infrastructure, (b) offering summer training for undergrad students (REU) and high school and community college teachers (RET), and (c) collaborating with Sand Diego County's community colleges and high school administrators and teachers to develop and implement *quality nano-curriculum contents that can be integrated to their respective current STEM curricula*. The curricula will include lab activities, some of which will incorporate characterization using remote access to SDNI's Scanning Electron Microscope. The results obtained with this pilot program will then be expanded to the entire state of California by 2025. In one year, SDNI has reached 2,500 students from its "remote hands-on SEM sessions" with samples selected and prepared by high school science teachers in collaboration with SDNI staff.



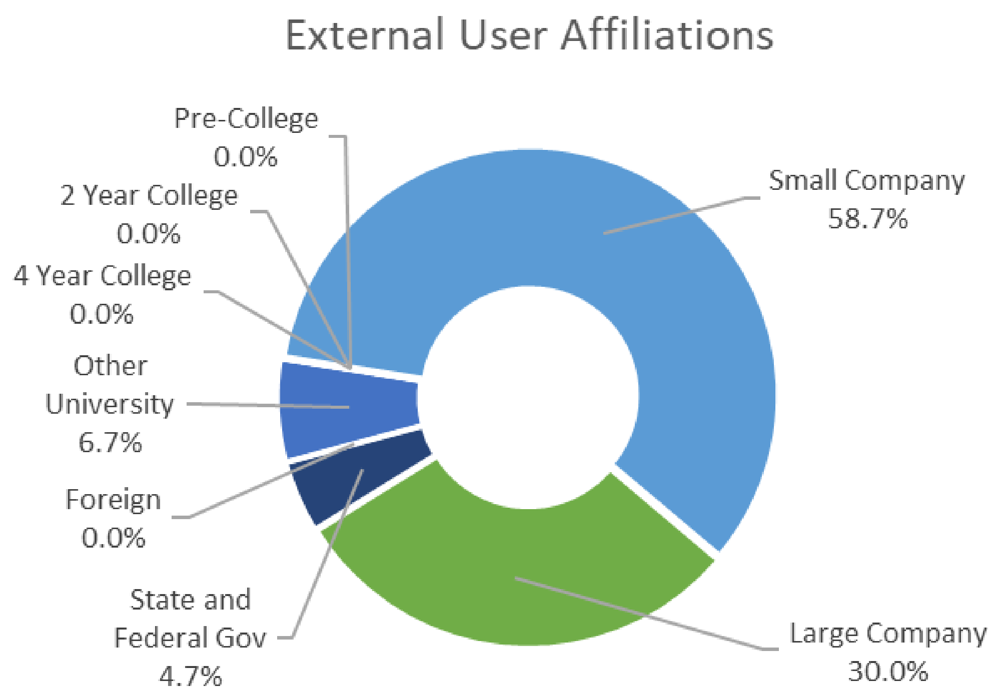
Map of minority (Hispanic) high schools and community colleges receiving "remote hands-on nanotechnology courses" taught jointly by their teachers and SDNI staff. All institutions have expressed an interest in bringing nanotechnology education to their institutions/jurisdictions.

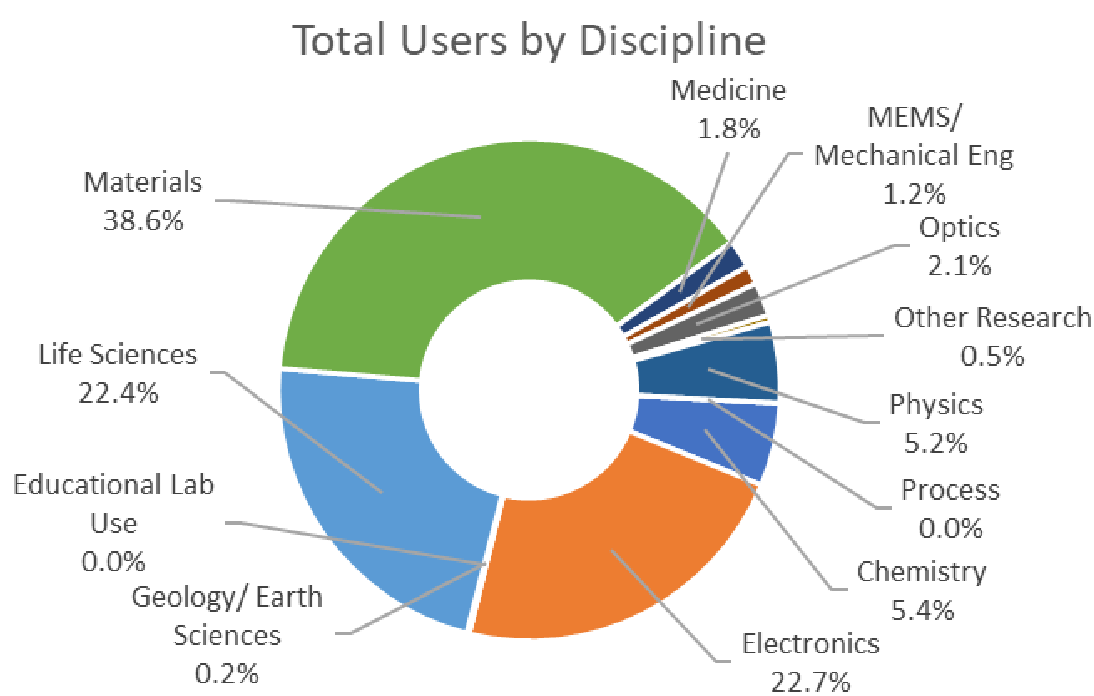
SDNI Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	650	644	692	653
Internal Cumulative Users	495	478	518	503
External Cumulative Users	155 (24%)	166 (26%)	174 (25%)	150 (23%)
Total Hours	47,893	50,497	49,519	69,367
Internal Hours	40,890	38,890	39,372	56,393
External Hours	7,003 (15%)	11,607 (23%)	10,147 (20%)	12,974 (19%)
Average Monthly Users	290	285	300	296
Average External Monthly Users	49 (17%)	56 (20%)	54 (18%)	50 (17%)
New Users Trained	183	210	225	202
New External Users Trained	34 (19%)	50 (24%)	46 (20%)	40 (20%)
Hours/User (Internal)	83	81	76	112
Hours/User (External)	45	70	58	86



SDNI Year 4 User Distribution



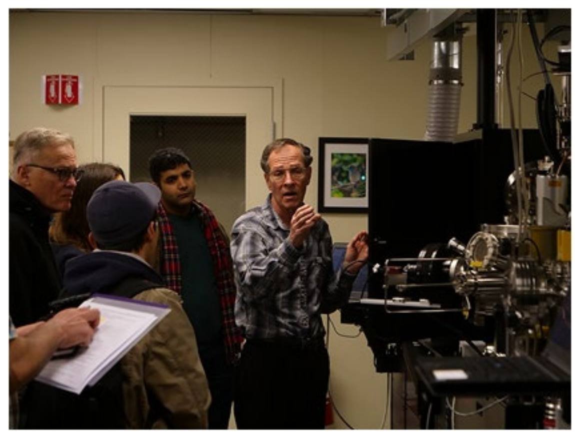


11.13. Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

A joint venture between **Northwestern University** and **University of Chicago**, SHyNE Resource represents the Midwest within the NNCI, providing researchers from academia, government, and companies large and small with access to user facilities with leading-edge fabrication and characterization tools, instrumentation, and technical expertise within all disciplines of nanoscale science, engineering and technology. Under the leadership of site director, Professor Vinayak Dravid and co-director Professor Andrew Cleland, SHyNE Resource coordinates the integration of a diverse group of open-access nanoscale fabrication and characterization facilities across Northwestern University (NU*ANCE*, SQI, NUFAB, IMSERC, NUCAPT, JB Cohen XRD, PLD) and the University of Chicago (PNF).

<u>Facility, Tools, and Staff Updates</u>

SHyNE facilities are actively engaged in acquiring, updating or replacing key equipment within the facilities through a combination of internal and external funding mechanisms. In total, more than **25 new instruments** and numerous tool upgrades were installed in Year 4. Many new fabrication tools were added across the two fabrication facilities: two new e-beam evaporators in the PNF, laser cutter and maskless aligner tools in NUFAB, and Pulsed-Laser Deposition. Highlights on the characterization side include two direct electron detectors (Gatan K2-IS [JEOL ARM200CF] and Gatan K3-IS [ARM300CF]) in NU*ANCE* Center, the NUCAPT facility upgraded to a LEAP5000XS configuration, and IMSERC completed a major upgrade of NMR capabilities.



Pulsed Laser Deposition facility joined the SHyNE Resource, adding PVD Products nanoPLD 1000 and PLD/MBE 2300 to supported capabilities.

Maintaining an active and engaged user base for SHyNE facilities is contingent upon the successful recruitment and retention of high-quality staff. **Eleven new technical staff** joined the SHyNE team in Year 4, six of whom are in newly created positions and many receive partial funding through NNCI (10-1-2018 through 8-31-2019): NU*ANCE* – Kathryn Dean – Outreach Coordinator (20%), NU*ANCE* – Elise Beck – Program Assistant (20%), NU*ANCE* – Dr. Xiaobing Hu – TEM Facility Manager and Research Assistant Professor (24%), NU*ANCE* – Dr. Kun He – Postdoctoral Research Associate (0%), NU*ANCE* – Dr. Roberto Dos Reis – Scientific Officer and Research Assistant Professor (20%), William Mohr – Research Associate (20%); IMSERC – Gabrielle Allison – Assistant Core Facilities Scientist (5%); PNF – Chrystian Posada – Process Engineer (57%); SQI – Charles Bressan – Core Technician (15%); SQI – Dr. Suvendu Biswas – Assistant Core Scientist (0%); XRD/PLD – Dr. D. Bruce Buccholz - Manager Pulsed Laser Deposition Facility (0%).

<u>User Base</u>

SHyNE facilities served nearly **1700 unique users** who logged over **200,000 hours** of instrument time generating **$5.1M in revenue**. External users represented 13% of total users and 12% of revenue. SHyNE actively engages local and regional companies, colleges, universities, non-profit research organizations and governmental agencies to recruit new users. This is accomplished by a number of marketing strategies including: exhibitions at conferences and trade shows, production of a web portal, a marketing video and promotional materials, networking with alumni, coordination with university-wide corporate engagement and media relations offices, and an active social media presence. In Year 4, SHyNE continued managing a **SEED** (SHyNE External Experiment Development) funding program to recruit new external users by providing start-up grants for up to $2500 in facility usage. Three proposals were funded for new users from the Illinois Institute of Technology, Argonne National Lab and Biomsense (an early-stage startup). In Year 5, the primary programmatic focus will be on recruiting additional external academic users through a combination of efforts, including: an active marketing campaign, redevelopment of our web presence and expansion of the SEED program.

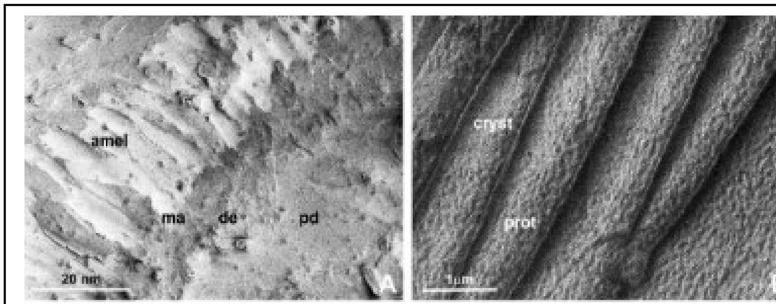
SHyNE External Experiment Development

SHyNE SEED funding initiative expects to fund 3-4 projects per year.

Research Highlights and Impact

The research output facilitated by SHyNE facilities is substantial, including more than **300 publications** which specifically cite the NNCI grant and/or one of the facilities funded through SHyNE. We expect the actual output is much higher and are actively working with University administration to find strategies to approach total compliance with facility acknowledgement. In addition, **84 patents, patent applications and invention disclosures** benefited from SHyNE facilities in their conception. Research activities resulted in many high-profile publications in journals such as *Science*, *Nature*, *Nature Photonics*, *Nature Astronomy, Nature Chemical Biology, Nature Chemistry* and *Nature Nanotechnology*.

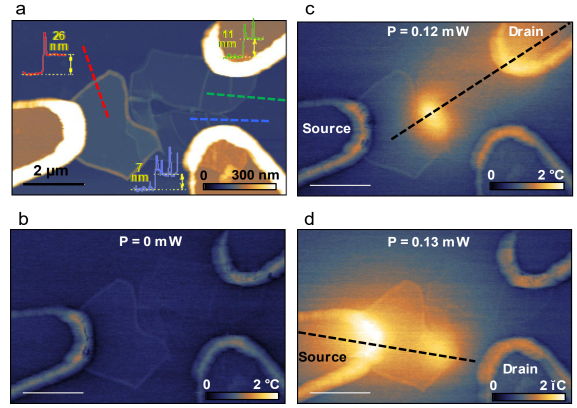
The **Diekwisch Lab** in the Center for Craniofacial Research and Diagnosis at **Texas A&M University College of Dentistry** collaborated with NU*ANCE* staff on the use of cryo-SEM to understand enamel crystal nucleation and growth at a nanoscale level with minimal sample preparation artifacts. Cryo-fracture micrographs (figure at right) revealed reticular networks of an organic matrix on the surface of elongating enamel crystal ribbons, suggesting that protein coats facilitate c-axis apatite crystal growth. The data demonstrate (i) the involvement of particle attachment in enamel crystal nucleation, (ii) a combination of matrix- and lattice-guided crystal growth, and (iii) fusion of individual crystals via a mechanism similar to Ostwald ripening.



Cryo-SEM images showing the interface between ameloblasts, protein matrix, dentin and and predentin (left) and the organic matrix and enamel crystals (right). (Diekwisch, et. al; ACS Nano 2019)

SHyNE staff worked with **APPNano, Inc.** to develop super-sharp nanomechanical thermal probes for high resolution thermal mapping. Scanning Thermal Microscopy (SThM) was developed to spatially map the temperature rise across defects and heterogeneities of titanium carbide

(Ti3C2Tx; T stands for surface terminations) MXene nanostructures under high bias with sub-50 mK temperature resolution and sub-100 nm spatial resolution. The results suggest that the atomic structure at the interface plays a crucial role in enabling efficient charge transport without inducing localized heating. (figure at right).



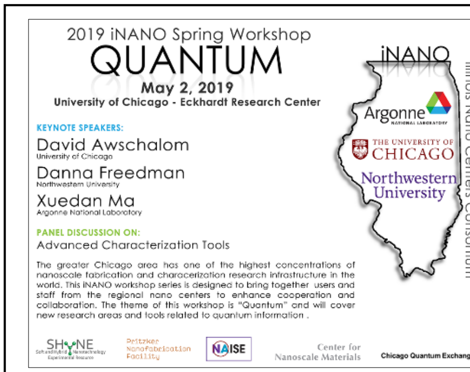
SThM characterization of vertical interfaces of Ti3C2Tx flakes. (a) Topography maps and height profiles of three Ti3C2Tx MXene flakes. (b) Temperature map of the device before applying any current. (c-d) Temperature maps of the device under electrical biasing applied to different electrodes. (Yasaei, et. Al; ACS Nano 2019)

<u>Education and Outreach Activities</u>

These are critical part of SHyNE's mission and include academic courses with laboratory components, monthly user meetings, an REU program, hands-on workshops, seminars, vendor symposia/demos, facility tours/demos (K-12, higher-ed, public) and related web and social media communications. Facility tours for more than **1200 visitors** in Year 4. Over **1450 students** participated in courses utilizing SHyNE facilities in Year 4. SHyNE facilities hosted workshops and seminars reaching more than **900 participants**. SHyNE sponsored **four REU students** in a unique, facilities-focused REU program that exposed undergraduates to advanced instrumentation as a key component of their projects. Key workshops and seminars:

1. "Cleanroom Ellipsometry Workshop, J.A. Woollam Company"; hosted by NU*ANCE* and co-sponsored by NU-MRSEC.
2. "BioCryo mPrep Automated Sample Prep, ASP-1000 Workshop, Microscopy Innovations"; hosted by NU*ANCE*, co-sponsored by Thermo Scientific and NU-MRSEC
3. "Midwest Microscopy and Microanalysis Society (MSA) Spring Meeting"; hosted by NU*ANCE*, co-sponsored by NU-MRSEC and supported by numerous vendors.

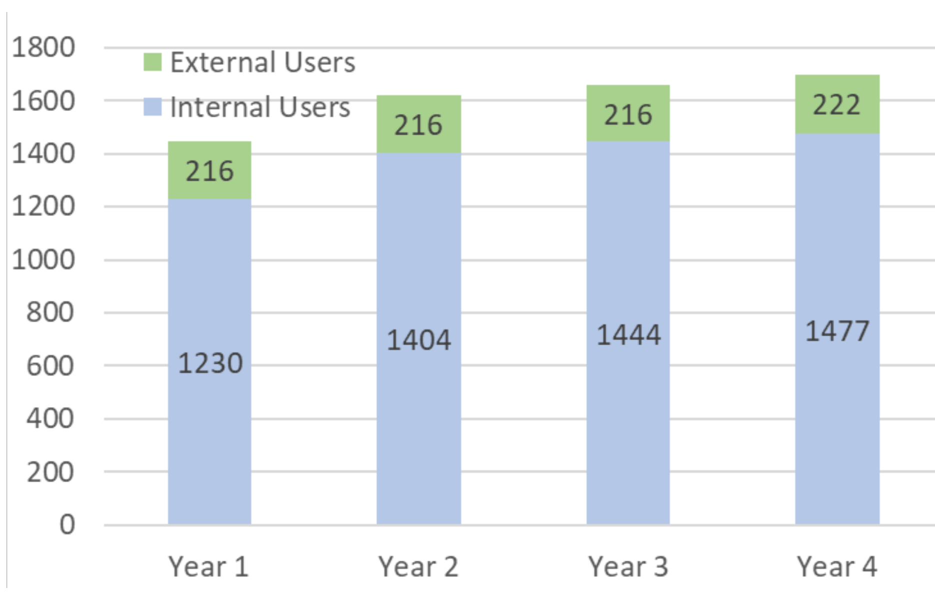
SHyNE resource spearheaded creation of Illinois Nano-Centers Consortium (**iNANO**), seeks to bring together researchers, staff and external users of several regional institutions (NU, UChicago and ANL) with interest and capabilities in nanoscale fabrication and characterization. A second meeting in Spring of 2019 focused on the topic of Quantum. We are currently planning a third event for Year 5, and looking to expand participation to other regional universities. SHyNE continues to develop our novel capstone **Nano-Journalism** program with NU Medill School of Journalism. In Year 4, we expanded internship program by sponsoring Medill and School of Communications students to embed in our facilities. PhD candidate Mohammad Behroozian is creating facilities-centric multimedia content targeted to an international K-12 audience.



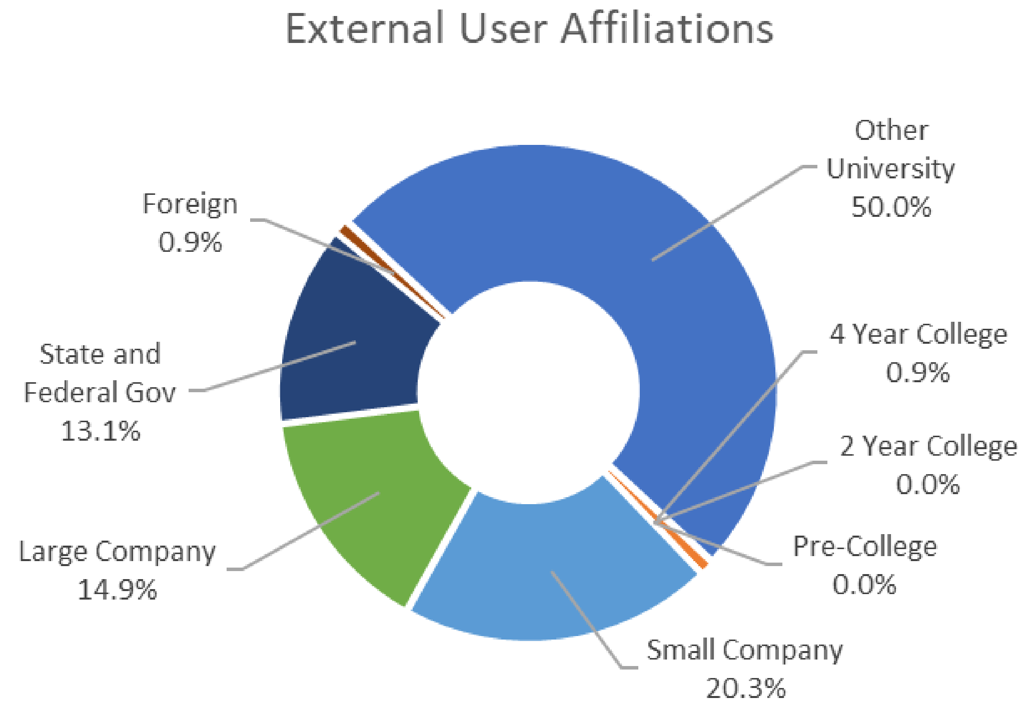
iNANO 2019 focused on Quantum initiatives with keynote addresses by David Awschalom, Danna Freedman, Xuedan Ma.

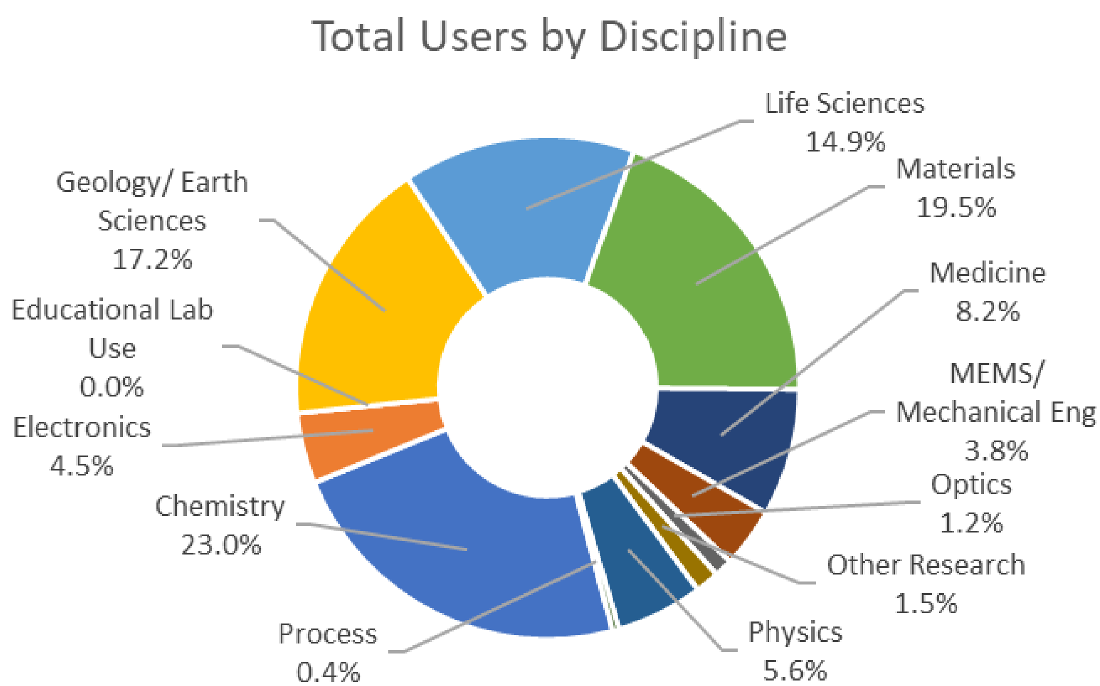
SHyNE Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	1,446	1,620	1,660	1,699
Internal Cumulative Users	1,230	1,404	1,444	1,477
External Cumulative Users	216 (15%)	216 (13%)	216 (13%)	222 (13%)
Total Hours	138,000	132,673	137,375	202,844
Internal Hours	128,838	127,127	131,206	192,434
External Hours	9,162 (7%)	5,545 (4%)	6,169 (4%)	10,410 (5%)
Average Monthly Users	679	802	797	829
Average External Monthly Users	54 (8%)	54 (7%)	52 (7%)	61 (7%)
New Users Trained	699	698	605	649
New External Users Trained	152 (22%)	140 (20%)	86 (14%)	120 (18%)
Hours/User (Internal)	105	91	91	130
Hours/User (External)	42	26	29	47



SHyNE Year 4 User Distribution





11.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Facility, Tools, and Staff Updates

SENIC continues to build upon the "one facility, two locations" approach to the partnership, and the two sites have also continued to exchange best practice techniques for installing and maintaining common toolsets.

Georgia Tech has completed several construction projects, including some faculty-specific renovations, in the Marcus Nanotechnology Building and Pettit Microelectronics Building, which are managed by the IEN. The execution of the shared research facilities master plan for laboratory space in support of the IEN Packaging Research Center has begun. The IEN core facilities will consolidate the existing PRC assembly laboratory and office area into the Pettit Building. The new laboratory expansion consists of 2,000 sq. ft. of shared space and is designed to accommodate the laser laboratory, electrical test laboratory, and assembly laboratory in a single building. The Micro/Nanofabrication Facilities at Georgia Tech added or replaced three staff members including a research scientist for support of baselining recipes for cleanroom tools and external users and a research engineer to support the femtosecond/UV laser tool. At JSNN, a concerted effort is underway to revise/update the standard operating procedures (SOPs) of all tools based on experiences gained in user training, maintenance and usage. The online user consultation and training request form has greatly helped the Technical Support team to better manage training and process/characterization consultation requests. Lastly, the Equipment Manager (hired last year) continues to manage the Technical Support team and oversee lab operations. The Materials Characterization Facility (MCF) at Georgia Tech brought onboard a full-time researcher to optimize results and training on the Hitachi HD-2700 dedicated Scanning Transmission Electron Microscope (STEM) system and a part-time staff member with expertise in polymer chemistry to oversee the IR spectroscopy tools. Finally, JSNN is continuing to strengthen its Technical Support team, with the addition of two full-time staff members to help meet the growing demand for analytical characterization, cleanroom fabrication and remote service requests. This team is also responsible for providing user consultation, training, process and characterization support, remote jobs and data analysis, if requested by the user.

Over the past year, the SENIC facilities at Georgia Tech and JSNN have invested approximately $3.2M in 19 tool acquisitions and upgrades including the following:

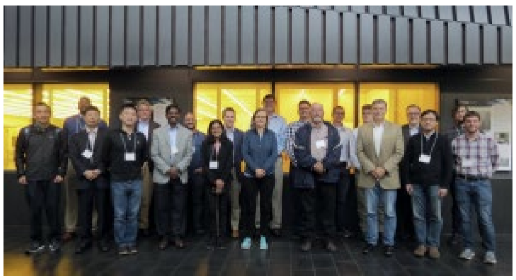
Lithography & Direct Patterning: Optec WS-Flex Laser Micromachining (new purchase); AJA International Sputterer (new purchase); Pulsed Laser Deposition (new purchase); CHA E-beam Evaporators (upgrades); Heidelberg MLA 150 (new purchase)

Deposition: Veeco Fiji G2ALD (new purchase); Thermal ALD System (ellipsometry upgrade), MRL Nitride Furnace (new purchase)

Etching: Advanced Vacuum RIE (upgrade), STS AOE Pro Silicon Carbide Etcher (new purchase)

Imaging & Metrology: Asylum MFP-3D Origin+ AFM (new purchase); Bruker Icon AFM (new purchase); PerkinElmer 2400 CHNS/O Series II System (new purchase); Rheosense m-VROC™ Viscometer (new purchase); Tinius Olsen Model IT 503 Low Energy Pendulum Impact Tester (new purchase); Renishaw Confocal Micro-Raman Spectrometer (new purchase); Protochips In-situ Liquid Holder for TEM (upgrade); ThermoFisher ESCALAB™ Xi+ XPS (sample exchange upgrade); Agilent 700 MHz NMR (upgrade)

During the fall of 2018, SENIC contacted more than 30 nanoscale fabrication and characterization facilities located at universities in the southeast US (GA, SC, NC, FL, TN, AL, LA, and AR) to solicit interest in forming a regional network. Within NNCI, similar regional networks have been created in the mid-Atlantic (organized by MANTH) and upper Midwest (organized by MINIC), and SENIC sought to duplicate this success in a different region of the country. Georgia Tech organized a one-day meeting on Nov. 12, 2018 for the ***Southeastern Nano Facility Network (SENFN)***, which was attended by representatives from ten institutions (6 states). The goals of the meeting were to share information on capabilities and challenges at each facility, discuss best-practice solutions to common challenges, begin a process for informal staff-level technical exchanges, and networking. Since the initial SENFN meeting, several more facilities have asked to be added to the network. An email listserve was established, a contact directory compiled, and a second meeting (Nov. 14, 2019) was recently held at Oak Ridge National Lab.



User Base

Marketing of SENIC continued through the website (http://senic.gatech.edu/), as well as additional promotion and communication efforts through email and social media, with SENIC-specific efforts on Facebook, LinkedIn, and Twitter. SENIC began targeted marketing based on geographical area (southeastern US academic and company profiles) and discipline of work (electronics, MEMS, biomedical, materials, chemistry, environmental, etc.) using LinkedIn Text Ads. A quarterly SENIC newsletter was initiated this past year and was emailed to over 3,000 current and potential users along with other stakeholders.

User recruitment events such as SENIC webinars and presentations at various sites in the southeastern region continue to be held. SENIC Ambassadors (existing users) hosted outreach representatives for presentations at University of Alabama, Clemson University, University of Georgia, and Albany State University as well as UNC Pembroke, MERCK, and Conyers-Rockdale County Economic Dev. Office. SENIC staff attended or exhibited at local and regional conferences and events to help recruit new users including the Biomedical Engineering Society Conference (Oct. 17-20, 2018), Spring School of Medical Robotics & International Symposium on Medical Robotics (April 1-5, 2019), Southeastern Medical Device Association (SEMDA) Medtech Conference (April 8-10, 2019), and ACS Colloid and Surface Science Symposium (June 16-19, 2019). IEN's Materials Characterization Facility (MCF) hosted a meeting of the Georgia Microscopical Society (March 27, 2019.

In support of its vision to strengthen and accelerate discovery in nanoscience and nanoengineering across the US, SENIC established the ***Catalyst Program***, modelled after the RTNN Kickstarter program. This funding program allows researchers limited (up to $1000) free access to the SENIC facilities to aid in research, obtain preliminary data, conduct proof-of-concept studies, or for educational purposes. So far, 14 awards have been made to new PIs from Clemson Univ., UNC-Charlotte, Duke Univ., Elizabeth City State Univ. (HBCU), Clark Atlanta Univ. (HBCU), Georgia State Univ., Kennesaw State Univ., Auburn Univ., and Wheeler High School.

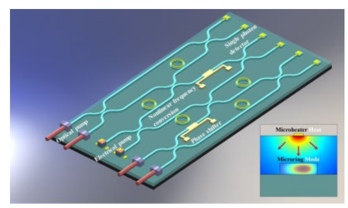
During this fourth year of the NNCI program (Oct. 2018 - Sept. 2019), the SENIC facilities have served more than 1300 individual users, including 278 external users (6% increase over Year 3) representing 93 companies, 25 colleges and universities, and 10 other institutions. Several users have accessed capabilities at both SENIC locations with minimal difficulty. The majority of users access the facilities on-site, although 167 users obtained services remotely, and some users operated in both on-site and remote fashions. Monthly users averaged 576 (5% increase), and 42 new users were trained each month on average (502 total during the reporting period, 30% increase over the prior year).

As part of a network-wide NNCI effort, SENIC participated in the annual user satisfaction survey. The online survey was emailed to all IEN and JSNN users and received 64 responses (as of 12/9/19). Overall, the results are very positive with high levels of satisfaction (>90% somewhat or extremely satisfied) for most assessment criteria, and 98% would refer SENIC to a colleague. The overall site rating was 4.7/5.

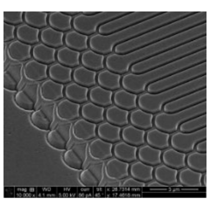
<u>Research Highlights and Impact</u>

Notable new users this period came to SENIC from University of Arkansas, University of Washington, Wake Forest University, Biocircuit Technologies, Imerys Minerals, ResonanceDX Inc., Silpara Technologies, Surfanetix, Akoustis, Goulston, VX Aerospace, Delta Airlines, Evonik, ITG, RTI, Volvo, and Parker Hannifin.

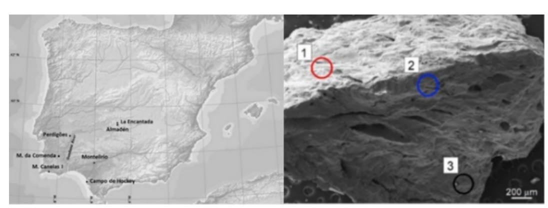
Example research highlights include:



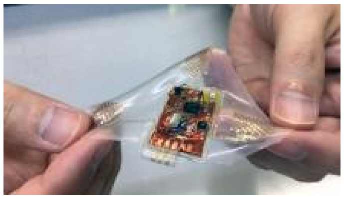
Tunable Optical Chip for New Quantum Devices (Ali Adibi, Georgia Tech) - Researchers at Georgia Tech created a silicon carbide (SiC) photonic integrated chip that can be thermally tuned by applying an electric signal. The approach could one day be used to create a large range of reconfigurable devices such as phase-shifters and tunable optical couplers needed for networking applications and quantum information processing. The research was funded by the Air Force Office of Scientific Research and published in *Optics Letters*.



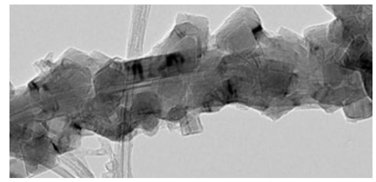
Continuous Flow Nanofluidics for Whole Genome Optical Mapping (Genturi Inc) - Genturi is developing nanofluidic devices for the real-time restriction site mapping of whole genomes. Devices are fabricated with nanochannels, using electron beam lithography, through which single molecules of DNA are electrokinetically driven. The genomic data provides a means to illuminate the full spectrum of variation impacting human health.



Mercury in Archaeological Human Bone (Alison Taylor, UNC-Wilmington) - The SENIC characterization facilities were used to investigate mercury (Hg) in human bone from archaeological sites in the Iberian Peninsula. This pattern of Hg deposition in skeletal material from different sites and ages strongly suggests a biogenic origin for the mercury. This research was published in *Journal of Archaeological Science*.



Stretchable Electronics for Wearable Health Monitoring (Woon-Hong Yeo, Georgia Tech) - A wireless, wearable monitor built with stretchable electronics provides comfortable, long-term health monitoring without some of the side effects of conventional adhesive sensors with conductive gels. The research was funded by the Imlay Innovation Fund at Children's Healthcare of Atlanta, NextFlex (Flexible Hybrid Electronics Manufacturing Institute), and by a SENIC Seed Grant and was published in *Advanced Science*.



PET Yarn Doped with Boron Nitride Nanotubes (BNNano) - BNNano has developed a novel process to produce high-purity boron nitride nanotubes (NanoBarbs™) in large volumes. SENIC (JSNN) advanced material characterization facilities have helped BNNano in quality control and process verification. Recently, BNNano created the world's first PET yarn doped with boron nitride nanotubes, which is expected to compete as a low-cost alternative to aramids/Kevlar®.

Scholarly impact can be measured indirectly with more than 750 publications, presentations, and patents in CY2018, including papers in *Science*, *Nature*, *ACS Nano*, *Nano Letters*, and *PNAS*. Using a Google Scholar search, approximately 100 of these 2018 publications (and nearly 350 publications since 2015) were found to have acknowledged the specific SENIC NSF award number (ECCS-1542174). Additional impact of SENIC is indicated by the centers and other large programs that are enabled by the supported core facilities: **Atlanta Center for Microsystems Engineered Point of Care Technologies (ACME POCT)**, a member of NIH's Point-of-Care Technologies Research Network, **Application and Systems driven Center for Energy-Efficient Integrated Nanotechnologies (ASCENT)**, part of the SRC-funded JUMP (Joint University Microelectronics Program) and headquartered at Notre Dame, and **NSF ERC for Cell Manufacturing Technologies (CMaT)** at Georgia Tech.

While economic impact can be difficult to quantify, there are individual examples.

- Florida based commercial licensing company, **NXN-Licensing Inc**., is involved in the development of electrochromic multi-color changing polymers technology and used IEN's special project space from Sept. 2017 to Feb. 2019 in a collaboration with Prof. John Reynolds (Georgia Tech Chemistry and Biochemistry) for development of working demonstration prototypes.
- **Mavric Semiconductor** is an early stage start-up located in the ATDC incubator at Georgia Tech that is commercializing neuromorphic circuits developed at Georgia Tech for sensor processing.
- Two Georgia Tech startups that have benefitted from their previous access to SENIC facilities include **NextInput**, which develops MEMS force sensors and has received $30 million in venture capital funding and has begun mass production for automotive and mobile touch panel applications, and battery maker **Sila Nanotechnologies** which has received a $170 million investment from Daimler for automotive batteries.
- Large companies that have recently expanded SENIC usage include **Abbott, Imerys Minerals, Kimberly-Clark,** and **Solvay Specialty Polymers**.

<u>Education and Outreach Activities</u>

SENIC's vision for education and outreach is focused on the development of a strong workforce capable of meeting the needs of a growing nanotechnology-enabled economy. This year through our programs, we reached more than 8,500 individuals from young children through adults.

SENIC provides a number of internship opportunities for college students. The *SENIC Undergraduate Internship in Nanotechnology (SUIN),* an NSF REU Site at Georgia Tech (2018-2020), offers summer internships for students from Southeastern institutions. SUIN hosts 10 students/year for 10 weeks of research with a mentor and faculty member. JSNN is home to the NIH *Maximizing Access to Research Careers* (MARC) Undergraduate Student Training in Academic Research (U-STAR) Fellowship Program. This program annually offers two students underrepresented in the biomedical sciences an opportunity to engage in research projects and focused workshops and courses to prepare them for graduate school. Additionally, JSNN hosts up to four interns/year from Forsyth Technical Community College's Nanotechnology and Biotechnology programs. Interns receive up to 160 hours of on-site and paid workforce training in one of the JSNN core labs.

The Graduates in Nanotechnology (GIN) group, formed in 2018 to support students involved in nanotechnology research, continues to host events, and JSNN recently started a Materials Research Society Chapter. These two student groups plan to stream or teleconference events when relevant. This past year, GIN hosted several outside seminar speakers including Prof. Yi Cui (Stanford), Prof. John Rogers (Northwestern), and Prof. Ying Diao (University of Illinois) with an opportunity for students to have lunch and less formal conversation with the speakers. GIN students also participated in outreach events including activities for the Atlanta Science Festival, Georgia Tech's Middle Schools Day, and National Nanotechnology Day. The MRS student chapter at JSNN hosted an industry panel on successful career pathways for graduate students in celebration of Nano Day (Oct 9, 2019). Georgia Tech held its annual User Science and Engineering Review (USER) Day (September 6, 2019) in conjunction with the annual James T. Meindl Distinguished Lecture at which facility users presented oral presentations and research posters.

IEN hosts 16 Nano@Tech seminars each academic year with speakers primarily from the local community, which includes Georgia Tech faculty, as well as faculty from neighboring universities and researchers at companies in the region. JSNN also holds at least 20 seminars each academic year with speakers primarily from colleges, universities and industries in North and South Carolina. Both of these events are live-streamed and video archived. IEN's NanoFANS Forum, a biannual symposium at the intersection of life sciences and nanotechnology was held in October 2018 (Trends in Medical Robotics) and May 2019 (Nanobiomechanics), with nearly 100 attendees at each. A variety of different vendor-supported and sponsored workshops were also held at both SENIC locations. Short courses were conducted with a special focus on hands-on experiences for the participants: "Soft Lithography for Microfluidics" (April and Sept. 2019), "Microfabrication" (March and August 2019), "Materials Science SEM & X-Ray Microanalysis" (Oct. 2018), and "Transmission Electron Microscopy Workshop" (May 2019). Students from JSNN are provided scholarships (using SENIC funds) to attend any of the Georgia Tech workshops.

SENIC has been active in providing outreach to K-12 students, teachers, and the general public. Georgia Tech and JSNN reach K-12 students with school visits, both on and offsite, occurring each month of the year. Unique to JSNN is the NanoBus, an after-school mobile hands-on laboratory which includes an STM, 3D printer, and a variety of lab activities. Staffed by JSNN students, the NanoBus visited 16 schools during the 2018-19 school year reaching over 1500 students. JSNN faculty, staff and students also provided summer research opportunities for high school students in Guilford and Forsyth counties through programs such as Canterbury Summer Science Academy and Draelos Science Scholars program. In collaboration with the American Association of University Women Greensboro branch, JSNN continues to host a STEM-focused event to give female students "hands-on" experience to help them gain knowledge and confidence to enhance their success. IEN also has a strong relationship with Atlanta Public School's Gifted and Talented program, providing spring research internships for minority high-school students. GT also provided summer internships to five local high school students.

JSNN hosted the Annual Gateway to Science event during the NC Science Festival, which included demos, tours, and videos on careers in nanotechnology, while IEN participated in the Atlanta Science Festival through three activities and an expo booth. In collaboration with SENIC's SEI coordinator, one activity encouraged participants to think about future applications of and access to nanotechnology. For outreach to K-12 teachers, IEN introduced an annual Nanotechnology Summer Institute for Middle School Teachers this past June. Fifteen teachers from across GA spent 4 days learning about nanotechnology and thinking of ways to introduce concepts into their classrooms. IEN also exhibited and provided a workshop at the Georgia STEM Forum and the Georgia Science Teachers Association meeting. At the NSTA annual (April 2019), SENIC personnel supported the joint NNCI/NNCO booth.

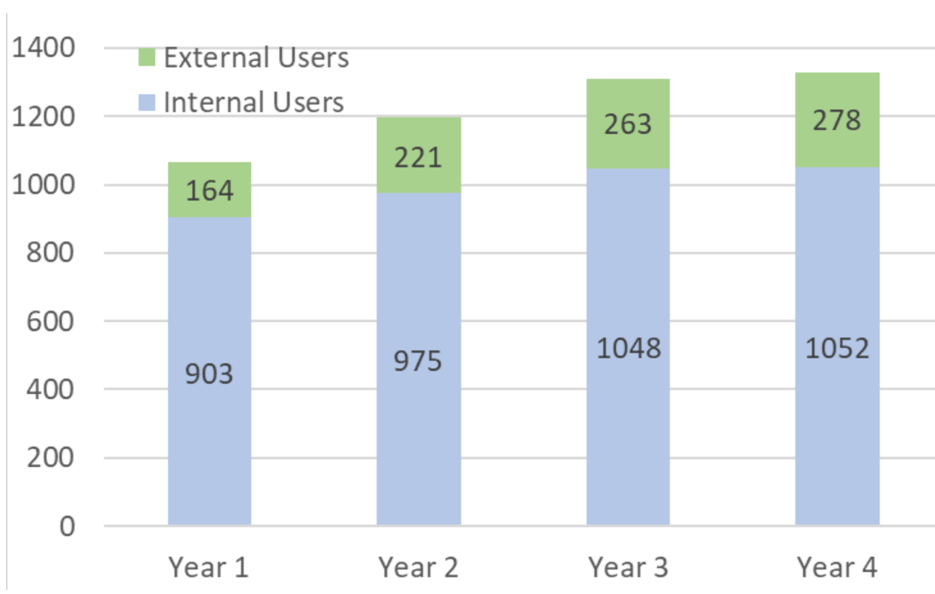
Societal and Ethical Implications Activities

The aim of the SEI work at SENIC is to increase attention to application and commercialization of nanotechnology, while still attending to social and ethical implications. We have developed a model which incorporates societal impacts in a pragmatic manner that parallels elements of the I-Corps program ("I-Corps Plus SEI"). We developed an interactive exercise from this model, which was delivered at the January 2019 NNCI Winter School as well as in July 2019 to IEN's summer REU students. At the suggestion of the NSF Reverse Site Review panel, we conducted an evaluation using concept mapping to measure the effects of the SEI program, including an SEI training video, "8 Things You Need to Know About the Social Implications of Nanotechnology Research." and the interactive exercise on understanding of the concepts among REU students. The students were asked to complete concept maps before and after the program interventions, and these were compared in terms of the number of SEI concepts as well as the content of these concepts. The results suggest that an explicit program of interventions does improve understanding of the various dimensions of SEI over and above existing preconceptions. We also conducted a bibliometric analysis of 2.2 million nanotechnology related publications, identifying over the 2013–2017 period more than 20 emerging topics, primarily in the energy and two-dimensional material domains that are apt to be actively researched in the coming few years.

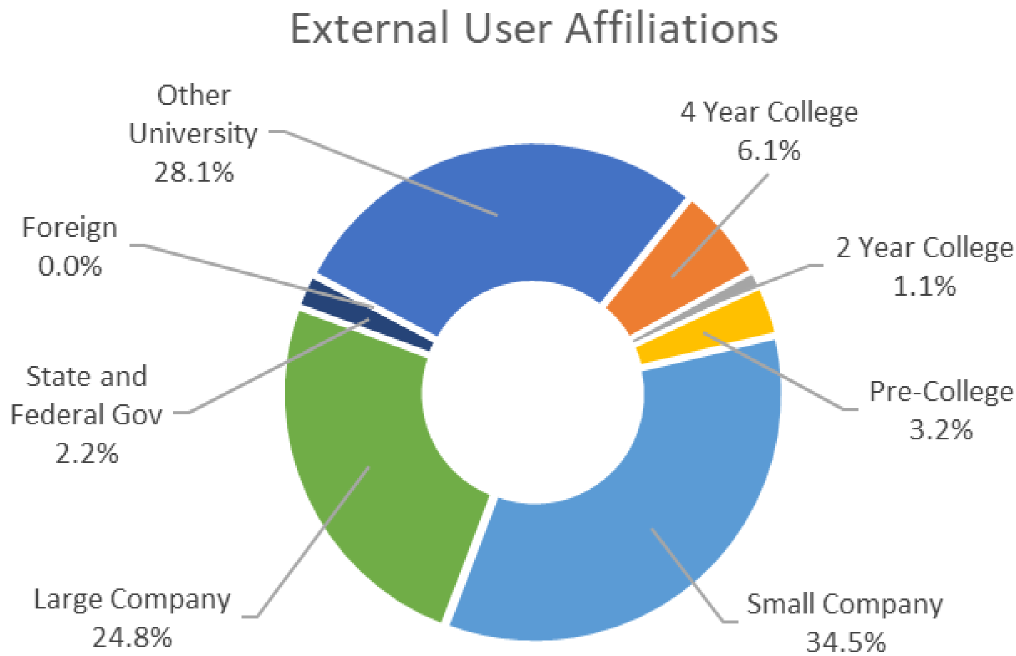
SENIC Site Statistics

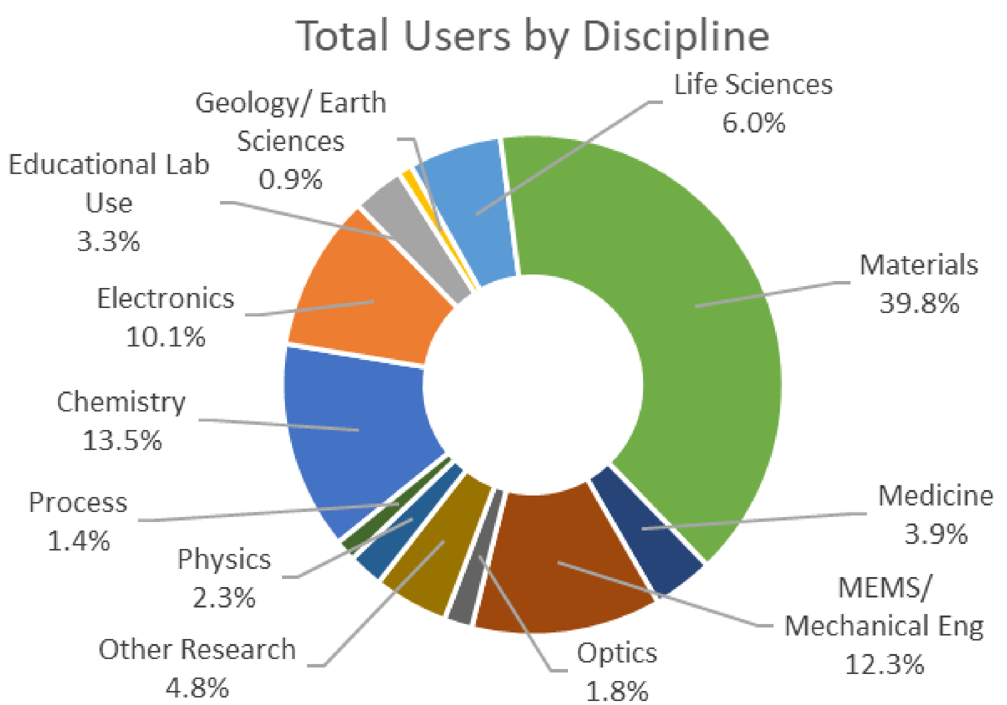
Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	1,067	1,196	1,311	1,330
Internal Cumulative Users	903	975	1,048	1,052
External Cumulative Users	164 (15%)	221 (18%)	263 (20%)	278 (21%)
Total Hours	79,581	85,275	99,118	101,571
Internal Hours	71,659	73,499	85,730	88,282
External Hours	7,922 (10%)	11,733 (14%)	13,388 (14%)	13,289 (13%)
Average Monthly Users	447	498	546	576
Average External Monthly Users	60 (13%)	63 (13%)	83 (15%)	89 (15%)
New Users Trained	313	313	386	502*
New External Users Trained	67 (21%)	110 (35%)	123 (32%)	132 (26%)
Hours/User (Internal)	79	75	82	84
Hours/User (External)	48	53	51	48

*During Year 4, SENIC began adding new users of the Materials Characterization Facility to this metric.



SENIC Year 4 User Distribution





11.15. Texas Nanofabrication Facility (TNF)

Facility, Tools, and Staff Updates

TNF is composed of the Microelectronics Research Center cleanroom, which provides nanofabrication capabilities, the Texas Materials Institute, which provides advanced metrology capability, and the NASCENT Engineering Research Center, which is developing unique roll-to-roll etching and deposition, as well as nanoimprint capabilities.

Major tool upgrades at TNF this year include:

- JEOL Aberration Corrected TEM (funded by Univ. of Texas) ($3M)
- Kurt J Lesker load-locked 6-pocket E-beam evaporator ($ 289k)
- AJA International Ion Milling System with RF sputterer and end point detector($275k)
- VK-X1100 Optical profilometer for TMI facility ($120k)
- Park NX10 Atomic force microscopy tool for TMI facility ($100k)
- Advanced deposition and etch systems: NASCENT has installed a novel roll-to-roll atomic layer deposition system on flexible substrates. A roll-to-roll etch system is being installed.

New Staff updates: To keep up with the training demands for new users and current users, we have hired 3 undergrad part-time trainers, and hired 2 graduate students in Spring 2019 from UT Austin Colleges of Engineering and Natural Sciences.

User Base

The TNF NNCI site is on track to meet most of the user base metrics, while we have exceeded others. Our external users include 50 companies (small and large) as well as 17 academic institutions. More than half of the current companies which benefit from the TNF shared facilities were already users at TNF in the past year.

User profiles including demographics and research fields (i.e. disciplines) are reported voluntarily through an online survey by each user during the orientation session. Half of the TNF users self-declared their research project to be related to Materials (31%) or Electronics (18%) disciplines. The TNF shared facilities are utilized significantly by women (32%). This percentage has increased compared to the same period in Year 3.

A major challenge in the coming year is to increase the percentage of outside users to 25%, from the current level of 22%. Under NNIN, the Texas Microelectronics Research Center had a user base of ~300, of which ~35-40% was external. Under NNCI, our total user number has gone up to over 685, well above our target of ~500, but the majority of the new users are internal. TNF will continue to organize activities such as technical workshops that are known to attract users from within and outside the University. The NASCENT Industrial Liaison Officer (Dr. Larry Dunn) will continue to work closely with TNF to promote the shared facilities to industrial partners. We have redoubled our efforts to pro-actively advertise the expanded capabilities to external users. Towards that end, we have reached out to universities in Oklahoma and Arkansas, and offered new users 5k$ “seed grants” to use TNF facilities, either remotely on in person. This has started bearing fruit, and the External usage percentage has increased slightly in Year 4, compared to Year 3.

Research Highlights and Impact

This year, TNF users have published over 125 archival journal publications, numerous conference presentations and filed four patents. The publications have been in high impact journals such as *Nature* and *Nature group journal*, *Physical Review Letters* and *Physical Review B*, *Nanoletters* and *ACS Nano*, etc. The majority of the work is in nanoelectronics, nano-optics and nanomaterials.

Work on "Moiré Excitons in Van der Waals Heterostructures" involving Internal-External-Academic-National Lab-Collaboration between Univ. of Texas, NIST, Argonne, as well as other US and foreign universities has led to a joint publication in *Nature*. There has been joint work on Band Structure Engineering of Layered WSe_2 via One-Step Chemical Functionalization involving a Multi-NNCI-Site Collaboration (TNF, SDNI and CNF), leading to a publication in *ACS Nano*.

About half of the 150+ external users at TNF are small companies, funded by NSF or other agency SBIR and STTR grants. Omega Optics is a startup, funded by a NASA SBIR contract, building a monolithic handheld mid infrared absorption spectrometer for trace gas sensing.

Nanohmics, funded by DHP Phase II SBIR Program and NIH Phase I SBIR Program is working on Multiplexed Metal-Oxide Gas and Fluid Sensor Arrays. Bioassays employed to evaluate the diverse range of biomarkers associated with organ injury are time-consuming, costly and require multiple instruments/testing formats to reach a diagnosis (i.e. fluorescence-based capture, ELISAs, PCR, etc.). Individually, these platforms are incapable of predicting the onset of irreversible organ tissue injury (e.g. kidney, liver, heart and lung). One barrier to transitioning microarray technology into multiplex medicinal diagnostics has been the limitations imposed by fluorescence/optical-based labeling and endpoint detection. To overcome these limitations, Nanohmics Inc., developed the SnO_2 nanowire chemiresistive sensor array.

In the area of energy, PC Krause and Associates is working on fabrication of metamaterials for efficient passive cooling using embedded resonant polar dielectric microspheres randomly in a polymeric matrix, resulting in a metamaterial that is fully transparent to the solar spectrum while having an infrared emissivity greater than 0.93 across the atmospheric window.

Applied Novel Devices (AND), supported by an NSF SBIR grant, is working on Thin Crystalline (~30 Microns) Silicon Vertical Power Transistors that can be fabricated without grinding away the Si substrate. AND Inc. has developed a thin crystalline technology that can peel off 20 - 50µm of silicon from semi-processed wafers and enable reuse of the parent wafer. Using this exfoliation technology, AND has recently demonstrated the world's first Thin Crystalline (~30 Microns) Silicon Vertical Power MOSFET. Various major companies are evaluating their IP.

Silicon Audio is developing high-temperature piezoelectric pressure sensors for hypersonic flow measurements based on a microelectromechanical-system (MEMS) piezoelectric pressure sensor for measurements in hypersonic flows at extreme temperatures (>1000 °C). This represents the first demonstration of MEMS piezoelectric pressure sensor to capture hypersonic-flow-specific features in field measurements, including shock waves and second-mode instabilities associated with laminar-to-turbulent transition, successful audio capture while the sensor is immersed in a butane flame, demonstrating operation at extreme temperatures, and first dynamic pressure sensor to include on-diaphragm thin-film platinum temperature sensors for high-temperature readout.

Another startup in the audio space is GraphAudio, which was co-founded by Prof. Alex Zettle at Univ. of California Berkeley. They decided to relocate to Austin to use TNF facilities because of the low-cost structure enabled by NNCI, as well as expertise in large area graphene and hBN growth by chemical vapor deposition developed by Prof. Rod Ruoff at the Univ. of Texas at Austin under the prior NNIN program. Initial work has successfully demonstrated feasibility of novel graphene-based transducers for audio applications in support of GraphAudio's mission to become the global leader in acoustic sensing, micro-speakers and microphones in mobile, consumer and enterprise electronics. They are demonstrating their product at the Consumer Electronics Show to many interested smart phone manufacturers.

Education and Outreach Activities

TNF has hosted five REU students for 9-week research internship each summer. We have tried to focus on recruiting women and under-represented minorities. The NNCI TNF REU interns went to Cornell for the Annual Review. Three unique programs at TNF are briefly described next.

a) Introduce a Girl to Engineering Day and the Girl Day, April 2019: TNF (TMI) gave elementary and middle school students a chance to explore STEM through grade-appropriate, hands-on activities hosted by volunteer scientists, engineers, and STEM enthusiasts from over 160 student organizations, research centers, corporate partners and community organizations. It is specifically designed for girls, but boys are also welcome as well. We had 8,781 K-8th Grade Registrants: 89% Girls, 33% Latina/Latino, 9% African American and 13% Asian.

b) Arranged a hands-on demo program for the high school students at the national nanotechnology day, on October 9^{th} 2018. 20 students from a local high school participated in the program. The students made simple circuits with insulating and conducting squishy dough, and lemons. Nails, coins and the wires were used to connect the circuits.

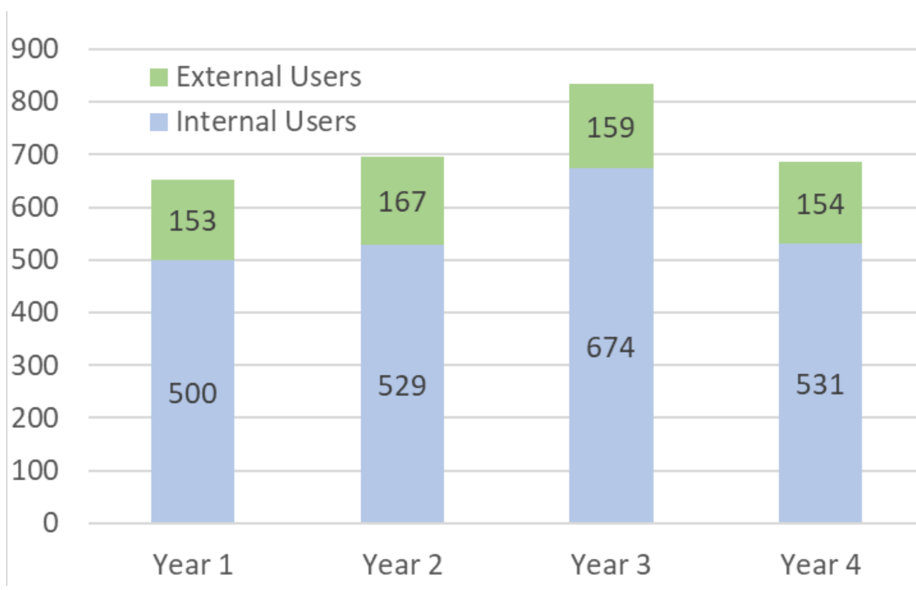
c) "Alice in Wonderland for Girls" demo and tour were arranged in July 2018. Its goal is to attract women to physics by getting high-school students involved in research over the summer before they make decisions about colleges. TNF offered a half day program as part of this, including a tour inside the cleanroom and a video demonstration with discussion, describing the state of art fabrication procedure followed in the semiconductor industry for the participants.

Societal and Ethical Implications Activities

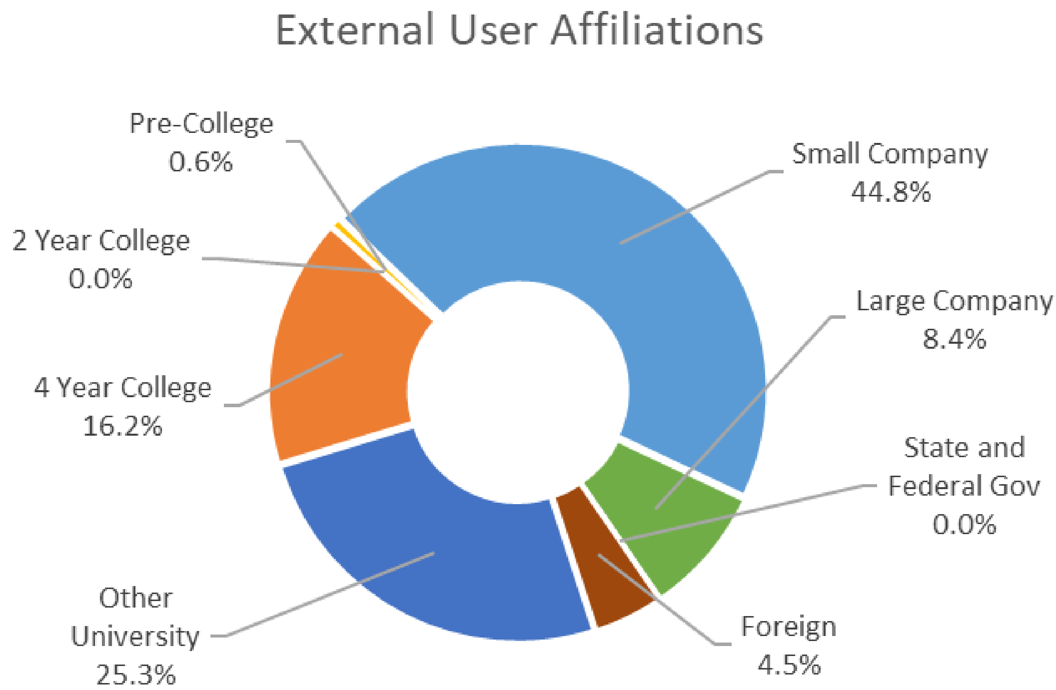
The SEI team at TNF is composed of Prof. Lee Ann Kahlor (SEI Director) and Jacy Jones (Graduate student researcher on SEI). One of the goals for the SEI work at TNF has been to develop a useful training tool for helping Nano-scientists to think about the social and ethical implications of the work that they do across multiple meaningful dimensions. They have developed and pilot-tested an evidence-based training module that is accessible, effective and scalable to other NNCI sites. Initial results have been published in the journal *Nanoethics*.

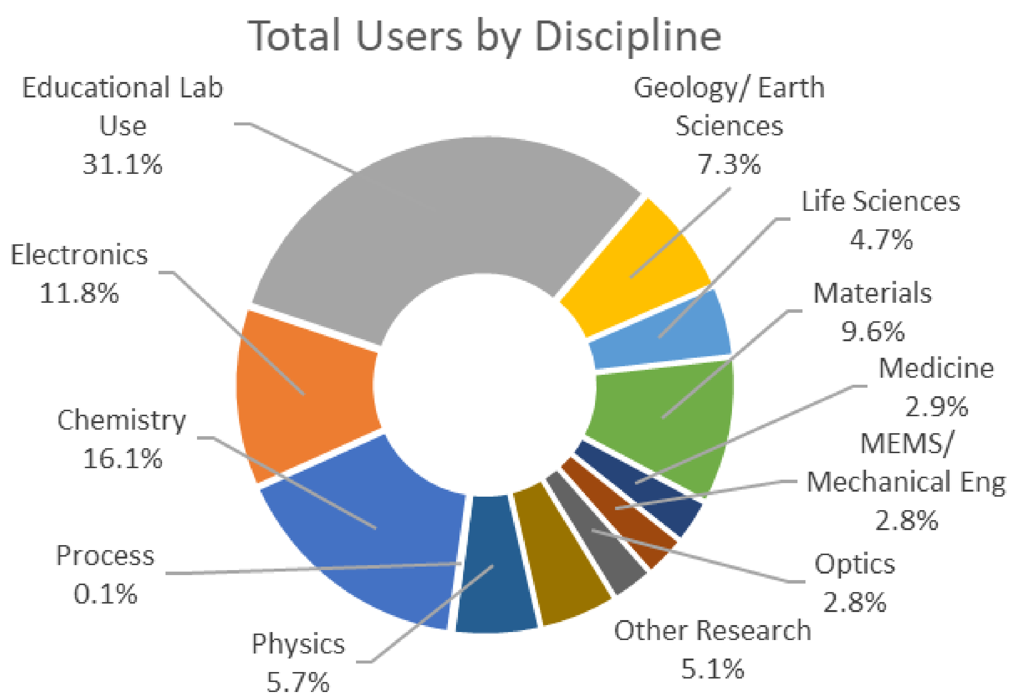
TNF Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	653	696	833	685
Internal Cumulative Users	500	529	674	531
External Cumulative Users	153 (23%)	167 (24%)	159 (19%)	154 (22%)
Total Hours	67,570	58,354	63,645	65,166
Internal Hours	53,484	45,952	46,464	48,254
External Hours	14,084 (21%)	12,402 (21%)	17,181 (27%)	16,912 (26%)
Average Monthly Users	244	272	287	315
Average External Monthly Users	45 (18%)	50 (19%)	59 (21%)	65 (21%)
New Users Trained	99	193	80	62
New External Users Trained	48 (48%)	45 (23%)	33 (41%)	29 (47%)
Hours/User (Internal)	107	87	69	91
Hours/User (External)	92	74	108	110



TNF Year 4 User Distribution





11.16. Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth)

Facility, Tools, and Staff Updates

Facility and Tools – NanoEarth has been working closely with the Nanoscale Characterization and Fabrication Laboratory (NCFL) at Virginia Tech to make the case for University support of major instrumentation upgrades in the university-wide shared facility.

Staff – Founding Director and PI Michael Hochella officially retired from Virginia Tech on February 1, 2019. Upon his retirement, Mitsuhiro Murayama became the NanoEarth Director with Linsey Marr taking the Deputy Director position. Murayama was formerly the site's deputy director. Marr, an outstanding environmental scientist (h-index 36, total citations >5,000) and co-PI, is the Charles P. Lunsford Professor of Civil and Environmental Engineering. Marr's research focuses on characterizing the emissions, fate, and transport of air pollutants in order to provide the scientific basis for improving air quality and health. Hochella, who still works with NanoEarth's partner facility at Pacific Northwest National Laboratory, will continue to have an active role in NanoEarth as the Director of User Development.

Last year our TEM Specialist, Debora Berti, left NanoEarth to pursue her Ph.D. at Texas A&M University. After her departure, we began a search for a suitable replacement. Replacing a high level TEM specialist who understands Earth and environmental samples is exceptionally difficult, as such people are rare. After an extensive and long international search, NanoEarth hired Elizabeth Cantando, a highly skilled TEM and dual-beam FIB operator for nanoscale characterization. Cantando has a B.S. in aerospace engineering from Virginia Tech and a Ph.D. in Engineering Physics from the University of Virginia. After a post-doc at the University of Maryland, she worked for FabMetrix as a research engineer/scientist. Cantando began working at NanoEarth on December 10, 2018.

User Base

NanoEarth is designed for users in the Earth and environmental sciences and engineering fields, but many other scientists and engineers accomplish important research in related fields using our labs and instrumentation. In the case of NanoEarth, Earth and environmental science and engineering related users have included those in the fields of chemistry, mechanical engineering, civil engineering, medicine, materials, electronics, and physics.

As mentioned above, Michael Hochella has taken on the role of Director of User Development for NanoEarth. When traveling to conferences and universities for invited talks, he engages the Earth and environmental communities and shares information about the capabilities and support provided by NanoEarth and the NNCI as a whole. In addition to making personal connections with researchers, NanoEarth has recruited users at several targeted conferences including the Centennial Meeting of the Mineralogical Society of America and the annual meeting of the Association of Environmental and Engineering Geologists.

After clarifying who qualifies for our MUNI (Multicultural and Underrepresented Nanoscience Initiative) program last year, NanoEarth used this year to reach out to those underserved populations. MUNI provides financial support for individuals engaging with NanoEarth for research or educational purposes. In our fourth year, we supported 150 MUNI participants from 43 different organizations, including high school students, undergraduate and graduate students, professors, governmental researchers and professionals, and industry users. With our strategic priority populations now broadened, we expect that the MUNI program will continue to have an even greater impact in the coming year.

Research Highlights and Impact

Discussed below are one academic and one industry highlight from this year. Additional highlights are described in the included PowerPoint slides.

Leading Academic Highlight (led by Mike Hochella, Mitsu Murayama, Linsey Marr, and Peter Vikesland from NanoEarth with Peter McGrail, Nikolla Qafoku, and Paul Schroeder from NanoEarth partner institute PNNL, Dave Mogk from MONT, and Paul Westerhoff from NCI-SW), published in *Science*, entitled "*Natural, incidental, and engineered nanomaterials and their impacts on the Earth system*": This extended paper was selected for *Science* magazine's "Tomorrow's Earth" series of articles. It describes how nanomaterials are critical components in the Earth system's past, present, and future and their characteristics and behavior. It is now possible to frame their immediate and long-term impact on environmental and human health at local, regional, and global scales.

Leading Industry Highlight (from a team of lead external users - the company and participants are not named for proprietary purposes - and internal users), *Commercially Scalable Production of Layered Double Hydroxides (LDHs)*: This work demonstrates commercially viable production of a specific type of layered double hydroxide (LDH). The unique features of LDHs including high surface area, purity, basic surface properties, and stability, make them useful in a broad range of commercial applications. Examples include applications in catalysis, separations, filtration, controlled release, electroactive and photoactive materials, sensors, and electrodes. The ability to manufacture LDHs of suitable quality and at sufficient scale is important to the adoption of these novel nanoscale materials in commercial applications.

Education and Outreach Activities

NanoEarth has a very active and robust Education and Outreach (E&O) program. A few highlights are included below.

- NanoEarth continues our partnership with Jim Metzner (multiple radio media major-award winner, plus multiple NSF, Grammy Foundation, and Fulbright grants) with 10 new shows developed for *Pulse of the Planet* this year. In addition to featuring Adam Coates from Virginia Tech, the shows hosted individuals from two other NNCI sites: Quinn Spadola (Georgia Institute of Technology) and Paul Westerhoff (Arizona State University). *Pulse of the Planet* is heard on over 265 NPR radio stations by 1.1M listeners per week; additionally, these 10 new shows were downloaded over 27,000 times in Jan-Sept 2019.
- NanoEarth served as a major sponsor for the 2018 HBCU/MSI Research Summit organized by Virginia Tech's Graduate School and Office of Recruitment and Diversity Initiatives. Additionally, NanoEarth recruited, financially supported, and hosted attendees from Hampton University, Johnson C. Smith University, Fayetteville State University, Georgia State University, and North Carolina A&T for meetings, instrument demonstrations, and networking. The summit provides an opportunity for faculty, students, and administrators to explore research opportunities and potential collaborations between historically black colleges/universities (HBCUs), minority serving institutions (MSIs), and Virginia Tech.

- NanoEarth created and/or participated in 16 industrial engagement and innovation/ entrepreneurship activities during this reporting period, including presenting at the NanoBCA 17th Annual Meeting and engaging industry and government representatives with hands-on activities at the Contaminants of Concern: Chemistry, Toxicity, and Treatment workshop.
- In partnership with Virginia Tech's Nanoscience undergraduate major in the College of Science, NanoEarth hosted NanoCamp events in our facilities. During the 3.5 days of NanoCamp, 45 9th-12th grade campers participated in over 8 hours of activities with NanoEarth team members.
- In coordination with VT's Nanoscience undergraduate degree program, NanoEarth hosted a workshop for high school teachers. The purpose of the workshop, which provided continuing education credit, was to provide teachers with nano-related hands-on activities and lesson plans that they could take back to their classrooms. Sixteen teachers, who reach more than 1,130 students per year, attended the workshop. Thanks to a $10,000 grant from the Virginia Space Grant Consortium, teachers were able to return home with over $300 in lab supplies and teaching materials.

Societal and Ethical Implications Activities

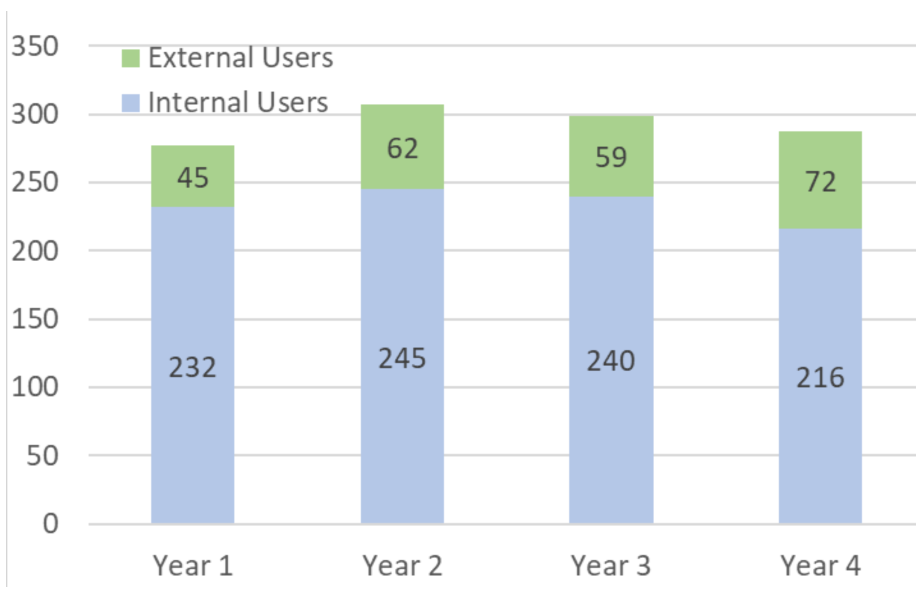
NanoEarth participates in Societal and Ethical Implications (SEI) of nanotechnology activities that are coordinated across participating NNCI nodes under the direction of Professor Jamey Wetmore of the Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) node. SEI activities initiated within NanoEarth include: 1) engagement with diverse and underrepresented groups, 2) empowerment of individuals and social change through nanotechnology entrepreneurship, and 3) earth and environmental nanoscience in the service of society. These activities were shared with representatives from other NNCI nodes during the NNCI annual meeting, and will help form the basis of inter-node SEI activities in the future.

Computation Activities

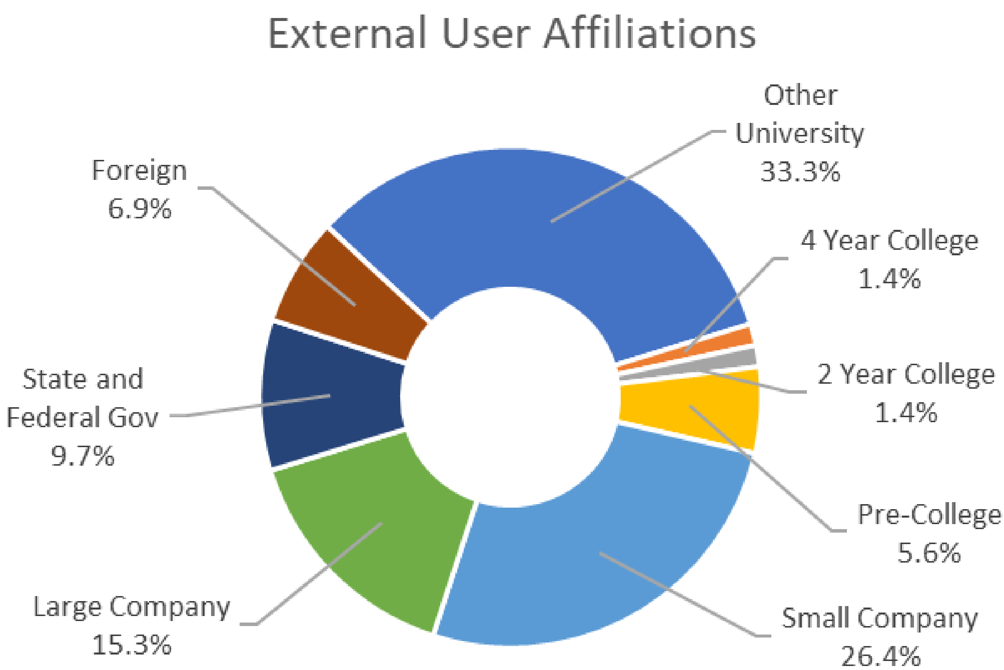
NanoEarth continues to manage access requests for users of the Nanotechnology Consumer Products Inventory (CPI) (www.nanotechproject.org/cpi/). While the inventory no longer receives funding support from the Pew Charitable Trusts, NanoEarth faculty, staff, and students have played a vital role in sustaining this critical nanoinformatics resource.

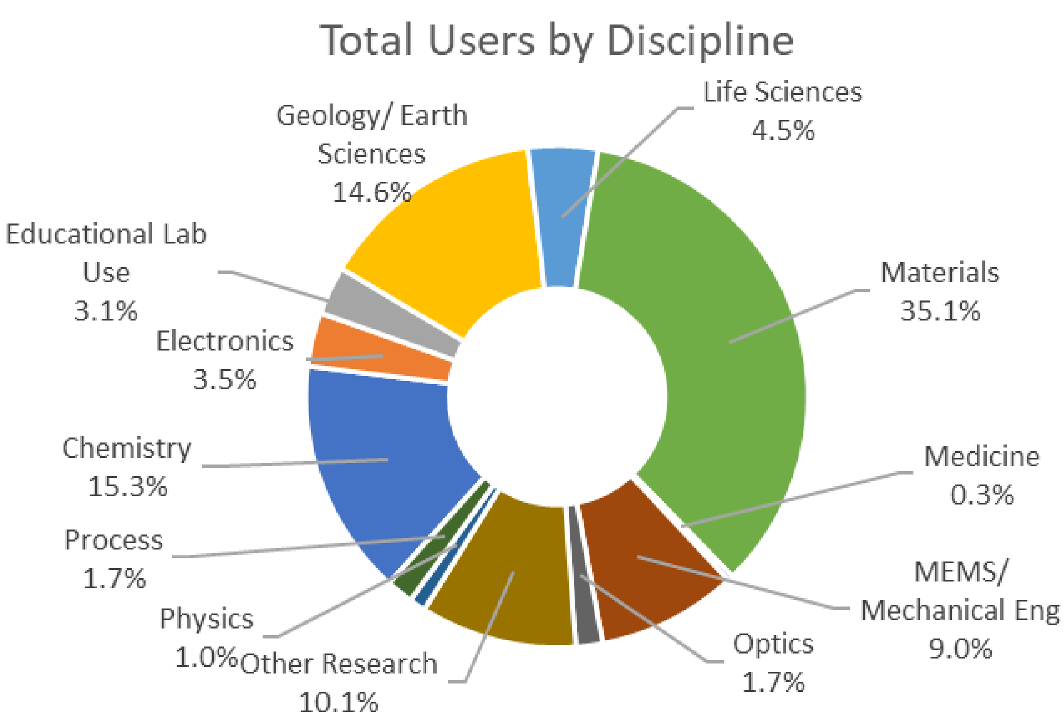
NanoEarth Site Statistics

Yearly User Data Comparison				
	Year 1	**Year 2**	**Year 3**	**Year 4**
Total Cumulative Users	277	307	299	288
Internal Cumulative Users	232	245	240	216
External Cumulative Users	45 (16%)	62 (20%)	59 (20%)	72 (25%)
Total Hours	7,627	18,056	16,455	15,291
Internal Hours	6,196	14,277	14,073	11,622
External Hours	1,431 (19%)	3,779 (21%)	2,382 (14%)	3,669 (24%)
Average Monthly Users	78	90	93	91
Average External Monthly Users	9 (12%)	14 (15%)	13 (14%)	18 (20%)
New Users Trained	277	134	94	80
New External Users Trained	45 (16%)	27 (20%)	0 (0%)	0 (0%)
Hours/User (Internal)	27	58	59	54
Hours/User (External)	32	61	40	51



NanoEarth Year 4 User Distribution





12. Program Plans for Year 5

Many of the program aspects for the Coordinating Office (see Section 2 for details) will remain the same as we go into Year 5. The role of the Coordinating Office will continue: (1) promote and market the NNCI and its sites, (2) assist users in finding appropriate resources across the network and beyond, (3) coordinate site activities and share best practices across the network and beyond, (4) assist the sites wherever possible, and (5) serve as the main interface with the NSF. Thereby, the goal is to ***make the network greater than the sum of its parts***.

As highlighted in the Charter Letter provided to the NNCI Advisory Board, the initial roles of the Coordinating Office (CO) were defined as follows in the NSF program solicitation:

- "The Coordinating Office will be responsible for establishing a comprehensive web portal to ensure close linkage among the individual facility websites such that they present a unified face to the user community of overall capabilities, tools, and instrumentation."
- The Coordinating Office "will also work with all sites in ways to guide users regarding which site or sites, which instruments, and which processes would enable users to complete their projects most successfully."
- "The Office will help to coordinate and disseminate best practices for national-level education and outreach programs across sites, as well as the instruction and study of social and ethical implications of nanotechnology."
- The CO "will seek to harmonize capabilities for modeling and simulation in nanoscale fabrication and characterization across sites, and provide effective coordination with the NSF-supported Network for Computational Nanotechnology (NCN)."
- "The Office will work with the individual sites to establish uniform methods for assessment and quantifiable metrics of overall site performance and impact, including those for educational and outreach activities."
- The CO "will help to share best practices and laboratory safety and training procedures across all sites. It will engage all sites in a planning process to explore emerging areas of nanoscale science, engineering, and technology that can lead to future growth of the external user base."
- The CO "will coordinate the acquisition needs for specialized instrumentation across all sites to enhance new areas of research growth."
- "The Office will also coordinate data management across all sites"
- The CO will coordinate "the dissemination of shared knowledge to research, education, and technology communities"
- The CO will enhance "connections with other nationally funded academic centers or networks and facilities supported by government, the private sector, and international partners."

To achieve these goals, the three Associate Directors of the CO will continue to coordinate activities in Education & Outreach, Societal and Ethical Implications, and Computation across the network. Moreover, the CO will continue its support of the Subcommittees and Working Groups, as well the NNCI website development and the NNCI Annual Conference. In prioritizing its programs in view of the limited resources, the CO considers recommendations from the NSF, the NNCI Advisory Board, the NNCI Executive Committee, as well as the NNCI Subcommittees and

Working Groups. The CO appreciates the strong support from all sites in making the network more than the sum of its parts and counts on continued site support for Year 5.

A number of specific activities planned for Year 5 are highlighted below:

- *NNCI Website*: The CO will continue to include new content on nanoscale applications to highlight the networks capabilities, add scientific highlights as well as commercialization highlights ("nuggets"), and attempt to update -*with site input*- the current tools and experts databases.
- *NNCI Annual Conference:* The 5th NNCI Annual Conference will be hosted by SHyNE and will be held at Northwestern University in Evanston, IL, October 26-28, 2020. The program will be again adjusted slightly based on feedback from the Advisory Board and the survey conducted at the 4th NNCI Annual Conference.
- *REU Convocation*: The 4th annual REU Convocation will take place at TNF, University of Texas, Austin, TX, August 2-4, 2020.
- *Subcommittees and Working Groups*: The CO will continue to emphasize the importance of the subcommittees and working groups to coordinate network activities and develop/share best practices. Participation in subcommittees and working groups will be further promoted and the formation of additional working groups will be encouraged and supported. Subcommittees and working groups will be encouraged to report outcomes of their work, including recommendations and particular programs, via the NNCI webpage, at conference calls with the NNCI Executive Committee, and at the NNCI Annual Conference. The CO will look into disseminating developed recommendations and best practices and adjust its procedures/programs where needed. Limited funds are available to support working group events, such as targeted symposia and workshops.
- *Research Communities*: In addition to subcommittees and working groups, the NNCI will explore the formation of research communities in Year 5. These research communities will be composed of groups of faculty, students, and staff from NNCI sites organized around a particular research topic, national research priority, or grand challenge. In addition to serving as networking opportunities for researchers, the research communities provide an external facing NNCI component and benefit the larger scientific and engineering communities by addressing questions such as (a) What infrastructure capabilities are needed to support the research topic? and (b) What are the challenges of current fabrication infrastructure for the specific research area? Initially, four research communities focused on the topics of "Quantum Leap", "Understanding the Rules of Life", "Growing Convergence Research", and "Nano Earth Systems" are planned, with others added based on interest.
- *NNCI Staff Awards:* The CO plans to continue the successful NNCI-wide staff awards program started in Year 3 to promote staff and recognize excellence in areas of user support, technical activity, and education and outreach.
- *Workshops*: The CO will continue incentivizing sites to collaborate via symposia and workshops. A budget has been established to financially support workshops that involve and benefit multiple NNCI sites (see also Subcommittees and Working Groups).
- *Marketing:* The CO, with assistance from all of the NNCI sites, will continue to market the

NNCI at conferences and trade shows and through printed and electronic collateral.

- *User Survey:* The CO will further refine the annual user satisfaction survey and will administer this survey again in Summer 2020.
- *Data Collection and Reporting:* The CO will continue to collect statistical data on network usage and report these data to the NSF as part of the annual reporting. In addition, the collection of data on funding sources supporting research done at NNCI sites that was done in Year 4 for the first time on a network level will be refined and repeated in Year 5 on request from the NSF.
- *NNCI Impact:* The CO will work with the Metrics and Assessment Subcommittee and the Entrepreneurship and Commercialization Subcommittee to define NNCI Societal & Economic Impact Metrics, collect those metrics and disseminate them as appropriate. The goal is to better showcase, using quantitative and qualitative data, the societal and economic impact of the NNCI and, thus, complement the data collected on the scientific and scholarly impact of the network.
- *NNCI Emerging Areas and Network Outlook:* The CO will continue working with the NNCI sites and appropriate subcommittees to identify emerging areas of nanoscale science, engineering, and technology that could further grow the user base and will identify acquisition needs for specialized instrumentation needed to support these emerging areas. The goal is to develop a clear vision for the future of the NNCI network, how it impacts national research priorities such as artificial intelligence, quantum and medical innovation, and how it has to develop and address its challenges going forward.
- *NNCI National and International Connections:* The CO will work with NNCI sites and the Global and Regional Interactions Subcommittee to connect with other nationally-funded as well as international "nano" networks and facilities supported by government, the private sector, and international partners.
- *NNCI Site Interactions:* The CO will further promote and incentivize where possible site to site interactions, including but not limited to multiple sites supporting a given user project, sites sharing resources and best practices, and sites having staff exchanges.
- *Prioritization of NNCI CO Funds:* With more and more requests for financial support from the CO, the CO will review how it spends its annual budget and, together with the Executive Committee, prioritize its resources to impact the programs that help the network be more than the sum of its parts. Examples include co-funding workshops and a staff exchange program, as suggested by the Global & Regional Interactions Subcommittee.
- *NNCI CO Program Evaluation:* As the NNCI approaches the second 5-year period, it is timely to review and adjust network-wide activities as needed, including Education and Outreach, Societal and Ethical Implications, and Computation efforts. This will be done in concert with the sites and feedback from NSF and the NNCI advisory board.