NNCI Coordinating Office Annual Report (Year 7)
April 1, 2022 – March 31, 2023
NSF Award 2100059

Submitted: February 21, 2023

NNCI Coordinating Office Annual Report 2023

Table of Contents

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 program was renewed for an additional 5 years in 2020. The Coordinating Office (CO) for the network was awarded to the Georgia Institute of Technology on April 1, 2016 and renewed in 2021. Total NSF funding for the 10 years of the NNCI network is approximately $165 million.

The NNCI sites are located in 16 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.

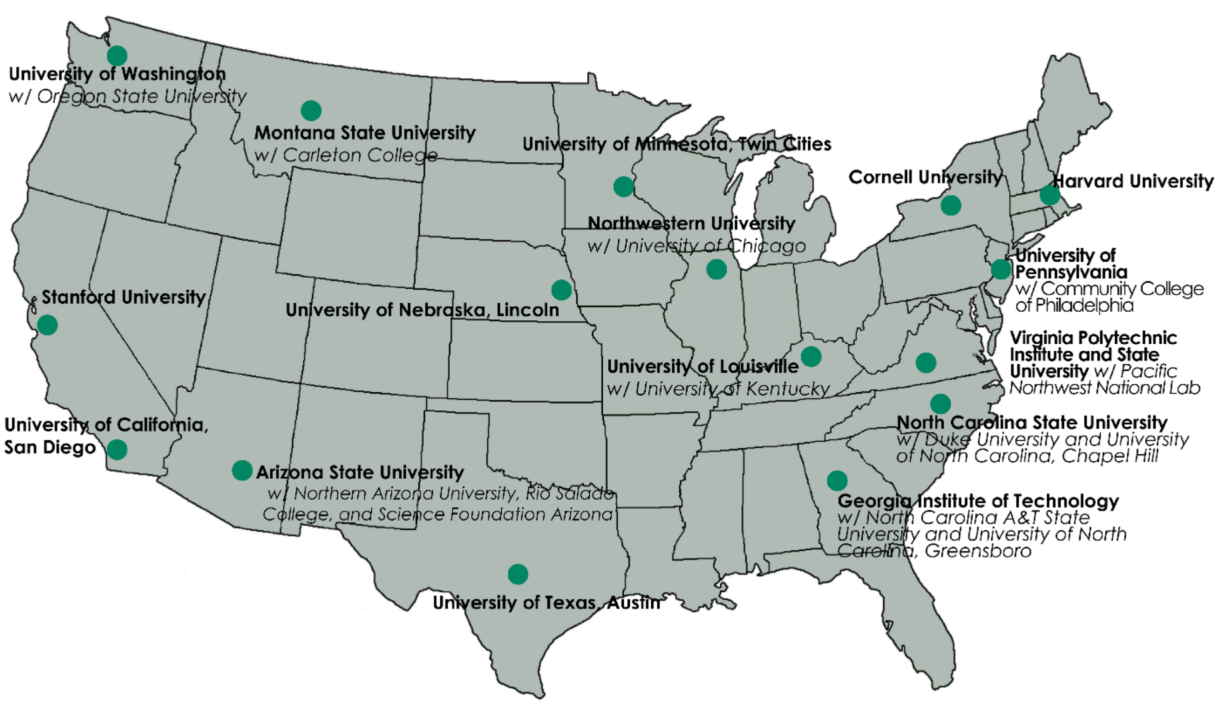


Figure 1: US Map with Locations of the 16 NNCI Sites (Years 6-10)

The goals of the NNCI network are (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 2,200 tools located in 71 distinct facilities. As will be detailed later in this report, these tools have been accessed during Year 7 by more than 13,000 users including nearly 3,400 external users, representing more than 230 US academic institutions, more than 750 small and large companies, 40 government and non-profit institutions, as well as ~40 foreign entities. Overall, these users have amassed more than 1 million tool hours. During Year 7, the network trained more than 5,000 new users. These statistics represent significant improvements compared to Year 6 and are comparable to the years before the COVID-19 pandemic, suggesting a return to nearly normal operations.

This report summarizes the activities and progress for Year 7 of the Georgia Tech Coordinating Office of the NNCI, from April 1, 2022 - March 31, 2023. NNCI sites are funded via separate cooperative agreements between NSF and each site, with reporting of site-specific data and activities corresponding to Year 7 (October 1, 2021 – September 30, 2022).

As indicated above, the second 5-year funding period of the NNCI began in 2020. This report reflects changes to the sites, partners, facilities, and network activities proposed and enacted starting in Year 6. In addition, previous reports have described aspects of the NNCI affected by the COVID-19 pandemic, including cancellation of numerous programs throughout the network and the closing of most NNCI facilities from mid-March to mid-June 2020. NNCI and its sites have adapted to these conditions, providing a wide variety of online programs to support users and provide education and outreach opportunities, many of which continue during this reporting period. These closures obviously affected the usage of NNCI resources, and a return to pre-pandemic levels of usage is still ongoing as noted in the network statistics in Section 11.

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 during Year 7 (Table 1) support research and development for academic education and research purposes, as well as product and process development for commercial purposes. It should be noted that NNCI Year 6 began the renewal period of the network, and some sites either added and/or subtracted facilities which may impact the user statistics reported in Sections 11 and 12. Each site operates under its own procedures for user recruitment, user access, training, rates, billing, and other logistical details. However, each site 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) and simulation and modeling (Section 4.3). With the NNCI renewal, the Coordinating Office also began to coordinate network activities that promote and support innovation and entrepreneurship (Section 4.4).

Table 1: NNCI Sites, Locations and Facilities (Years 6-10)

NNCI Sites and Locations	NNCI Facilities
Cornell Nanoscale Science and Technology Facility (CNF) Cornell University	Cornell Nanoscale Science and Technology Facility Cornell High Frequency Test Lab Cornell 3D Visualization and Imaging Facility Cornell Rapid Prototyping Lab
Center for Nanoscale Systems (CNS) Harvard University	Center for Nanoscale Systems
Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY Multiscale) 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 Additive Manufacturing Institute of Science & Technology
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	Minnesota Nano Center Characterization Facility
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 Nanoscale Characterization and Fabrication Laboratory PNNL Environmental Molecular Sciences Laboratory
Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) Arizona State University Northern Arizona University Rio Salado College Science Foundation Arizona	ASU NanoFab Eyring Materials Center Advanced Electronics and Photonics Core Facility Nano in Society User Facility Center for the Life Cycle of Nanomaterials ¡MIRA! Center at NAU

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 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 CMRR Materials Characterization Facility
Southeastern Nanotechnology Infrastructure Corridor (SENIC) Georgia Institute of Technology Joint School of Nanoscience and Nanoengineering (NC A&T State University, University of North Carolina-Greensboro)	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 Pulsed Laser Deposition Core
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

Through a 2020 update of the NNCI Staff Directory (following the renewal proposals), sites have identified approximately 250 staff that support the NNCI program (Table 2), although some individuals fulfill multiple roles within a site's operations. Many additional technical staff not included in this count are typically supported by NNCI funds while assisting both internal and external facility users. In general, Site Leadership includes Site Directors and Deputy/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 (2020)

NNCI Site Staff	
Site Directors	16
Other Site Leadership	44
New User Contacts	31
Program Managers	19
Facility Managers	70
Education/Outreach Coordinators	35
SEI Coordinators	7
Computation Coordinators	4
Safety/Facility Director/Technical Staff	22
Facility Administrative Staff	11

An analysis by the Diversity Subcommittee (see Section 5.1) examined the demographics of NNCI site PIs and co-PIs as reported to NSF. During Year 5 of the initial NNCI awards, 9 of the 61 individuals (15%) listed as PI or co-PI on the sixteen awards were women, which is comparable to the percentage of women tenure-track faculty in departments of electrical and computer engineering in the United States (13%) and engineering departments in general (17%), but significantly under the percentage of PhD degree holders who are women in the US (53%). With the renewal process in 2020, 20 of the 66 individuals (30%) listed as PI or co-PI are now women, indicative of a concerted response to their under-representation within NNCI leadership. In addition, several of these new NNCI leaders are African-American or Latinx, demonstrating broadening participation by race and ethnicity.

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 (Research Administrative Manager, Georgia Tech IEN and Program Manager, SENIC). Four **Associate Directors** manage the network activities in specific areas. Dr. Quinn Spadola (Academic Professional, Georgia Tech IEN and Director of E/O, SENIC) coordinated the NNCI education and outreach (E&O) programs for most of Year 7 before leaving NNCI to assume the position of NNCO Deputy Director in July 2022. In October 2022, Dr. Mikkel Thomas (Senior Research Engineer, Georgia Tech IEN and Director of E/O, SENIC) was appointed as the new NNCI Associate Director for Education and Outreach. Prof. Jameson Wetmore (School for the Future of Innovation in Society, Arizona State University and Deputy Director, NCI-SW) coordinates the societal and ethical implications (SEI) activities. Prof. Azad Naeemi (School of Electrical and Computer Engineering, Georgia Tech) coordinates the computational activities and facilitates interactions with nanoHUB/NCN at Purdue University. Dr. Matthew Hull (Program Manager, Virginia Tech ICTAS and Associate Director, NanoEarth) coordinates innovation and entrepreneurship (I&E) programs. This Coordinating Office staff meets monthly by conference call.

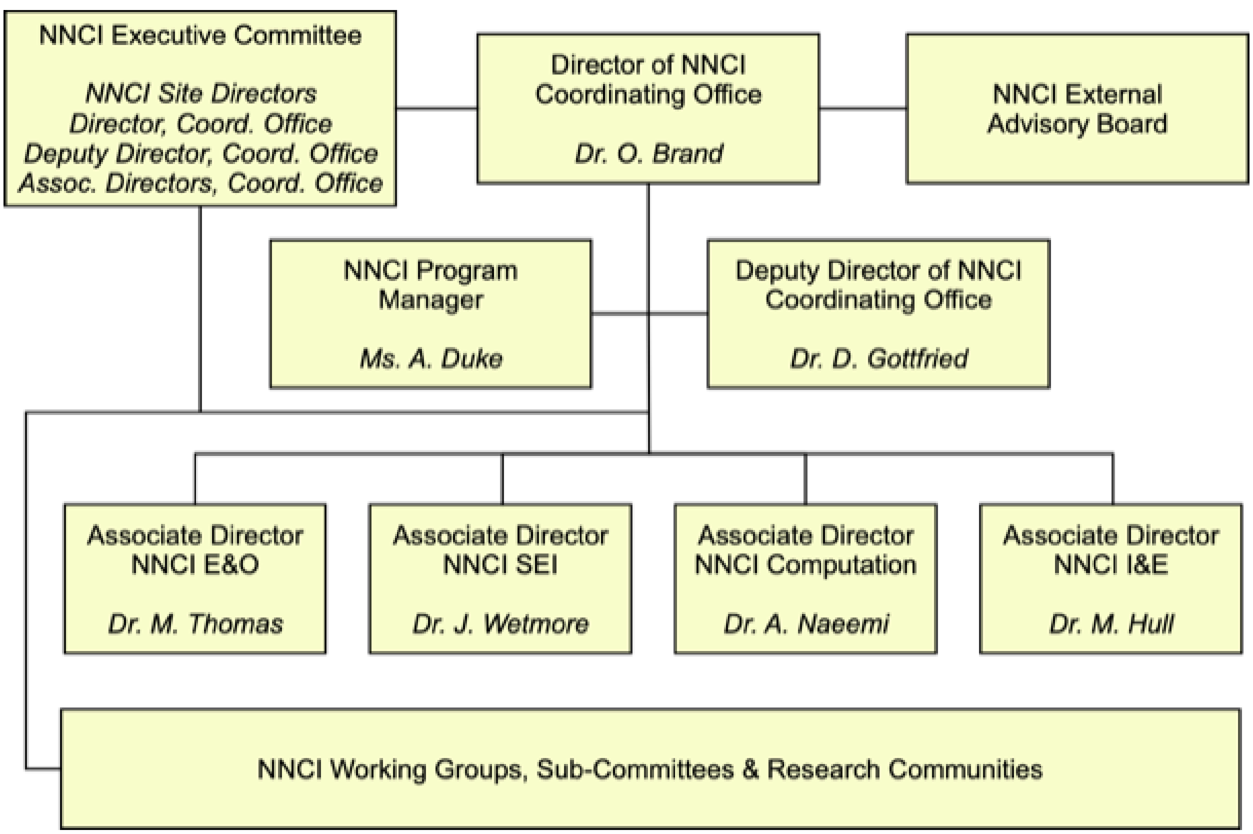


Figure 2: NNCI Coordinating Office Organizational Chart (Years 6-10). Revised October 2022.

The Coordinating Office staff is guided by an **Executive Committee,** which includes the 16 NNCI site directors and other site leadership. 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, and provides an annual written report and recommendations.

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, and these were revised at the start of Year 6 (see Section 5). 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, and education and outreach (see Section 6). Finally, during Year 5 the network created **research communities**, which are organized around key scientific and engineering challenges and represent an opportunity for the NNCI to interact with the broader research ecosystem (see Section 7). 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
- coordination of the NNCI webinar series and YouTube channel
- facilitating interactions among the sites via an email listserv
- 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 and other impact metrics
- 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 13.

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 periodic changes in the EAB membership and Table 3 shows the Advisory Board members and their affiliations as of January 2023.

Table 3: NNCI External Advisory Board

Name	Affiliation
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	CEO, MEMStim
Mr. Joe Magno	Executive Director, National Institute for Innovation and Technology
Dr. Kurt Petersen	Member, Silicon Valley Band of Angels
Dr. Thomas Theis	Director of Innovation, Utopus Insights, Inc.
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 2022) is provided in Appendix 14.1.

4. Associate Director Reports

4.1. Education and Outreach

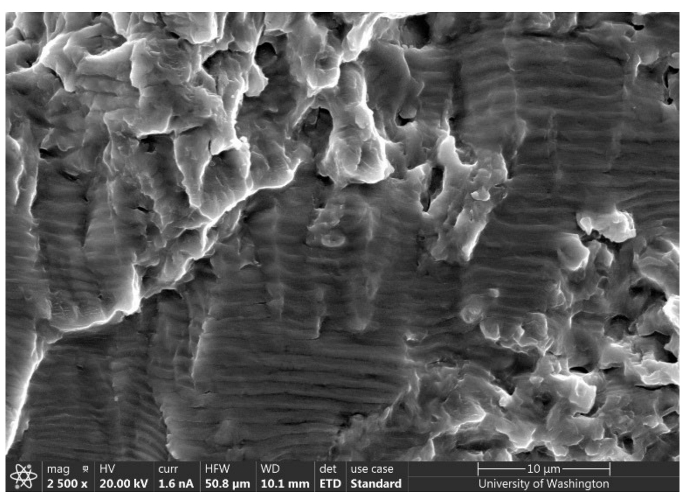
The mission of the NNCI Education and Outreach (E&O) efforts is to offer education and training to address the growing need for a skilled workforce and informed public, provide resources, programs, and materials to enhance knowledge of nanotechnology and its application to real-world issues, and support 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 7, E&O coordinators reached more than 23,000 people, achieved in personal/virtual interactions through classroom visits, teacher workshops, remote sessions, short courses, seminars, symposia, community events, conference booths, tours, internships, REUs, and RETs. This reach is a significant increase from the previous year (14,500 people), but still a decrease from Year 5 (33,000 people) because of the continued effects of the COVID-19 pandemic. That being said, sites quickly pivoted to virtual activities, continued to serve their communities, and many activities have returned or are beginning to return to in-person format. Of the people reached this past year, 46% are K-12 students, 15% post-secondary students (undergraduate and graduate students), 5% educators (K-12 teachers and community/technical college faculty), 7% general public, and 26% professionals (short course and workshop participants, seminar attendees, etc.). While outreach to K-12 students continues to improve compared to the previous year, overall reach is still depressed from pre-pandemic levels. While sites are continuing to offer virtual options with many providing materials for hands-on activities, one possible reason for the continued decrease may be that teachers are occupied with transitioning back to in-person classrooms and concentrating on making up lost learning after many students spent the previous years in virtual formats. Programs for educators increased participation to nearly 1,100 teachers and community or technical college faculty, an increase over last year. The number of post-secondary students and professionals reached also increased to more than 9,500 (from 8,800 in Year 6) as more sites offered webinars, virtual symposia, and other online options. The 23,000 figure also does not include NanoEarth's booth at the ACCelerate Creativity and Innovation Festival (32,000), Nebraska Nanoscale Facility's traveling museum exhibit (38,000), NanoEarth's "Pulse of the Planet" radio programs, or the "Nanooze" magazines distributed by the Cornell Nanoscale Science and Technology Facility. "Nanooze" released its latest issue (#18) this past year with the theme "All About Organic Light-Emitting Diodes." Also not included are the 9,000+ people enrolled in the online courses offered through RTNN and nano@Stanford.

In celebration of National Nanotechnology Day, the NNCI again hosted its image contest, *Plenty of Beauty at the Bottom*. Thirteen sites submitted 35 images created at one of their facilities during the past two years to three categories: Most Stunning, Most Unique Capability, and Most Whimsical. Public voting took place during the week of National Nanotechnology Day (Oct. 6-13) with sites promoting the contest through their various channels. More than 2,800 votes were cast to determine the winner in each category. Besides the image contest, individual sites hosted local National Nanotechnology Day events with more information provided later in this report. In addition to the winning entries shown below, honorable mentions were awarded to entries from SENIC (Most Stunning), SENIC (Most Whimsical), and nano@stanford (Most Unique Capability).

2022 Most Stunning (nano@stanford)

2022 Most Whimsical (nano@stanford)



2022 Most Unique Capability (NNI)

To facilitate the sharing of information across the network, coordinators participate in monthly calls and post to the education and outreach listserv. 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. Additionally, topic specific teleconferences are organized if multiple sites are interested in learning more from each other. Topics have included launching a multi-site virtual Nano Summer Institute for Middle School Teachers, best practices for pivoting to virtual programs, and contingency planning for 2021 summer programs. Each year education coordinators are also asked to update a worksheet that lists all the different types of activities offered across the NNCI. Everyone has access to the sheet so if someone wants to learn how to run a specific activity they have never done before, they know which site(s) to contact for information.

Across the network, E&O coordinators make an effort to reach groups historically underrepresented in STEM fields. The transition to virtual and asynchronous instruction has allowed sites to extend their reach beyond their traditional areas, increasing connections to rural communities. For example, the team at RTNN had numerous efforts to reach under-represented minority groups and those in disadvantaged socioeconomic status communities or schools through new programs or working with existing programs or organizations. These programs include Girl Scouts STEM Day in collaboration with Triangle Women in STEM, activities with Step Up to STEM, a 1-week summer program with the North Carolina School of Science and Math for underrepresented minority 9th and 10th grade students and Building Opportunities and Overtures in Science and Technology (which serves under-represented children in public schools), and an RTNN-organized STEM career panel for Durham Children's Initiative (which serves low income families in Durham). They have also increased nano-themed activities and career discussions in underserved (Title 1) schools in the local area.

Many other sites also leverage their efforts by working with local organizations, such as local Boys and Girls Clubs, 4-H chapters, Society of Women Engineers sections, Girls, Inc., Oakland Promise, Upward Bound, and local school districts, as well as national organizations including national 4-H and Hitachi High-Tech America STEM Education, to provide programming. In addition, most sites work closely with other NSF-supported NSE education efforts like NACK's Remote Access Instruments for Nanotechnology (RAIN) and the Micro Nano Technology Education Center (MNT-EC). NCI-SW, SENIC, NNF, nano@Stanford, SDNI, and RTNN all provide remote sessions through RAIN.

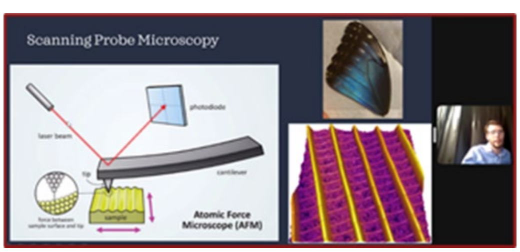
With outreach to K-12 students, the NNCI is inspiring our future skilled workforce and helping to create an informed citizenry. Many sites participate in summer camps, high school student internship programs, after school programs, career fairs, and both off-site and on-site visits. In response to the pandemic, many sites used the switch to virtual activity as an opportunity to expand outreach. During this past year, in order to further increase the effectiveness of activities with students, many sites provided hands-on materials for students to work with during virtual instruction. SENIC's virtual class trips, in which middle and high school teachers invite staff to join their classroom, reached over 1,500 students and helped strengthen connections with school districts across Georgia. The NNF site hosted 17 summer high school interns, sponsored by the J. A. Woollam company and the EpSCOR EQUATE program. This sponsorship provided for more activities, tours, and faculty lectures, in addition to the students' summer research. One Univ. Nebraska professor at the poster sessions said, "if he did not know these were High School

SDNI Remote SEM at Kearny High School (San Diego)

students, he would have assumed they were part of the Summer REU program." SDNI hosted sessions using their remote SEM which reached 600 students, and more than 4,000 since 2019. The sessions are held in real-time, and students can attend from the comfort of their homes or classes (photo at right). The opportunity to remotely control the Zoom and Focus functions of the SEM proves very engaging for the students. Typical specimens include pollen, prehistory deep sea sediments (phytoplankton, zooplankton), butterfly wings, gecko foot, bee, optical card, CD, tungsten wire, MEMS, gold and silver nanoparticles.

In order to develop a STEM-literate workforce and informed citizenry, coordinators provide many activities for educators. Often sites provide multi-day workshops, summer long RET programs, or sessions at conferences in which teachers leave with free resources and a personal connection to a nearby site. The Research Experiences for Teachers across the National Nanotechnology Coordinated Infrastructure collaborative proposal, submitted to NSF by SENIC, MINIC, SHyNE, and NNF, held its second cohort of teachers in summer 2022. All four sites were able to welcome high school teachers and community/technical college faculty to campus, 5 at each site, for in-person research. In addition to research, teachers participate in career webinars to give them both a local and national understanding of careers in nanotechnology featuring industry users of NNCI facilities. The educators will present their experience and lessons at the 2023 annual National Science Teachers Association Meeting. Their lessons will also be posted on the NNCI's searchable database and nanoHUB, and the teachers are recording short videos intended to help their peers implement the lessons. In addition, SDNI virtually hosted their Annual Education Symposium (Nov. 2022) with the theme "Nanotechnology Education: A Driver for Academic and Career Development." The symposium featured presentations from NNCI sites, NNCO, MNT-EC, Penn State/NACK network, UCSD MRSEC, and local middle and high school teachers. In the 2-day virtual event, people exchanged ideas and collaboration plans to promote STEM in K-12 and integrate nanotechnology into the current science curricula.

More than half of NNCI sites offered some version of the Nano Summer Institute for Middle School Teachers (NanoSIMST) virtually or in-person. Teachers in these programs engage in 4 to 5 days of instruction on nanotechnology and how to implement it in the classroom. Classroom supplies are provided to teachers (mailed in advance or at the workshop) to facilitate hands-on activities. Teachers also participated in virtual/in-person cleanroom tours, listened to guest speakers, and alumni of the program shared their implementation strategies. Nano@Stanford offered NanoSIMST in 2022 as a virtual workshop to further expand the reach of the program and enrolled 39 teachers in 11 states sponsored by other sites (CNS, RTNN, MONT, and NanoEarth). Another resource used during NanoSIMST and available to the community are video recordings of talks on nanotechnology careers posted on the NNCI's YouTube channel: "X/Nano: The enabling Potential



NanoSIMST Virtual Session led by nano@stanford of a Career in Nanotechnology" (Matt Hull, NanoEarth) has nearly 500 views and "Careers in Nanotechnology: Opportunities for STEM Students" (Jim Marti, MiNIC) has more than 1,300 views. The nano@Stanford education coordinator maintains a listserv for educators that have participated in an NNCI program, and it is also open to teachers who have not yet participated in an NNCI program. Twice a month the teachers receive an email highlighting 1 or 2 NSE education resources with information on how they connect to the Next Generation Science Standards and tips on implementation.

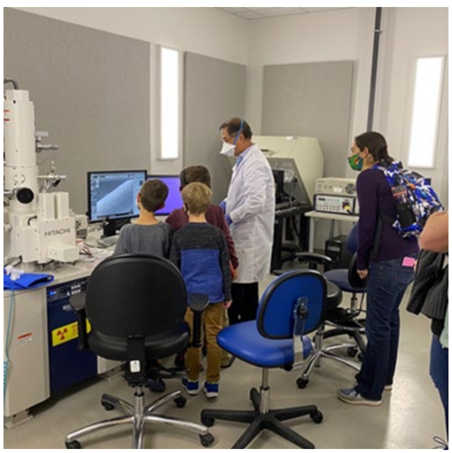
As part of building a skilled workforce, NNCI sites provide technical workshops, short courses, seminars, webinars, and/or symposia for undergraduates, graduate students, post-docs, and other professionals. The network continues to maintain a strong connection to this group by providing virtual and in-person resources. The MiNIC site created an Environmental Health and Safety course for technical college faculty members. Created by Jim Marti and Prof. Peter Raynor of the University of Minnesota, this effort was supported by the Micro Nano Technology Education Center (MNT-EC) and designed for lab instructors at 2- and 4- year colleges who teach classes about nanomaterials. The course provided information related to nanoparticle properties, use of PPE, and safe materials synthesis. SHyNE hosted the 2nd annual *Women in Microscopy Conference* with 181 global attendees. The event highlighted the work of female researchers, product specialists, and lab managers from universities, national labs, and microscope vendors. The conference was inspired by the desire to enhance female representation in the field, which historically has been limited. MONT partner Carleton College hosts the "Nanotechnology in STEM" website which showed a surge in visitors during the previous year (more than double, to 35,000+ website visitors). The website contains content from the Earth and Environmental Sciences Research Community Workshops and houses equipment databases and tutorials directed at researchers in the Earth and geological sciences.

REU Convocation 2022 Attendees at Univ. of Louisville

Most NNCI sites were able to have their regular Research Experience for Undergraduates (REU) programs this past summer and most were hosted on campus and in-person. Six sites supported addition of the entrepreneurship module (REEU) led by NNCI Assoc. Director for Innovation and Entrepreneurship Matt Hull, in collaboration with the NNCI Assoc. Director for Education and Outreach (Mikkel Thomas; previously, Quinn Spadola) and local REU coordinators. The NNCI REU Convocation returned as an in-person event hosted by University of Louisville (KY Multiscale), in parallel with the NNCI Nano + Additive Manufacturing Summit. The convocation was a 3-day event and featured 59 student short talks and posters on their summer research. They also heard keynote talks from academia, industry, and the NSF, discussion of entrepreneurship, a career panel, and they learned about follow-up research opportunities in Japan. As an alternative to a summer program, the TNF site has continued to host a year-long REU program in collaboration with Austin Community College.

In further support of undergraduates, NNI (University of Washington), using a combination of intensive academic programming, summer bridge, and cleanroom job opportunities, launched the inaugural cohort of the Engineering Dean's Scholars program. The first cohort of 48 students had a remarkable retention rate of over 95%, with 92% continuing their pursuit of Engineering. Two students are now employed in the WNF cleanroom and a second cohort of 47 students has already been formed. NCI-SW continues to provide hands-on lab sessions for community college students enrolled in Rio Salado College's Nanotechnology AAS/Certificate programs and MANTH provides the hands-on programming for the "Introduction to Nanotechnology" course offered at the Community College of Philadelphia.

Finally, NNCI sites provide outreach to the general public through participation in science festivals, science cafes, science days at their institutions, and National Nanotechnology Day and Nano Days celebrations to help enable an informed citizenry. RTNN organized a Girl Scouts STEM Day with 145 participants and 80 volunteers and also took part in the Carolina Science Symposium in partnership with JSNN (SENIC). CNF continued its 4H programs with 100 students participating in "Space Exploration" with CNF staff member Tom Pennell and Cornell Prof. Mason Peck (former NASA Chief Technologist and advisor to the Breakthrough Starshot program). NanoEarth participated in the ACCelerate Creativity and Innovation Festival (31,000+ visitors) by contributing to "Benthos 360", an immersive 360° VR experience about conservation in the freshwater ecosystem. The exhibit was a partnership between technologists, including Matt Hull, and artists and received the People's Choice award at the festival. SENIC organized the first Georgia Tech Science Day as part of the annual Atlanta Science Festival. More than 500 campus visitors interacted with 26 campus units, with nearly 300 attending an open house at the Institute for Electronics and Nanotechnology cleanroom and materials characterization facilities.


Attendees view the SEM at Georgia Tech Science Day

Education and outreach coordinators have embraced the move to virtual outreach as an opportunity to reach a larger and more diverse audience. While sites are moving back to in-person activities, the online content that has and continues to be developed will be integrated into sites' programming. Moving forward, sites are working together to engage with larger organizations including other NSF-funded NSE education and workforce development efforts, expanding the opportunities they offer to students, implementing teacher workshops developed by other sites, and creating more virtual content for training and outreach. More details on education and outreach efforts across the NNCI can be found in the education working group reports. The report of the *K-12 Teachers/RET, Students, and Community Outreach* working group (Section 6.7), led by James Marti (MiNIC), discusses their plans to redefine the role of the working group. The report of the *Workforce Development and Community Colleges* working group (Section 6.8), led by Andrew Lingley (MONT), includes information on approaches for addressing workforce readiness. The report of the *Evaluation and Assessment* working group (Section 6.9), led by Jessica Hauer (NCI-SW), shares results from the student worker/mentor surveys that were developed in collaboration with the *Workforce Development and Community Colleges* working group. The *Technical Content Development* working group, co-led by Daniella Duran (nano@stanford) and Eric Johnston

(MANTH), report (Section 6.10) provides details about their database of tool training resources and education/outreach content.

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 consider nanotechnologies' impacts as we conceive, develop, design, and implement them. To that end, the Coordinating Office is working to help all NNCI sites develop Societal and Ethical Implication (SEI) research and engagement programs. Associate Director Jameson Wetmore (also Deputy Director of the NCI-SW site) leads these activities. Since summer 2021 a graduate student research assistant – Martin Perez Comisso – has assisted with the SEI program.

Over the past year, the NNCI CO has advanced SEI efforts in three primary ways: (1) Through coordinating with the other four main SEI sites in the NNCI; (2) Through small events and meetings within the NNCI and beyond; and (3) Through the coordination of two major events: the Winter School and the Science Outside the Lab Washington, DC program.

Coordination of NNCI-SEI Sites

SEI work continues to be largely advanced by five NNCI sites with significant SEI expertise and commitment. Dr. Lee Ann Kahlor at TNF continues to develop SEI lab training materials that she is sharing with the rest of the network and this past year published work on how nanoscientists perceive themselves as ethical leaders in their organizations. Dr. David Berube at RTNN has been using the lessons learned at the interface of nano and society to help understand issues of communication and resilience in the midst of the COVID-19 pandemic. The SENIC site's SEI efforts were coordinated by Dr. Jan Youtie until her retirement this past year. While Youtie's work on assessing the impacts of NNCI sites will continue to be discussed and used, her leadership role has been filled by Dr. Diana Hicks, Professor in the School of Public Policy at Georgia Tech, and first author of the Leiden Manifesto, an influential report aimed at better contextualizing the way in which academic scholarship is assessed. We are excited to welcome Dr. Hicks to the SEI group. And while not initially funded as one of the four SEI NNCI sites, Dr. David Mogk at MONT has paid significant attention to ethical issues in the geosciences and participates regularly in SEI discussions within the NNCI.

The NNCI SEI team also led the 2022 response to the US Department of Labor's request for assistance in its o*net program. After helping the Department gather contact information to help flesh out statistical details of the careers of "Nanosystems Engineers" in 2019, the Department returned to the NNCI for help on an additional category. This year the NNCI CO helped gather information about "Engineering Technologists" from 8 NNCI universities and more than a dozen corporations across the U.S.

Small Events and Gatherings

In addition to coordinating the other core SEI Sites, Dr. Wetmore has been extending the reach of SEI throughout the NNCI through forums, panels, and online workshops. For instance, in June 2022 he led an REU/RET webinar on "Science Policy: Where Values meet the Laboratory," which brought together participants from several NNCI REU and RET programs. In November 2022 he presented to graduate students at North Carolina A&T State University about science policy and social change. In addition, his Research Assistant, Mr. Perez Comisso was invited to participate as a reviewer for a capstone project in a class in technology and society at NYU about Nanotechnology and Society in late April 2022.

The SEI team coordinated two NNCI webinars this past year. The first was given in February 2022 by Kristen Kulinowski, Director of the IDA Science and Technology Policy Institute, who reflected on her two plus decades working in nanotechnology and noted the ways in which nano risk has been normalized. The second webinar was a panel discussion in May 2022 that brought together scholars from around the world – Arie Rip (University of Twente, The Netherlands), Carlo Altamirano Allende (Albaa Legal+Tech, Mexico), Ayesha Chaudhary (World Bank, India), and moderator Oluwabukola Makinde (Arizona State University) – to discuss how science policymakers are responding to recent innovations and uncertainties.

David Berube, of RTTN was one of the co-chairs of the "Evidence-based SEI knowledge, attitude and practice" session at the 2022 NSF Grantees Conference: Nanotechnology for Sustainable Society. At that meeting Jameson Wetmore presented on the "Societal and Ethical Implications Training Programs in the National Nanotechnology Coordinated Infrastructure," and Lee Ann Kahlor presented on "Science Communication Research at the University of Texas at Austin."

Immersive Trainings and Sessions

The flagship exercise of the NNCI CO SEI effort is the Winter School on Emerging Technologies. The Winter School is held every January at Saguaro Lake Ranch, just east of Phoenix and has typically been designed to train the next generation of social science scholars interested in the future of science and technology.

After the 2021 cancelation for COVID-19, the NNCI has sponsored and run the program twice: January 3-10, 2022 and January 3-10, 2023. We took the relaunching of the program as an opportunity to adjust the focus and scope of the winter school. In an effort to strengthen the interdisciplinary nature of the endeavor as well as keep pace with the interests of the participants, we extended invitations to not just social scientists, but natural science and engineering graduate students as well. And we shifted the program to focus on "increasing impact" – a concern that graduate students across disciplines have been increasingly interested in. Throughout the seven-day program participants meet with a series of scholars and professionals who help them develop unique ways to increase the chances that their work will make a difference in the world well beyond their laboratories.

In 2022 the program facilitated a sandpit-type exercise wherein the participants formed teams and pitched possible ideas that, if funded, could facilitate the impact of academic work far beyond the 7-day program. Ultimately an independent panel suggested the funding of four projects. One of these funded projects was a proposal by Sarah Bartley (NC A&T State Univ.) to develop a podcast focused on why there are significant federal funding disparities at Historically Black Colleges and Universities. With the modest funding we could offer, Ms. Bartley was able to launch her podcast - "Funding is the Matter" – which has already totaled 10 episodes.

The 2023 Winter School was led by a team including Ira Bennett (ASU), Nich Weller (ASU), Rider Foley (Univ. Virginia), Lauren Keeler (ASU), Vasiliki Rahimzadeh (Baylor College of Medicine), and Martin Comisso Perez (ASU). Based on the feedback from the 2022 program, in the latest 2023 program we chose to replace the sandpit exercise with an experience that focused more specifically on the research each participant is engaged in. We began with a series of eight talks addressing different ways of scholarly impact, including community engagement, publication, teaching and mentorship, policy, partnerships, and the media. We then developed a variety of strategies and pedagogical tools that enhanced participants' ability to think about the impact of their own personal career, including partnership strategies, worksheets for relevant funding, and self-assessment exercises such as the "Impact Hexagon" to leverage the critical capacities of the participants with the support of speakers and facilitators.

Our annual summer event, co-sponsored with the NCI-SW, is "Science Outside the Lab" (SOtL), a science policy summer school traditionally held on-site in Washington, DC. In 2022, because many policymakers were still working remotely, the program was held virtually May 17 to 27. The program bought together 17 graduate student scientists and engineers from across the NNCI to get a crash course in how science influences policy and how policy influences science. This past year we had participants from across the NNCI and beyond, including Stanford, Georgia Tech, North Carolina A&T State Univ., Univ. of Wisconsin-Milwaukee, Univ. of North Carolina at Greensboro, Univ. of Pennsylvania, Arizona State Univ., and Univ. of Chile. The group met for 40 hours over the 10 days with speakers from the EPA, NASA, NSF, Sloan Foundation, NASEM, US Congress, and the Smithsonian Institution. In a first for the program, this past year we met with an NIH Institute Director - Dr. Eric Green.

From the very beginning the SOtL program has sought to train scientists and engineering students in the social and political dimensions of their work not just for their own knowledge, but so that they could spread that understanding throughout their communities and colleagues. Thus, in the 2022 program all the participants were trained in basic techniques to bring what they learned in the program back to their home institutions and to develop policy briefs. Each participant produced a proposal for an independent project to continue the conversations they had in the program with others at their universities.

These "SEI Ambassador" projects were carried out over the summer and into the fall. Many students worked with the education coordinators at their NNCI site to more fully integrate them, and SEI work, into their local programs. Projects include outreach efforts to K-12 students, podcasts on the struggle to fund research at traditionally black institutions, and gatherings of graduate students to discuss science policy issues. One student, Nina Fraticelli-Guzman of Georgia Tech, used her SEI Ambassador project as an effort to explore a topic she was interested in but was not covered in the June program. In November she pulled together a virtual seminar on "Navigating Innovation Policy: Interactions between the US and Small Island States," with Dr. Zak Taylor (Georgia Tech) and Dr. Ubaldo Cordova-Figueroa (Univ. of Puerto Rico) and made it available not only for SENIC students, but anyone interested in the increasingly important topic.

Feedback from the last two years of SOtL was quite positive and it's clear that everyone involved believed it was time well spent. As one 2022 participant reflected, the program:

> …allowed me to see how my scientific and personal background could be of use in a science policy role. I now see that though my research is specific, many of the skills I have gained through my training, from critical thinking, to planning, can be put to use in helping inform policy decisions that will impact society. I've also realized my thesis work is an opportunity for me to learn more about any societal implications surrounding that work and am now considering adding a policy/public health chapter to my thesis regarding my research area.

Because of the success of the online version of the program, there has been a question as to whether to return to an "on-site" program. It is clear that the virtual nature of the program made it easier to engage with and learn from multiscalar policy issues through an international science policy in a public panel (open to the entire NNCI community), as well a conversation with Dr. Heather Ross, who leads a science-based team on the COVID-19 response in Phoenix, AZ. But many students expressed regret that they were not able to participate in a traditional "Science Outside the Lab" and get the experience of exploring Washington, DC first hand. The opportunity to engage more directly with DC policy dynamics is something we would like to reintroduce to the program. Therefore this coming summer we plan to return to an in-person program for 15 graduate students in Washington, DC June 4-10, 2023.

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. The main objectives of the computation activities within NNCI are 1) to facilitate access to the modeling and simulation capabilities and expertise within the network, 2) to identify the strategic areas for growth, and 3) to promote and facilitate the development of the new capabilities.

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. So far, 10 NNCI 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. Most of these hardware resources serve internal users, with the exception of the UT-Austin computing cluster which can be accessed by external users with a nominal fee and the CNF Nanolab Computing Cluster that is available to all users. The users of the CNF Computing Cluster have access to a wide range of modeling software packages tailored for nanoscale systems. Several classes of nodes, all linked via Gigabit Ethernet, are available on the cluster. The cluster runs Scientific Linux 7 with OpenHPC and a batch job queuing system. The staff would install new scientific codes on the cluster upon user request. The users can also remotely access software tools via "CNF Thin" Hotdesking service such as Computer Aided Design (BEAMER, L-Edit, Java GDS, AutoDesk); Simulation (Coventor, Cadence, PROLITH, Layout LAB, TRACER) and Image/Data Analysis (ProSEM, NanoScope Analysis, WinFLX). For tasks that are heavily memory or time demanding, Amazon Web Services (AWS) conversion capabilities are also available. More information on CNF computing resources is available at http://computing.cnf.cornell.edu/Cluster.

Regarding education for computational capabilities, Professor Dragica Vasileska from Arizona State University (NCI-SW) and her team have been collaborating with Prof. Gerhard Klimeck from nanoHUB to develop educational materials for Silvaco Victory usage such as PowerPoint slides, videos, sample problems regarding device and simulations ranging from low to room temperatures. A new collaboration between nanoHUB and Silvaco will provide access to Slivaco Victory to nanoHUB users.

Prof. Vasileska has also been working on a self-paced short course on device and process simulation. The five-week course is roughly equivalent to 1 credit hour and is similar in structure to courses on nanoHUB University. The course consists of lectures, quizzes and projects and is based on Silvaco TCAD software. Prof. Vasileska is working with nanoHUB leadership to make the course is publicly available on nanoHUB. The course content and slides are now ready, and she is in the process of recording the lectures.

On the modeling and simulation side, Prof. Frank Register and his collaborators at UT-Austin (TNF) have developed rigorous models to quantify the impact of quantum confinement in ultra-scaled transistors. They have also expanded their simulation framework for band *alignments* in 2D material heterostructures, revisiting the commonly used electron affinity rule.

Prof. Azad Naeemi's team at the Georgia Institute of Technology released their recently developed circuit-compatible SPICE model for antiferromagnet/ferromagnet bilayers (e.g. BFO/CoFe) that captures the dynamics of the magnetic, antiferromagnetic, and ferroelectric order parameters in such heterostructures.

Another major education activity in the past year has been a webinar series on computation with talks from three modeling and simulation experts. The talks were recorded and are available on the NNCI YouTube channel.

4.4 Innovation and Entrepreneurship

The 2021 NNI Strategic Plan calls for *"innovative mechanisms to realize the transformational societal benefits that flow from faster commercialization of nanotechnologies."* More recently, in 2022, the NSF launched the Regional Innovation Engines or "NSF Engines" program to help catalyze and foster innovation ecosystems across the US. Additionally, in 2022, the US National Nanotechnology Coordination Office (NNCO), launched the Nano4EARTH program, which aims to mobilize the nanotechnology community to help develop and commercialize nano-enabled solutions to climate change. The NNCI is well-positioned and resourced to contribute to these federal initiatives through its NNCI Innovation and Entrepreneurship (I&E) program, which was established in April 2021. The mission of the NNCI I&E program is to connect and amplify an ***NNCI-wide Innovation Ecosystem*** focused on training a new generation of "nano-savvy" innovators and entrepreneurs, identifying and meeting the unique needs of industry users, particularly start-ups and small to medium-sized enterprises (SMEs), and supporting the translation of nano-enabled innovations to society. Unlike NNCI programs in support of education and outreach, societal and ethical implications, and computation, I&E activities are undertaken at sites in a more indirect and decentralized manner (i.e., dedicated funding and reporting mechanisms are not specifically defined or required for I&E activities). Consequently, I&E activities pose both unique challenges and opportunities for collaboration across the 16 NNCI sites. The sections below summarize NNCI I&E accomplishments during the past year.

I&E Working Group

In 2022, the NNCI I&E Working Group (Figure 3) established a quarterly meeting schedule and met on the following dates: April 7th (Q1), June 29th (Q2), August 31st (Q3), and October 19th (Q4). The Q4 meeting coincided with the NNCI Annual Meeting at Cornell University. The objective of the I&E Working Group is to ensure site-level representation in NNCI I&E programming development, decision-making, and assessment. The activities of the I&E Working Group will complement and support those of other NNCI working groups.

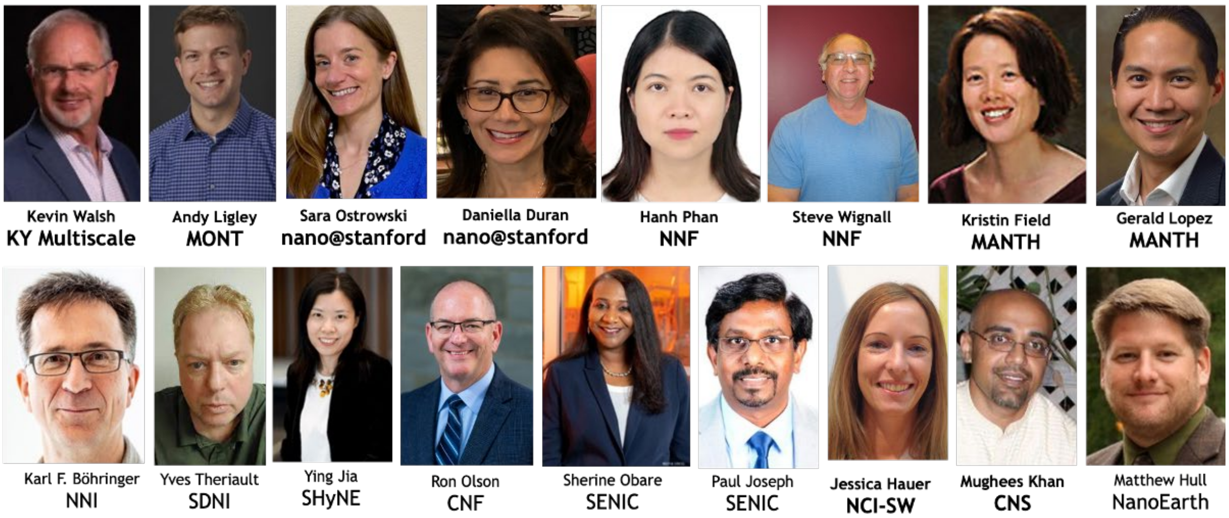


Figure 3: The 2022 NNCI I&E Working Group includes representatives from 13 NNCI sites.

The primary program areas and topics addressed by the I&E Working Group agenda are described below:

NNCI I&E Speaker Series – recommendations for NNCI-wide speakers who can speak on topics pertinent to I&E and industry engagement

NNCI-wide Entrepreneurs-in-Residence (EiRs) – faculty/staff entrepreneurs based at individual sites (including external users from small companies) who may be interested in serving as EiRs in an assortment of capacities

NNCI-wide Student-led Nanotechnology Entrepreneurship Challenge (NTEC) – strategies to develop/sustain student-focused entrepreneurship at the site-level and NNCI-wide

"REEU" program – collaborative effort with the NNCI education program focused on sharing and scaling an "entrepreneurship" module/experience to complement existing REU programs

Development of an "NNCI Innovators Academy" – coupling of virtual learning modules across sites to train and support "nano-savvy" innovators and entrepreneurs

Industry user recruitment – sharing of strategies to recruit/engage industry users, particularly users from start-ups and SMEs

Underrepresented and Minority Entrepreneurs – focused engagement and support of nanotech entrepreneurs from diverse & underrepresented groups

Lessons Learned – general sharing of I&E lessons learned across sites from the first 5 years

Goals – establishing and refining I&E goals for the next 5 years and beyond

<u>NNCI Site-Specific I&E Activities</u>

In addition to the I&E activities organized through the working group, individual NNCI sites continue to be a source of impactful I&E programming. Lessons learned from these programs are shared broadly and openly across the NNCI either ad hoc or during quarterly working group meetings. Some notable I&E activities organized by individual sites are listed in Table 4 and summarized below.

The Nebraska Nanoscale Facility (NNF) hosted an event in April 2022 entitled, *Commercializing Quantum Technologies in Nebraska: from Research to Licensing*, which featured multiple talks from faculty innovators, entrepreneurs, and leaders in technology commercialization, such as NUtech Ventures and the Nebraska Business Development Center (NBDC). Dr. Christopher Ober and Dr. Ron Olson of the Cornell Nanoscale Science and Technology Facility (CNF) hosted the first New York State Nanotechnology Network (NNN) Symposium, which helped connect more than a hundred student and industry participants from across the state. To help illustrate how this event may serve as a useful model for other NNCI sites, Dr. Ron Olson led a presentation at the 2022 NNCI Annual Meeting I&E session to share lessons learned from the NNN event. Dr. Paul Joseph of SENIC/Georgia Tech hosted the NanoFANS Forum's 25th biannual meeting at Georgia Tech on May 24th, 2022. The NanoFANS Forum is a long-standing bi-annual event focused on commercialization opportunities and challenges at the intersections of micro-/nanotechnology and biotechnology. Dr. Gerald Lopez of the Mid-Atlantic Nanotechnology Hub (MANTH) and the Singh Center for Nanotechnology was an invited participant in a webinar hosted by the National Nanotechnology Coordination Office (NNCO) entitled *"Nanotechnology Commercialization: Perspectives from a Regional Innovation Ecosystem."* A highlight from Dr. Lopez' presentation was the nearly $60M in investment secured by MANTH-supported start-ups. Dr. Lopez shared insights from the MANTH industry engagement model during the I&E session at the 2022 NNCI Annual Meeting. Dr. Kevin Walsh and colleagues from the Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY Multiscale) hosted the 2022 NNCI Nano+Additive Manufacturing Summit on August 9-10. The event brought together more than 300 researchers and innovators and included a keynote presentation from NNCI advisory board member, Dr. Kurt Petersen, on Micro/Nano/MEMS Entrepreneurship.

Table 4: Summary of 2022 NNCI Site-specific I&E Activities

	**NNF: Toward Commercialization of Quantum** April 14, 2022

CNF: 2022 NNN Symposium @ Cornell

"Bridging the Workforce Gap" May 19, 2022

SENIC: NanoFANS Forum

Faculty presentations about startup companies based on academically-developed technology.

May 24 and Oct. 13, 2022

MANTH: Nanotechnology Commercialization: Perspectives from a Regional Innovation Ecosystem

Nearly $60M in support for start-ups

June 28, 2022

KY Multiscale: Micro/Nano/MEMS entrepreneurship

August 9-10, 2022

Research and ENTREPRENEURSHIP Experience for Undergraduates (REEU)

The REEU program sits at the interface of the NNCI Education and Outreach (E&O) and I&E domains and aims to expose NSF REU students to nano-enabled entrepreneurship opportunities linked to research. Since the extent to which entrepreneurship might "fit" within one REU program or another can vary from site to site, flexible REEU options are offered and tailored to meet the needs of individual REU coordinators. Coordination with the NNCI E&O program area facilitates engagement with REU coordinators and helps ensure careful integration of REEU content at an appropriate level. Four general REEU levels are offered and span from only a brief consideration of entrepreneurship to more advanced programming:

Level 1: No/brief discussion of entrepreneurship

Level 2: General/theme-focused (i.e., aligns with REU theme) entrepreneurship lecture and Q&A (~1 hr)

Level 3: Series of I&E lectures/seminars and/or visit/tour at nearby start-up facility

Level 4: Extended duration project ("I-Corps lite")

REU program coordinators can contact NNCI Associate Director Matthew Hull to discuss incorporating an entrepreneurship module within their REU program.

In 2022, a new site participated in the REEU program, bringing our total number of participating NNCI sites to six (Figure 4). REEU modules are offered in collaboration with the NNCI Assoc. Director for E&O (Mikkel Thomas; previously, Quinn Spadola) and local REU coordinators. Participating NNCI sites now include: NNF (Hanh Phan and Steve Wignall), SDNI (Yves Theriault), KY MultiScale (Ana S. Galiano), MANTH (Kristin Field), NCI-SW (Jessica Hauer; previously Ray Tsui), and SENIC (Leslie O'Neill). In 2021-2022, 78 REU students participated in the program. Dr. Yves Theriault (SDNI) continues to leverage the NNCI REEU program to implement a series of I&E seminars within the SDNI REU program at UC San Diego.

Figure 4: 2022 REEU Site Participation.

Interest in industry careers remains high among REU students participating in the NNCI REEU program. In 2022, nearly three quarters (74%) of REEU participants indicated that careers in "industry research" or "entrepreneurship" were of greatest interest to them (Figure 5). This number increased from 67% in 2021. The remaining students expressed interest in careers in government labs, academic/faculty positions, non-profit organizations or "other". Entrepreneurship was favored by double the number of students who were interested in academic/faculty careers. In both 2021 and 2022, more than half of the REEU participants claimed that they did not know much about entrepreneurship (Figure 5). In 2022, only 10% of participants claimed to know "a good bit" about the topic, which was down from 20% in 2021.

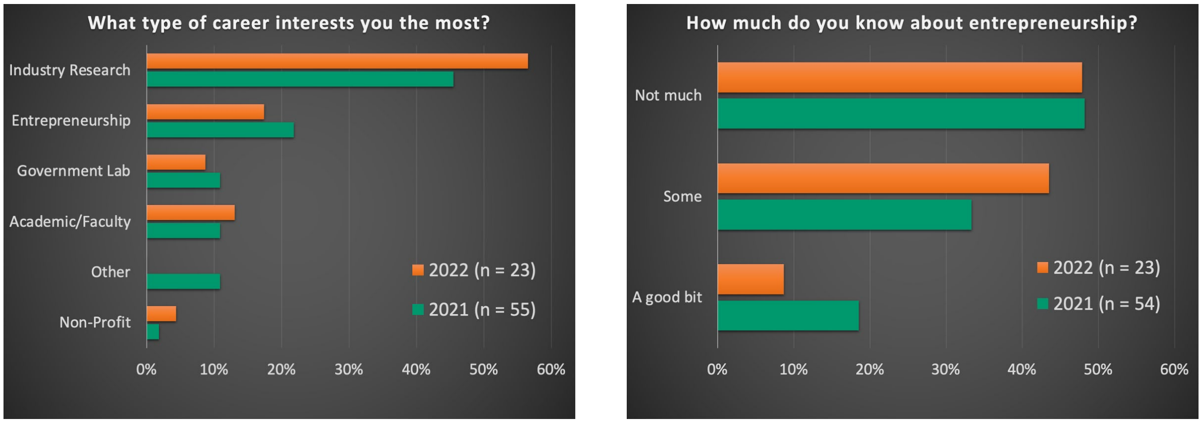


Figure 5. Feedback to date (2021-2022) from REU students participating in the NNCI REEU module when asked (left) about the type of career interests that interests them the most, and (right) how much they know about entrepreneurship.

Overall, the students continue to express a favorable opinion of entrepreneurship, using terms like "creativity", "innovation", and "leader" as entrepreneurship descriptors (Figure 6). Ongoing assessments of REU student perceptions of entrepreneurship can help the I&E and E&O working groups continue to better understand student interest in entrepreneurship and tailor program content for maximum efficacy.

Figure 6: Student response word cloud when asked "What comes to mind when you think of entrepreneurship?" (2022)

NNCI I&E Seminar Series

To date, three I&E seminars (one in 2022 and two in 2021) have been hosted as part of the broader NNCI seminar series and shared virtually across the NNCI to help foster awareness of industry-specific challenges and engagement of industrial problem solvers. Industry seminars foster awareness of key I&E topics or issues and enable the deeper relationships required to effectively engage and recruit non-traditional NNCI users, particularly small business users pursuing opportunities such as SBIR/STTR. Compared to site-level seminars, however, NNCI-wide I&E seminars: a) have relevance across multiple or all NNCI sites by elevating the message of an impactful I&E story (e.g., a success story), collaboration, trend, or opportunity, b) are promoted by the NNCI coordinating office, and c) are often co-hosted along with an NNCI site (e.g., the home site of the I&E WG member who proposed the seminar).

In 2022, the I&E WG hosted an industry seminar which was aligned with the July 2022 passage of the CHIPS for America Act & FABS Act. The seminar, held on October 12, 2022, and delivered by Miguel Urteaga, Director of Foundry Products and Services, Teledyne Scientific Co., was entitled "Lab-to-Fab: Transitioning from University Cleanrooms to Industrial Prototyping and Low-Volume Production." The seminar was organized and hosted by Dr. Andrew Lingley, Manager at the NNCI Montana Microfabrication Facility with support from the NNCO.

Planning is currently underway for the 2023 seminar series (I&E seminars will be held in May and October). Live online attendance at the three previous seminars totaled approximately 100 guests but the majority of attendees continue to view the archived seminars on the NNCI YouTube channel, asynchronously, where total views (as of this report writing) are approaching 300. Members of the I&E Working Group select seminar topics and host speakers. Emphasis is placed on selecting topics and speakers of broad interest across the NNCI sites.

NNCI Nanotechnology Entrepreneurship Challenge (NTEC)

The NanoTechnology Entrepreneurship Challenge (NTEC) is an NNCI-supported program that aims to train a new generation of "nano-savvy" student innovators and entrepreneurs about the process of commercializing nano-enabled technologies to solve global sustainability challenges. 2022 marked the launch of the first NNCI-wide NTEC program and the selection of our first cohort. Eight student-led teams participated in the first NNCI NTEC program and teams consisted of 11 students from five different NNCI sites who participated in a seven-week NNCI Virtual Accelerator program. The program began March 14th and concluded May 4th, 2022, with an NNCI Showcase event. Table 5 summarizes the 2022 NNCI NTEC cohort projects.

Table 5: 2022 NNCI NTEC cohort

Team #	Student Lead(s)	NNCI Site	Award	Mentor(s)	Title
27	Faisal Adams	NanoEarth	Regular	Marc Michel	Effective acid mine drainage treatment with composite nanotube-polymer membranes
28	Yi Shiou Duh	Nano@Stanford	Regular	Mark Brongersma	Illuminate Brain
29	Matthew McGlennen	MONT	Regular	Stephan Warnat	Microfabricated impedence sensor system for biofilm detection
30	Aditya Garg	NanoEarth	Regular	Wei Zhou Peter Vikesland	Multiresonant Plasmonic Meshes
31	Wesley Allen Williams	SENIC	Diversity	Shyam Aravamudhan	MPI nanoparticles for the sensing and remediation of toxic incident anthropogenically-derived nanoplastics in the hydrosphere
32	Ge Zhang	Nano@Stanford	Diversity	Anthony Kovscek	Rapid pH sensor on a chip
33	Amer Yaghi Tom Park Abdal Abdulhameed Elio Li	SDNI	Regular	Sheng Xu Yves Theriault	Bio-inspired self-powered and flexible wearable device for continuous detection and treatment of Parkinson's disease
34	Lauren Takiguchi	SDNI	Regular	Yves Theriault	Functionalized DNA origami-siRNA nanotube complex to reverse osteoarthritis

The top overall NTEC team was led by Amer Yaghi, a UC San Diego student affiliated with the San Diego Nanotechnology Infrastructure (SDNI) and the top Diversity Award team was led by Wesley Williams, a North Carolina A&T student affiliated with the Southeastern Nanotechnology Infrastructure Corridor (SENIC) and the Virginia Tech National Center for Earth and Environmental Nanotechnology (NanoEarth) (Figure 7).

Figure 7: Top NNCI NTEC Teams of 2022: Left to Right: Top Overall Winners University of California at San Diego Amer Yaghi, Tom Park, Dr. Yves Theriault, Abdal Abdulhameed; Diversity Award Winner North Carolina A&T Wesley Williams (Credit: S. Velasquez)

Designed as a pre-NSF I-Corps experience, NTEC provides experiential entrepreneurship education for teams led by undergraduates, graduate students, and post-doctoral scholars. NTEC teams learn about the importance of customer discovery and how to leverage NNCI resources to develop a nanotechnology-enabled minimum viable product (MVP). The seven-week program culminates in a "pitch" event where teams share their progress with business leaders. At one NNCI site, the site-level version of the NTEC program supported more than 30 students from 16 teams; nearly half were led by students from underrepresented groups and minorities; four invention disclosures were filed, and four student-founded companies were supported. By leveraging entrepreneurship resources available at each site, NTEC can be scaled and competed across the NNCI. Importantly, since Spring 2020, the NTEC program has been successfully administered virtually due to the pandemic, which demonstrates the potential for the program's broad reach.

The NTEC program is implemented across NNCI sites on an entirely voluntary basis (there is no requirement for sites to participate). Figure 8 summarizes the schedule for the 2023 NNCI NTEC program. Tentatively, the program will be announced by the NNCI Coordinating Office on January 9, 2023 with applications due February 11, 2022 (National Inventor's Day). The NNCI I&E Working Group will review the applications and recommend top applicants to the NNCI sites from which the applications were submitted. Sites will have the final say in which program they do/do not support based on their available resources (i.e., personnel, instrument time, funds for materials and supplies).

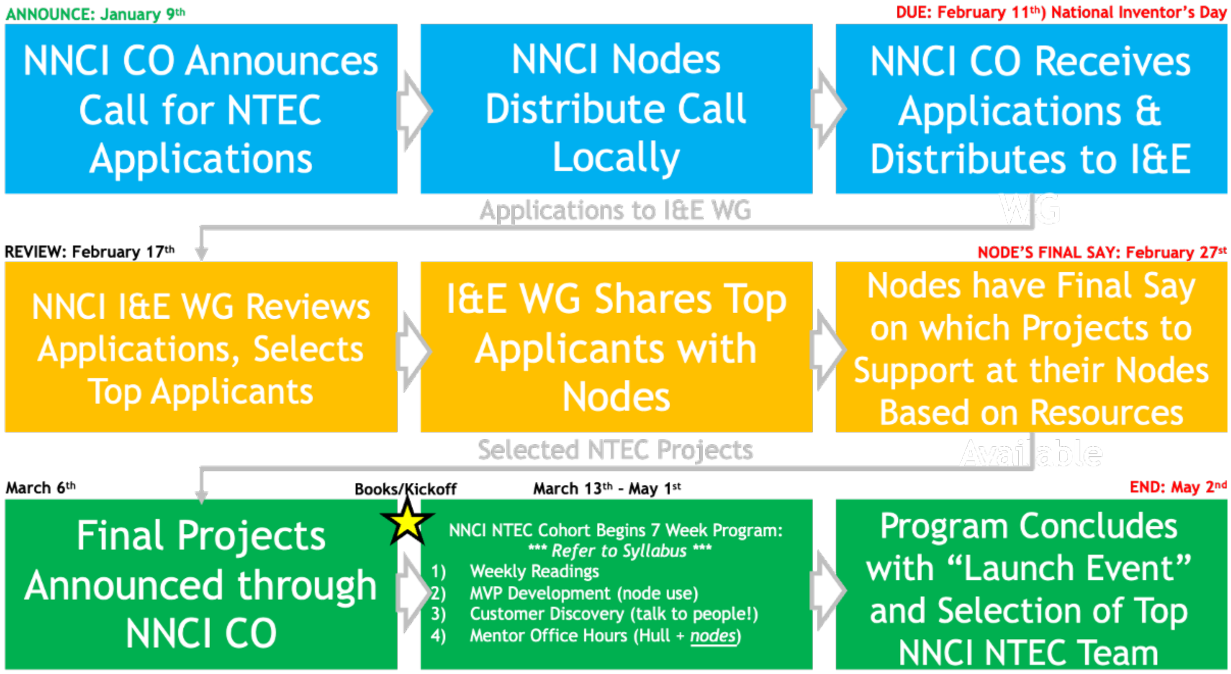


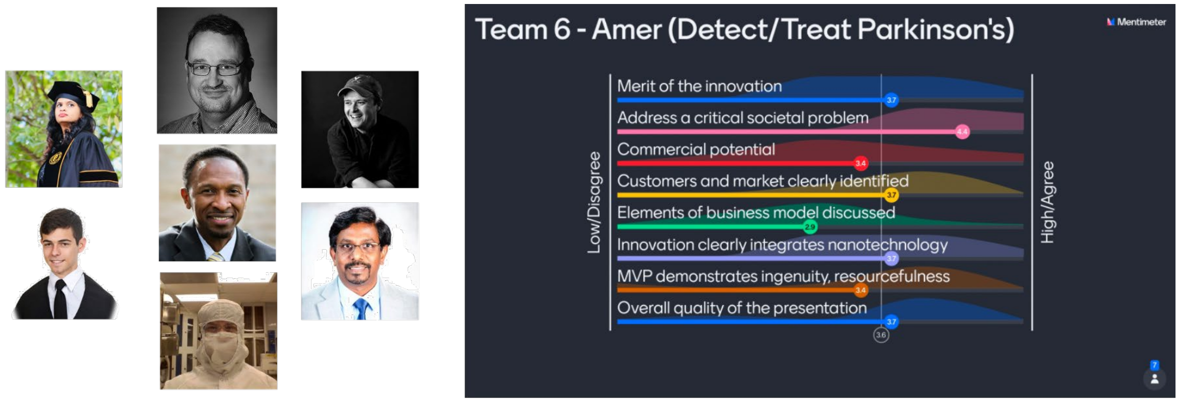
Figure 8: Timeline for the 2023 NNCI NTEC program.

In 2023, we anticipate awarding multiple award types – from in-kind instrument time to $500 team awards and $1,000 NTEC Diversity awards (to encourage teams led by underrepresented groups and minorities) – to allow for the broadest participation possible. Winning teams will once again participate in a seven-week, virtual NNCI NTEC Accelerator program aimed at providing teams with a gentle introduction to the concepts of the minimum viable product (MVP), business model generation and business model canvas (BMC), and customer discovery. Teams will work at their own pace but will have weekly readings, work with NNCI staff to use NNCI tools in the creation/evaluation of their MVP, and have the opportunity to engage with NNCI NTEC mentors via weekly virtual office hours.

In 2023, we anticipate that the weekly virtual touch-base meeting will include multiple members of the NNCI I&E WG, including Dr. Matthew Hull (NanoEarth), Dr. Yves Theriault (SDNI) and Dr. Paul Joseph (SENIC). These I&E WG members provide additional mentorship capacity to complement resources offered at local NNCI sites. Participation in the NNCI NTEC Accelerator program can help teams prepare for local/regional start-up pitch competitions or more intensive and highly successful programs like NSF I-Corps. Ultimately, the aim of the NTEC Accelerator program is to help inspire a generation of "nano-savvy" innovators and entrepreneurs across the United States who have both the technical competence and business acumen to translate nano-enabled breakthroughs from the lab bench to society.

The NNCI NTEC program concludes with a one-hour, fast-paced, virtual showcase event where teams share two-minute video clips of their progress during the NTEC Accelerator Program. A distinguished panel of innovators and entrepreneurs scores each team in real-time according to key performance metrics. Figure 9 shows the distinguished panel selected to evaluate teams during the

2022 NNCI NTEC showcase (a) as well as their scoring summary (b) for the top overall team from the 2022 competition. The 2023 NNCI-wide NTEC showcase is expected to occur on May 2, 2023.



(a) (b)

Figure 9. (a) Distinguished panelists for the 2022 NNCI NTEC program – clockwise, starting from the top: Pascal Deschatelets; Co-Founder & Chief Scientific Officer at Apellis Pharmaceuticals; Douglas Freeman, Senior Director, Founding Member, Jones-Dilworth, Inc.; Eduardo Gonzalez-Cantero, Student and previous NTEC recipient; Prof. Sylvester Johnson, Assistant Vice Provost for the Humanities at Virginia Tech; Paul Joseph, Principal Research Scientist at Georgia Tech; Andrew Lingley, Manager and Research Engineer at Montana State University; and Sheeba Dawood, CEO & Co-Founder at Minerva Lithium. (b) Scoring summary for the top overall NNCI NTEC team in 2022.

Entrepreneurs-in-Residence (EiR)

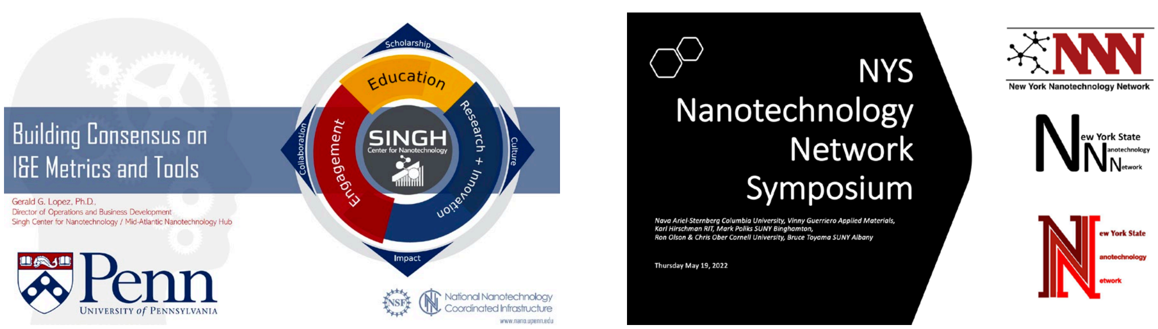
Currently, there are four identified NNCI EiRs as shown in Table 6. The I&E Assoc. Director serves as the NNCI EiR in situations where a site-specific EiR has not been identified. In 2023, we will work to identify additional EiRs at other sites, establish regular office hours during which EiRs can be consulted by prospective student and faculty entrepreneurs, and meet regularly with EiRs to evaluate activities and ensure successful outcomes. The role of the NNCI EiR is to help mentor (typically on an ad hoc and informal basis) NNCI users, faculty, students, and staff about topics related to entrepreneurship and commercialization, such as starting (or not starting) a new venture, where to find start-up capital, what local I&E resources (e.g., business accelerators) are available, how to navigate the university intellectual property process, and what common pitfalls to avoid. Developing entrepreneurs can benefit greatly from this mentorship and many established entrepreneurs are more than willing to provide it. A good candidate for an NNCI EiR role will have a "mentor mentality" and a strong existing connection with a particular NNCI site or group of sites. In many cases, an ideal NNCI EiR may be a faculty or staff member who already plays a role at an NNCI site but who also has prior or ongoing entrepreneurship experience and is willing to share that experience with others. The EiR may serve voluntarily, as part of assigned duties, or, if resources allow at a particular site, they can be additionally compensated.

Table 3: NNCI Site Entrepreneurs-in-Residence

Site	EiR
MONT	Trevor Huffmaster
SDNI	Yves Theriault (students and postdocs) Bernd Fruhberger (industry users and faculty)
NNI	Mike Robinson
NanoEarth	Matthew Hull
NNCI (when local site EiR is not available)	Matthew Hull

<u>I&E Session at 2022 NNCI Annual Conference</u>

An I&E session was held in-person during the 2022 NNCI Annual Conference. Attendees included members of the I&E Working Group but also others from the NNCI. Objectives of the session were to 1) provide an update on core programs and an outlook for 2023 I&E projects; 2) present insights from Dr. Gerald Lopez (MANTH) related to building consensus on I&E metrics and tools and Dr. Ron Olson (CNF) related to hosting an NNCI I&E showcase event (Figure 10), and 3) invite open discussion from all meeting attendees on how other NNCI sites could apply lessons learned from MANTH and CNF to assess I&E activity or organize an industry showcase event either at their own site or in collaboration with other NNCI sites.



(a) (b)

Figure 10: I&E Session at the 2022 NNCI Annual Meeting included presentations from (a) Dr. Gerald Lopez and (b) Dr. Ron Olson.

Discussion following Dr. Lopez' presentation emphasized 1) the need for metrics that specifically measure the impact of the NNCI on IP outcomes from universities and companies, 2) the importance of defining and categorizing companies appropriately (e.g., terms like "start-up" may be insufficient and approaches such as that described in the Youtie/Georgia Tech report may be preferred), and 3) that industry and economic data show value and impact, which is especially critical as we look ahead toward sustaining current and future versions of the NNCI. Following the meeting, the NNCI CO worked with Dr. Lopez to create a brief YouTube video that can be referenced on an ongoing basis as NNCI seek to build consensus on I&E metrics and strategies for collecting and reporting data reflective of the NNCI's impact on I&E and the economy. The video is currently unlisted but can be accessed at the following link: https://youtu.be/bQB6qucbolY.

There was also significant discussion following Ron Olson's (CNF) presentation on the 2022 New York State Nanotechnology Network Symposium, which provided a showcase for catalyzing interactions between students and companies. The theme of the workshop was "bridging the workforce gap" and it was attended by 88 participants. The topic may be especially timely given the need for such efforts following the passage of the CHIPS Act in 2022. Dr. Olson spoke on the process for organizing the workshop, which included the following: 1) an initial "mini" workshop to kick around nascent ideas; 2) the establishment of a steering committee; 3) identifying participants; 4) recruiting sponsors; and 5) developing the schedule. Overall, the event was considered a major success and generated enthusiasm for follow-on events. Feedback from attendees included 1) having undergraduate attendees in addition to graduate students; 2) wanting more communication between industry and students; 3) adding more time for students to interact directly with the industry/companies; 4) emphasizing a formal career fair component; 5) avoiding conflicting time-frames (e.g., finals week for students); 6) staggering of poster sessions so that students can network more effectively; 7) increasing talks to 5 min instead of 3 min; 8) adding more industry booths and industry engagement opportunities given tremendous interest from industry attendees; and, 9) making the event bigger and open to all students, not just those with presentations. It was also suggested that a tracking component be added to assess outcomes such as whether students received internships, job offers, or interviews.

In terms of broad relevance, it was agreed that NNCI showcase events that help connect NNCI students and leaders with industry (and vice versa) should be prioritized. The question was raised as to whether there was a single model for NNCI industry showcase events. Participants in the I&E WG meeting saw value in both regional and national efforts. More regional efforts could be organized and executed more readily, but a larger event could more effectively link students to industry opportunities with fewer geographic limitations. Such limitations can be especially problematic for NNCI sites located in less populated areas with fewer industry opportunities and jobs nearby. Attendees did note that if an NNCI-wide, national-scale showcase event was prioritized, it may be sensible to co-locate the event with the Fall 2023 NNCI national meeting. Further, the presence of site directors could add to the value of such an event for both students and industry attendees.

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 7). 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. Subcommittee topics, chairs, and members were reviewed and updated during 2021. The Entrepreneurship and Commercialization subcommittee was sunset, replaced by the new Associate Director and working group, the New Equipment and Research subcommittee was refocused on Research and Funding Opportunities, and a new subcommittee on Nanotechnology Infrastructure of the Future was added. Reports of the subcommittees on current and future activities are presented below as provided by the subcommittee chairs.

Table 7: NNCI Executive Committee Subcommittees (2022)

Subcommittee Topic	Subcommittee Chair(s)
Diversity	Bill Wilson (CNS)
Metrics and Assessment	Christian Binek (NNF)
Global and Regional Interactions	Vinayak Dravid (SHyNE), Yuhwa Lo (SDNI)
Research and Funding Opportunities	Chris Ober (CNF), Jim Cahoon (RTNN)
Nanotechnology Infrastructure of the Future	Debbie Senesky (nano@stanford)
Building the User Base	Shyam Aravamudhan (SENIC)

5.1. Diversity Subcommittee

All NNCI sites have fully resumed their outreach activities this year. Summaries from sites are listed below as well as some of their future directions for the coming year.

Center for Nanoscale Systems (CNS)

The Center for Nanoscale Systems (CNS) at Harvard University was created with a clear vision to provide a collaborative multi-disciplinary research environment to support world-class Quantum and nanoscience. As the New England hub of the NSF National Nanotechnology Coordinated Infrastructure (NNCI), the focus of the technical team is to develop specialized tools, processes, instrumentation, and expertise to help design, characterize, prototype, and fabricate novel materials, nanostructures, devices, and systems, that go beyond conventional approaches. CNS pushes the envelope of Quantum Science and Engineering. This year CNS has re-established our Research Experiences for Undergraduates (REU) program, as well as our annual summer nanotechnology and instrumentation seminar series. Moreover, we have reignited our CNS Scholars Program, which brings in underrepresented researchers, and our Research Experience for Veterans (REV) program to train U.S. veterans in nanotechnology. In addition, CNS this year has begun to "formally" teach academic classes in CNS spaces with staff support, a new addition for the Lab. In the past we have participated somewhat informally in class instruction.

As a new initiative for 2023 we have submitted a proposal to NSF:CMP to *support the creation of "Quantum Noir", a biennial meeting targeted at researchers of Color (+) in Quantum/Nanoscience and Engineering. The primary goals of this meeting are to network researchers from under-represented groups in the community, to integrate, and connect folks "collaboratively" with Leaders in the Quantum Community, and finally to create a recruiting event for researchers and students from under-represented groups into the Quantum and Nano Sciences*. The need for a topical meeting of this type is clear, while there are a variety of annual meetings for researchers of color, none *focus* on this important new branch of science and engineering. Today we are witnessing the emergence of Quantum Science & Engineering as a technology driver, an event that may be no less significant than the revolution in microelectronics at the beginning of the last century. The ascent of this new discipline demands we rally the nation's scientific community to address this opportunity. The ongoing revolution in Quantum Information, Quantum, Sensing, and Quantum Networking is a challenge we must meet with all of our nation's resources, human and otherwise. Nanotechnology has led the way, defining technologies and systems where *size* has been used to exploit quantum effects to enable technical function. Now an array of new technologies that harness the unique quantum properties of *coherence, entanglement, and measurement* are also emerging from fundamental advances. Much of the foundation of this work is based in condensed matter science and historically, there has always been a barrier of entry to this branch of science and engineering for researchers of color, particularly at small institutions, due to limited access to the extensive infrastructure and resources required to do *world-class* work in this space. Fortunately, today, in part because of diligent efforts at NSF and other agencies, that barrier to entry is lower than ever. For example, many NNCI sites offers access and training to all our nations researchers, enabling them to engage innovatively, but too few researchers at minority serving institutions are availing themselves of these opportunities. If we are to meet the challenges of innovation in the Quantum Technologies, we need to open the door wide for all potential innovators and train up a workforce that will ensure that Quantum Supremacy will reside in the US. Quantum Noir aspires to help fill this gap.

Quantum Noir will serve as an important workforce development event affording technology dissemination of the *"state-of-the-art"* from leaders in Quantum Engineering to a new generation of researchers. It will help create a collaborative nexus for researchers and students of color, and in addition will allow industry and the venture community access to an untapped source of innovation. Quantum Noir will be focused to truly diversify the Quantum community, but also, to more importantly, to build community to ensure we are optimizing the talent and human resources available by connecting "all" researchers with available infrastructure, resources, and training.

Finally, as a subcommittee we are exploring proposing the formation of an annual *"Fabrication Bootcamp"* hosted throughout the network. *Chair Wilson and the rest of the subcommittee are drafting a proposal to present to the NNCI leadership very early this spring.*

Cornell Nanoscale Facility (CNF)

The Cornell Nanoscale Facility (CNF) has from its beginnings engaged in efforts to broaden participation in nanoscience, taking a broad view of many ways to engage with the science and non-science communities. This year we submitted a proposal to the REU program to increase diversity in our summer program and enable use of CNF's "baked-in" REU budget to instead support the NNCI international REU program.

We are excited to take part in the planned NNCI HBCU Summer Fab Bootcamp using our teaching experience through our established Technology and Characterization at the Nanoscale (TCN) short course. We have also established for the first time at CNF a microcredential program with our local Tompkins Cortland Community College where students receive credit for taking our TCN course and gain some hands-on experience at CNF. Of particular focus are veterans.

We are in our second year of a special summer program with Morgan State University where up to 3 students will be supported by our college of engineering to take part in our REU program. We are expecting to expand this program to other HBCU schools.

CNF is also located in a rural setting in the middle of "fly over" country so efforts at diversity and inclusion must take this into consideration. Locally, we work with Diversity Programs in Engineering to recruit students to Cornell and to studies in nanoscience and engineering. We also work with 4H to increase our impact to all counties in New York and across the country on STEM topics.

And each year at our annual user meeting we celebrate the contributions of women scientist and engineers through our Nellie Whetten Award to women scientists who are not only outstanding scientists and engineers but exemplary citizens of the STEM community. This award was established in the 1980's in honor of a young staff member who died young and many award winners have gone on to have significant careers in academic and industry.

Mid-Atlantic Nanotechnology Hub (MANTH)

MANTH continues to keep DEI as a foundational value for our programming. Below are examples from MANTH that contribute to broadening participation in STEM.

The 2022 cohort of CCP interns (L to R): Anton McFadden, Michael Geraghty, Colin Bakum

MANTH and the Community College of Philadelphia (CCP) launched an internship program that hosted three CCP students at MANTH's Singh Center's Quattrone Nanofabrication Facility (QNF). In May 2022, the three selected students, Colin Bakum, Michael Geraghty and Anton McFadden, started the internship under Principal Scientist Gyuseok Kim's supervision. Kim engaged several master's students in the Singh Center for Nanotechnology's Graduate Student Fellows Program and fellow QNF staff to round out the mentoring team dedicated to the CCP interns. Over the 14 weeks, 20-hours/week, the interns moved through basic safety and nanofabrication training (lithography, etching, deposition, soft-lithography) and on to working on a project of choice (Bakum – 2D graphene transistors, Geraghty – solar cells, McFadden – microfluidics). Their internship required hands-on work with their devices and samples, attending lecture and lab demos, and presenting ongoing and final work. The interns participated in an international Mxene Conference (*MXenes: Addressing Global Challenges with Innovation*, Aug. 1-3, 2022) at Drexel University (Bakum and Geraghty presented posters).

In addition to continuing to work at jobs that they also held during the summer internship program, the interns will continue their academic trajectories. Bakum transferred to a four-year bachelor's degree program in Electrical Engineering (Temple University). Geraghty and McFadden are completing their associate degrees at CCP in Computer Science and Chemistry, respectively. Interns reported that the most valuable benefits of the internship experience included: access to the "instrumentation and learning how to fabricate my own device," "how to work and deliver under high pressure situations… how to learn and adapt quickly," and "to deeply explore a single technical discipline…I can take this experience to job interviews and discuss my project, the successes and failures, and my problem-solving experience."

Ongoing nano-related courses started by the NNCI's award to MANTH and CCP:

CCP courses have been created under the NNCI-enabled CCP-Singh Center partnership. Course descriptions are below the table.

Course	**Title**	**Semester** (student enrollment)
AET 140	*3D Printing-Additive Manufacturing*	F2019 (N=8), Su2020 (N=6), Sp2021 (N=10), Su2022 (N=6), Sp2023*
AET 201	*Introduction to Nanotechnology*	Sp2020 (N=8), Su2021 (N=6), Sp2022 (N=3), Sp2023*
AET 101	*Introduction to Robotics*	F2021 (N=17), F2022 (N=23)

*AET = Applied Engineering Technology (formerly ASET=Applied Science & Engineering Technology); Semesters: F=fall, Su=summer, Sp=spring; *enrollment ongoing or not started yet*

Nanoday@Penn (https://www.nano.upenn.edu/nanoday/) – MANTH led with participation from research/student groups at Drexel, Temple and Jefferson universities. October 11-14 2022: 23 Sessions offered for middle- to high school classes/student groups, both in-person (12 session) and remotely (11 sessions), which covered 16 topics.

Bargatin Lab's in-classroom "Sandwich Composite Materials and Paper Cups" Session (NanoDay).

The Singh Center's Research Experience for Undergraduate (REU) Program recruits from different types of institutions and aims to serve cohorts that reflect a diversity of STEM disciplines and demographics. The 2022 cohort started the program on May 31, 2022. They presented their work in a Symposium at Penn on August 4, 2022 and then at the NNCI REU Convocation (Aug. 8-10). The three women and three men identify as White/Caucasian (N=2), Asian (N=2), and Black or African-American (N=2). Their undergraduate majors are Chemistry, Chemical Engineering (N=2), Electrical Engineering, Bioengineering, and Intelligent Systems Engineering.

Intentional event programming with a diversity of speakers as well as broader impacts topics (e.g., Singh User Meeting, Oct. 13, 2022. Program available here.

Montana Nanotechnology Facility (MONT)

The MONT Empower Scholars program awarded 4 scholarships to place underrepresented undergraduate students with MONT researchers for research experience and tool training. Demographics include 3 Hispanic/Latinx students (one of which is female), and 1 female student. This award provides training in a MONT facility and a student stipend for one semester, with the option of an additional semester if both the student and PI would like to continue the work. Follow-up surveys found both the student and host PI found the program to be of significant benefit.

We continue with the Salish Kootenai College (SKC) middle/high school programs to incorporate nanoscience/technology education on the Flathead Reservation in northwestern Montana. We are working with SKC program directors on the possibility of taking a group to Yellowstone National Park for a Nano Earth and Environmental Sciences field trip this summer with follow up in MONT labs.

We are in the planning stages, but we have researchers from the above-mentioned SKC as well as another tribal college, Little Big Horn College (Crow Tribal Nation), who will have potentially MONT sponsored work in our chemical analysis lab.

We continue to focus outreach efforts on rural communities and K-8 schools with a high percentage of Title 1 students with activities such as sponsoring and co-coordinating MSU Science Day. In addition to hosting several nano-based activities, MONT sponsors the bussing of 150 5th grade classes from area high percentage Title 1 districts for a day of science on campus. We also work with 4H during summer congress, Science Olympiad and other programs that bring K12 students from rural Montana towns. It's amazing how just getting these kids to campus changes their whole perspective on attending college.

Our director, David Dickensheets, taught a workshop to 30 college-bound students in Burundi, Africa. The multi-day course, which included several activities developed by the MONT team for high-school outreach in Montana, was received enthusiastically and prompted lively discussions related to global and societal impacts of nanotechnology and opportunities for young people to pursue careers in nano-related science and technology fields. David was there visiting his son who teaches in Burundi.

Northwest Nanotechnology Infrastructure (NNI)

Oregon State University implemented holistic admission in 2021 which has helped increase diversity among both applicants and incoming graduate student class. A required graduate seminar on DEI for first year graduate students has also increased awareness of DEI topics and increased discussions among faculty and students. Weeklong, on campus, science and engineering camp for high school students from underrepresented groups in STEM was held last summer for the first time since before the pandemic. This year OSU hosted 30 high school students, that is about half the pre-pandemic camp size, but we hope to be back to the pre-pandemic size next year, as a part of this camp 8 highschool students did research projects related to nano technology hosted by NNI faculty.

NNI is in the second year of our partnership with the UW College of Engineering and the UW's Office of Admissions to support a new college transition program for a cohort of incoming University of Washington students coming from backgrounds farthest from educational justice – The Engineering Dean's Scholars Program. Each cohort is between 45 and 48 students, and we achieved a 96% retention in college after the first year of the program. The current cohort, #2, consists of 45 students as of autumn quarter 2022. Compared to the general population of admitted UW Engineering students, in the 2022 admitted pool of students who are eligible for Dean's Scholars, we saw a 5% increase in women, a 73% increase in first generation college students, a 52% increase in low-income students, and a 38% increase in URM students. We have hired our first two scholars who began working in the WNF cleanroom this academic year.

nano@stanford

nano@stanford has been active in education and outreach activities to promote diversity, equity and inclusion. Our focus has been on reaching low resource, underserved local communities including: partnerships with the Science Learning Institute at Foothill College (supporting first generation and underrepresented students interested in STEM) and with Oakland Promise; a mini grant opportunity for Stanford graduate students and postdocs to develop educational videos and K-12 classroom projects inspired by famous scientists from minority groups; engaging in NNCI Science Outside the Lab program to introduce broader concepts of ethics as applied to nanotechnology. We are particularly proud of expanding our community college internship program hiring a total of nine interns from West Valley College, Mission College, Foothill College, Chabot College, and DeAnza College. Six of the interns are women of color and eight are from underrepresented groups.

Community college internship participants.

Our staff continues to improve our general inclusive culture by developing best practices for hiring, intern selection and taking courses through Human Resources with associated certification. The interns from community colleges, in turn, share their experiences with a broader audience via Instagram.

San Diego Nanotechnology Infrastructure (SDNI)

SDNI's student internship program includes 50% female and URM students.

SDNI cooperates with the university's effort in providing a friendly workplace for all genders and ethnicities.

SDNI's remote SEM education program, a flagship program for education/outreach, was largely run by female students.

SDNI's REU program consists of a diversified cohort of undergrads with 50% URMs, including 1 female Hispanic or Latino; 1 female Back Hispanic or Latino, and 1 male American Native/Pacific Highlander.

SDNI reached out to 524 students in the K-12 community by performing Remote Scanning Electron Microscopy sessions in San Diego Classrooms. The percentage of underserved population in San Diego schools is approximately 70%.

SDNI trained 28 teachers in our 2022 Nanotechnology Summer Institute for Middle and High School Teachers who will integrate nanotechnology content to their science curricula in San Diego schools of 70% diversity index.

SDNI mentored the winning team, led by women, for the 2022 NNCI NTEC competition.

Research Triangle Nanotechnology Network (RTNN)

Year 7 marked a big return to in-person outreach for RTNN and the first year of hosting a new RTNN-focused collaborative REU Site in the summer of 2022. Many RTNN outreach programs engage directly with diverse communities including Underrepresented Groups/Minorities (URG/URM), i.e., Girl Scouts STEM Day @ Duke (>240 participants, ~95% URG), NC SciFest with Currituck County MS (Title 1 School, 98 Participants), Community STEM Day with a Waccamaw-Siouan Tribal community (95 participants), and STEM/nano activities at the Franklinton Middle School "Ram Camp" (38 participants, >50% URG) in Franklinton, NC (~1 hour drive outside the Research Triangle region). The success of these programs is facilitated by the relaunch of the RTNN Student Ambassadors Program and participation of new staff hires in Year 7. At least 45 outreach events were in-person this year with a total of >980 participants reached, meaning RTNN outreach programs reached more people in real-time this year face-to-face than through virtual outreach. Recruitment and success of RTNN programs rely on fostering relationships with diverse communities and talent pools to help improve recruitment and contribute to diversity in the RTNN STEM activities. For example, of 12 total 2022 REU program participants, 5 students self-identified as URM/AAPI and 7 self-identified as females. Two of these REU participants were initially enrolled at a local HBCU and successfully transferred to NC State University's College of Engineering in Year 7. The Analytical Instrumentation Facility (AIF) at NC State has a new woman scientist and faculty member as its director. As Director of one of the RTNN facilities, she serves on the RTNN Executive Committee, further diversifying the RTNN leadership team.

Nanotechnology Collaborative Infrastructure-Southwest (NCI-SW)

NCI-SW continued its efforts to expand opportunities to existing students from historically minoritized and marginalized communities as well as vastly expanded its efforts through partnerships to reach students, parents, and communities throughout Arizona and beyond. ¡MIRA! (NCI-SW NAU partner institution) was one of two higher education highlights for the entire state of Arizona in the Arizona Hispanic Chamber of Commerce "State of the Hispanic Market" publication with STEM outreach and opportunities for minoritized populations highlighted. Below are year-end highlights and a list of NCI-SW activities.

¡MIRA! Scholars Program: ¡MIRA! Scholars is an undergraduate research internship program that provides students an opportunity to perform research in the labs of ¡MIRA! faculty, gaining invaluable research experience. The financial support is intended to remove barriers and equalize opportunities for students who typically would not be able to pursue a research experience. This year ¡MIRA! received over 40 applicants and was able to support semester-long research experiences for eight ¡MIRA! scholars. All eight scholars are women and/or historically minoritized individuals.

NetROC: In 2022, NCI-SW NAU co-PIs Inès and Gabriel Montaño developed a new virtual symposium called Networking Research Opportunities Colloquia (NetROC). NetROC is an innovative speaker series designed to close the accessibility gap between students in junior colleges and public universities vs. highest research institutions. The colloquium experience and networking with invited speakers provides a meaningful advantage for students at higher tier institutions. NetROC uses a virtual platform combined with live-speaker engagement to provide opportunities for students at institutions without such colloquia to engage with prominent researchers and develop their networks and opportunities! NetROC was established via seed-funding from the Burroughs Welcome Fund and is set to be launched in 2023. (www.netroc.org)

(A) ¡MIRA! and Applied Physics PhD student Ysaris Sosa introducing a family to STEM **¡EN ESPAÑOL!** At Mall of America STEAM event! (B) Diverse Team of students and faculty at MoA. (C) Jessica Hauer introducing future scientist to TEM at Indigenous Peoples Day.

NCI-SW Outreach Events: In 2022, NCI-SW began a broader partnership in outreach teaming with Sparking Curiosity in Quantum Science (SparCQS), an outreach intitiative created by NCI-SW NAU PI Dr. Inès Montaño, as part of an NSF-funded Engineering Research Center, the Center for Quantum Networks. Along with SparCQS, ¡MIRA!, and ASU Center for Broadening Participation, NCI-SW introduced students across the state and country to nanotechnology and materials science. Importantly, our outreach interventions meet students and communities **WHERE THEY ARE** and **with role models who look like them** with a diverse group of students and faculty at every event!! The importance of these points cannot be overstated. The southwest is geographically sparse and rural with historically minoritized students often living 200+ miles from the closest research institution. Through our collective partnerships, students, families, and communities have been introduced to a potential future for their students and communities in STEM. Activities consist of "hands-on" activities including an array of photonics and materials experiments in **English and Spanish!!** An important component to this has been remote access and control of an NCI-SW TEM based at ASU and led by NCI-SW Program Coordinator, Jessica Hauer. This activity allows students to control the TEM and in doing so, perform nano-science as scientists. Activities of our collective team are designed to not only introduce communities to STEM, but to help them "see" themselves as scientists and engineers. The response to our outreach efforts has been overwhelming and we have a wait-list of schools, events, and communities we will continue engaging in 2023. Included in activities have been visits to four corners primarily Native American communities and low-socioeconomic schools in the Phoenix Valley and throughout Arizona. Our teams have been invited to participate in national events such as the Mall of America 30th Anniversary STEAM event, in August of 2022, in which we reached over 2,000 people in four days, Indigenous Peoples Day, Sept, 2022 in which we engaged over 800 individuals in one day and the upcoming "STEM Playbook for Youth" event, a part of Super Bowl 2023 activities in Phoenix, the 2023 Barrett-Jackson STEM event in February, 2023. Our team has quickly garnered a national reputation for activities including Dr. Inès Montaño being invited to give a talk on "Sparking Curiosity in Quantum Science-development of an Outreach Initiative" at the IEEE Quantum Science and Engineering Education

Conference (list of activities below). NCI-SW and partners continue to move beyond "checking boxes" implementing programing to make a difference in the communities we serve.

Members: Bill Wilson (CNS, Harvard), Jacob Jones (RTNN, NC State), Maude Cuchiara (RTNN, NC State), Liney Arnadottir (NNI, Oregon State), Yuri Suzuki (nano@Stanford), Kristin Field (MANTH, U Penn), Yu-Hwa Lo (UCSD), Sherine Obare (SENIC, NC A&T and JSNN), Christopher Ober (CNF, Cornell), Melanie-Claire Mallison (CNF, Cornell), Heather Rauser (MONT, Montana State), Charles Lowry (Virginia Tech), Gabriel Alonzo Montano (NCI-SW, Northern Arizona University)

5.2. Metrics and Assessment Subcommittee

This subcommittee report is based on communication between the committee members Christian Binek (Nebraska Nanoscale Facility (NNF)), Trevor Thornton (Nanotechnology Collaborative Infrastructure Southwest (NCI-Southwest)), David Berube (Research Triangle Nanotechnology Network (RTNN)), Sanjay Banerjee (Texas Nanofabrication Facility (TNF)), Mitsu Murayama (Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth)), David Gottfried and Jan Youtie (Southeastern Nanotechnology Infrastructure Corridor (SENIC)) in the time frame between May 2022 and June 2022 on the subject of collecting information on courses taught and based on a combined Zoom meeting between the members of the metrics subcommittee and the members of the subcommittee on Building the User Base (BUB). The Zoom meeting took place July 28, 2022 and was led by Christian Binek, chair of the metrics and assessment subcommittee (M&A). The meeting was recorded, and Binek took minutes which he shared, together with the recording, with the M&A and the BUB committee members. The results of this combined meeting were presented at the October 12, 2022 NNCI site directors meeting by the chair of the BUB committee Shyam Aravamudhan. The answers the M&A subcommittee is seeking will be critical in providing a template for assessment activities in the next iteration of infrastructure networks supported by the NSF and serve as a guide for other assessment activities.

Recommendations by the M&A Subcommittee on Collecting Information on Courses Taught

The subject of collecting information on courses and number of students taught by NNCI sites has been periodically resurfaced within the M&A committee. Discussions typically tried to balance between additional administrative burden for the NNCI sites and the benefit of better measuring the achievements of NNCI. Recently, the latter argument gained more weight due to two major developments. On the one hand, NNCI is approaching the end of its funding lifetime. As a result, a conversation about the next generation of nanotechnology infrastructure serving the nation is becoming increasingly important. In this context, it is critical that NNCI finds additional quantitative ways to report on its achievements. Workforce education and, hence, courses and students taught, is an important metric in this context. At the same time, with the CHIPS and Science Act signed into law in August of 2022, workforce development for the US semiconductor industry has rarely been more important and more supported than it is today. The contribution of NNCI in the nation's semiconductor workforce development has always been very significant and needs to be reported on a qualitative and quantitative level.

With NNCI directors being fully aware of these significant developments, the subject of collecting information on courses and number of students taught using the resources of NNCI facilities was discussed at the April 13, 2022 NNCI site directors meeting. Triggered by this, the M&A subcommittee started a discussion via e-mail exchange on which data to request and developed advice on how such data can be obtained network-wide.

As a result of this conversation, the M&A committee recommended that, *on an annual basis, as part of the end-of-year data collection for the Coordinating Office's annual report, each site provides the total number of courses they support, a list of departments in which these courses are taught, and total number of students enrolled for the academic year period*.

Outcomes of the Joint BUB and Metrics Committee Meeting, July 28 2022

The main purpose of this meeting was to address the question of how to broaden the definition of a user in a meaningful manner. All sites have users that do not fall into the traditional category of individuals utilizing facilities for research. Because of this, NNCI sites notoriously underreport and fail to publicize the full extent of the service NNCI provides. Various groups were identified which are not considered to be users in the traditional sense. Those include education and outreach participants using facilities either hands-on or via remote access (see RAIN), staff doing research, etc.

Generally speaking, criteria for what defines a user were first written down by one of NNCI's predecessors within the National Nanotechnology Infrastructure Network (NNIN) and were also considered by the Metrics subcommittee during the early years of NNCI. While this definition served NNCI well, it is time to revise it and adjust it to the new environment where an ever-increasing focus is given on workforce development and education. As of today, the work on this revised definition is not finished and remains a task for both the M&A and the BUB subcommittees. The two committees will continue to collaborate and seek feedback from the NNCI directors. More information about the outcomes of the combined M&A/BUB committee meeting can be found in the report of the BUB subcommittee.

Open Tasks for the M&A Subcommittee

Arguably the most important open task for the M&A subcommittee in particular is establishing metrics which allow NNCI to quantify the level of interaction between sites. There is no question that NNCI is more than the sum of individual sites. The networking of 16 sites gives rise to major synergy effects. Prominent examples are the research communities, working groups and joint E/O activities. Quantifying these synergies is difficult but possible and very important to make the case for the next incarnation of an NNI infrastructure network. The M&A committee will continue its work to develop metrics NNCI can build on.

Members: Christian Binek (NNF/Nebraska), Trevor Thornton (NCI-SW/Arizona State Univ.), David Berube (RTNN/NC State), Sanjay Banerjee (TNF/UT-Austin), Mitsu Murayama (NanoEarth/Virginia Tech), David Gottfried (SENIC/Georgia Tech)

5.3. Global and Regional Interactions Subcommittee

The main objectives behind the Global & Regional Interactions (GRI) subcommittee are to:

- Engage and leverage local NNCI node activities with regional programs and local institutions.
- Explore plans and develop ideas to identify and potentially connect NNCI network to analogous programs across the world.

- Encourage individual NNCI sites to identify their local partners and regional collaborators.

Toward these objectives, the GRI subcommittee has convened periodic meetings with members to discuss experience in regional and global interactions as well as updates to provide other members with some examples of such interactions. The NNCI network model revolves around regional strengths and impact of individual sites as well as coordination and cooperation across the network. In this spirit, the GRI subcommittee met and shared experiences periodically in the past year.

While not meant to be exhaustive, the examples below are representative of some of the NNCI sites that may also spur interest among other sites and may find inspiration to consider analogous programs and ideas at their respective sites

SHyNE Resource: SHyNE Resource has taken efforts to establish collaborative relationships with local colleges and universities in the Chicago metropolitan area. As examples, these institutions include Chicago State University (CSU), Oakton Community College and Northern Illinois University, which also represents outreach and DEI considerations (CSU is considered HBCU, while NIU serves rural communities, and Oakton for workforce development). SHyNE has also reached out and connected to public institutions such as the Art Institute of Chicago and Chicago's Field Museum of Natural History. These efforts, among other things, include such programs as the Research Experience for Undergraduate (REU) program and the Research Experience for Teachers (RET) program. SHyNE also led a regional i-Nano event in close collaboration among NU, UC and ANL; as a regional nano-initiative. The i-Nano event has become staple of SHyNE's regional initiative and represents a generic example of regional cooperation and coordination in education/outreach in nanoscience and nanotechnology.

San Diego Nanotechnology Infrastructure (SDNI): SDNI has offered 19 sessions to over 540 students and was recognized as the top performer of the RAIN (Remotely Accessible Instruments for Nanotechnology) network in the most recent year. In year 7 SDNI demonstrated effectiveness for remote scanning electron microscopy sessions with K-12 and community college students. During these sessions, students were introduced to the basic principles of microscopy and the difference between optical and electron microscopy. SDNI offered nineteen teachers the opportunity to participate in Nanotechnology Summer Institute for Middle and High School Teachers.

SDNI leverages its Chip-Scale Photonics (CSPTF) facility to its pilot integrated Photonic Education Kit (IPEK) as a regional activity. It enables SDNI to produce enough demo kits for growing regional needs. SDNI-CSPTF has completed a full curriculum for the device, and successfully implemented it as part of the several courses. SDNI has delivered several IPEKs to technical schools (Bridgewater State University, Rose Hulman Institute of Technology), universities, and industry. The largest demand for the kits came from technical schools, which is an indication of the value of IPEK to workforce training. The effort attracted 22 companies and around 100 students. Most participating companies are SDNI industrial users. SDNI has also collaborated with Penn State, Georgia Tech, NC State, and ASU to form Microelectronics and Nanomanufacturing for Veterans Consortium. Southwest College (SWC) recruits Navy veteran trainees and creates a special curriculum specialized in semiconductor manufacturing process. SDNI will implement a 12 weeks per year hands-on training program to teach the trainees the principle and operation of the micro/nano fabrication and characterization tools.

Other NNCI sites, Penn State (lead institute), Georgia Tech, NC State, and Arizona State University will partner with local community colleges near their locations to develop similar training programs. As a consortium, all the members can share experiences and best practice to improve and scale up the workforce development program.

Cornell Nanofabrication Facility (CNF): The CNF has taken the lead in establishing a New Yok State Nanotechnology Network (NNN) as it pertains to Micro and Nanotechnology. This network allows universities/colleges and industry to partner and expand technology skills and capabilities while providing synergies that are strengthening technology and the workforce in New York State. In May of 2022 the CNF hosted the first NNN symposium. This in-person event focused on connecting New York State undergraduate and graduate students with industry partners for the purpose of "Bridging the Workforce Gap". The career fair themed symposium showcased the NYS student talent pipeline and united New York State colleges, universities, and industries for the purpose of exchanging information and sharing technology research activities. It featured 88 total participants (65 from 10 academic institutions, 21 representing 10 industries), 2 government officials, a total of 37 posters (26 from highlighted and speed presenters), and 26 student talks (6 featured talks and 20 speed talks). The 2023 meeting will be hosted by SUNY Albany.

CNF also conducts IREU and IRTE programs. CNF node plays a major role in NNCI's international activities. Since 2008, CNF has conducted an international student exchange program with the National Institute of Materials Science in Tsukuba, Japan. This program sends the bests students from the prior year NNCI(NNIN) REU program for a summer REU-like experience; we refer to this program as IREU. CNF partner, NIMS, is manager for ARIM, formerly the Nanotechnology Platform Japan, the analog of NNCI. This program is supported entirely out of CNF's cooperative agreement and conducted for the benefit of NNCI REU students at all sites. Since 2008, almost 100 students have participated in this program.

NNCI sites also hosted a small number of graduate students from the Japan university network (ARIM/Nanotechnology Platform). In 2022, Nebraska and Georgia tech hosted students. In 2022, 18 different projects were proposed from five NNCI sites. Over 50 graduate students have participated in this program since 2008. CNF is a participant and awardee for Accelnet: Global Quantum Leap, (https://www.globalquantumleap.org/) a project linking the NNCI network with similar networks in Japan and Europe. Although funded separately, Global Quantum Leap (GQL) is part of the overall NNCI effort. GQL seeks to promote linkage between NNCI and sister nanotechnology networks in Japan and Europe through human resource focused program. A major part of the Global quantum Leap program is its IRTE program (International Research Training Experience). In 2022, GQL/NNCI sent three students to NIMS in Japan for quantum related projects. This leveraged off the existing IREU program with Japan; the cohorts for the 2 programs were mixed. IRTE is largely managed out of CNF for GQL.

For 2023, IRTE will expand to include projects at RWTH Aachen, part of our European partnership. We will send 3 students to Japan and 4 students to Germany. Participant selection is underway. Participant interviews for both IRTE and IREU are at https://www.cnf.cornell.edu/education/international/interviews/2022_japan; technical reports for both programs are available at https://www.cnf.cornell.edu/education/reu/2022

Northwest Nanotechnology Infrastructure (NNI): At the NNI site, Washington Nanofabrication Director Dr. Maria Huffman was selected as a member of the external advisory board of Myfab (http://www.myfab.se/default.aspx), the Swedish Research Infrastructure for micro and nanofabrication. She was also invited to give a presentation about the WNF, through NanoLund (https://www.nano.lu.se/start) and the Department of Solid State Physics. The University of

Washington is also in conversations with Japanese counterparts about a university level exchange program that will likely involve NNI facilities and QuantumX (https://www.quantumx.washington.edu/).

These examples are meant to provide regional sampling of interactions across the NNCI network. They also represent innovative and comprehensive approaches by sites in expanding the impact beyond the node with regional and global implications. Moving forward, the GRI subcommittee will not only continue to share individual experiences and examples, but also consider specific initiatives and activities that can further improve network camaraderie and impact (e.g., staff exchanges, AI/ML short courses and implementation across regional networks, etc.).

Members: Vinayak Dravid (Northwestern), Yuhwa Lo (SDNI), Debbie Senesky (Stanford), Mariana Bertoni (Arizona State Univ.), Maria Huffman (Univ. of Washington), Kevin Walsh (Louisville), Steven Koester (MiNIC), Stephanie McCalla (Montana State Univ.), Karl Bohringer (University of Washington), Oliver Brand (SENIC)

5.4. Research and Funding Opportunities Subcommittee

In 2022, the NNCI subcommittee on research and funding opportunities met four times (February 24, March 17, June 16, and September 15), delivered a report to the NNCI Directors (June 8, 2022), and plans to continue quarterly meetings for 2023.

Continuing from 2021, the subcommittee has identified three opportunities that it continues to monitor and develop. These include:

1. New federal opportunities: The subcommittee has remained up-to-date on new federal opportunities, primarily connected to the CHIPS and Science Act. Particular attention is given to focus areas that could work synergistically with the NNCI network, including on core facilities and infrastructure, workforce training, and research areas including artificial intelligence and machine learning, high performance computing and semiconductors, quantum technology, robotics and automation, communications technology, biotechnology, materials sciences, 2D materials, et al. Specific programs that are being evaluated include:

- National Semiconductor Technology Center (NSTC): public-private consortium that will conduct research and prototyping of advanced semiconductor technology, support workforce-training programs, and maintain an investment fund to help startup companies commercialize new technologies.
- DOD: National Network for Microelectronics R&D: NSTXL Microelectronics Commons
- DOE: Four Microelectronics Science Research Centers
- DOE: “quantum network infrastructure R&D program” with a funding target of $100 million per year
- NSF mid-scale programs. The act recommends ramping up funding for NSF’s agency-wide Mid-scale Research Infrastructure programs to $180 million in fiscal year 2027.
- DOE mid-scale program: funding equipment costing between $1 million and $20 million

2. Industry relations: Industry has been identified as a potential partner to the NNCI network to enhance workforce training and ensure access to state-of-the-art instrumentation to maintain U.S. competitiveness. The goal is to facilitate deeper industry engagement with the NNCI network and

core facilities to foster a less transactional relationship and better engage industry in the success of NNCI. The primary activity in 2022 was:

- NNCI student conference and career fairs. The goal is a conference/career fair open to graduate students and post-docs at each of the NNCI sites. It serves both as a conference to showcase their research, and also as a career fair to facilitate interactions between industry and their future workforce. In 2022, the Cornell Nanoscale Science and Technology Facility (CNF) and Research Triangle Nanotechnology Network (RTNN) spearheaded the conference and career fair. The CNF event was a bespoke event bringing in partners across the NY region while the RTNN event partnered with a preexisting Triangle Student Research Competition. Details of the CNF event are provided below. The events will be repeated in 2023, and best practices shared with the NNCI network to assist other sites in bringing on board these events.
- On May 19, 2022 CNF hosted a mini-symposium and career fair drawing students from across the state ranging in location from Buffalo to New York City. The event was purposely small and was also set up on short notice (over 6 weeks). The occasion was the inaugural meeting of the NY State Nanofabrication Network (NNN). Speakers from industry included George Gifford (Global) and Gert Leusink (TEL) A short zoom presentation by Jon Cardinal (Economic Development Director for Senator Chuck Schumer) discussed topics such as the CHIPS Act. All students were asked to give posters. Extended talks (10 minutes) were given by 6 students selected from among the top abstracts. Other students were asked to give a speed talk (3 minutes) related to their poster. Breakfast and lunch as well as student awards were provided using funds gifted by industrial sponsors who participated in the career fair. In addition to those students giving talks and posters, a dozen students also came to meet with the industrial representatives located at tables located around the poster session. Overall, the event was a major success. A summary of our experience with this event is available on request.

3. Training grant opportunities: The NNCI network and core facilities present potential opportunities to disseminate new techniques and capabilities to a broad user base. The NSF Research Traineeship (NRT) program is a potential point of collaboration and partnership between several NNCI sites. A focus on artificial intelligence and machine learning (AI/ML) for the 2023 application is in discussion. This topic could train students in this important topic before starting a career, enable new capabilities in our NNCI cleanrooms and helping to form a bridge between different NNCI sites.

Members: Chris Ober (Cornell University), Jim Cahoon (UNC Chapel Hill), Shaya Fainman (UC San Diego), Bob Westervelt (Harvard University), Todd Hastings (Univ. Kentucky), Julia Aebersold (Univ. Louisville), Theresa Reineke (Univ. Minnesota), Mo Li (Univ. Washington), Yuri Suzuki (Stanford)

5.5. Nanotechnology Infrastructure of the Future

The "Future of NNCI" subcommittee was formed in 2021 and is currently chaired by Prof. Debbie Senesky of nano@stanford. This subcommittee is composed of 11 members which represent numerous NNCI sites. The core mission of this subcommittee is to provide insights that help shape the strategic planning for the future of nanotechnology infrastructure.

This year, the futures subcommittee held one meeting and gave a report out during the NNCI Director's Meeting in December 2022. The major focus of the subcommittee this year was to shape a strategy for future nanoinfrastructure frameworks in America. More specifically, we created a plan (draft agenda) for a workshop on the "*Future of Nanotechnology Infrastructure*." Pending support, we aim to host this workshop (hybrid) in the summer of 2023 and will discuss a wide range of topics as outlined below.

- NNCI Today: Strengths and Gaps
- The "Top 5" in Nanotechnology
- What are the Nanotechnology Research Communities?
- Designing the Regional Structure of Future Nanotechnology Infrastructure
- Lab-to-Fab Translation
- Workforce Development
- Expansion of Education and Outreach Programs
- Evaluation and Metrics

To gain input from the broader nanotechnology community, we plan to invite external (non-NNCI) stakeholders from academia, industry, and government. The planned outcome of the workshop is a report outlining recommendations for the next nanotechnology infrastructure based on the discussions (e.g., breakout) and presentations held at the workshop.

Our plans for the upcoming year include: plan and execute the "*Future of Nanotechnology Infrastructure"* workshop; assist in outlining and writing the workshop report; engage with members of academia, industry and government to identify actionable items that may shape the future of NNCI.

Members: Debbie Senesky (Stanford), Chris Ober (Cornell), Bob Westervelt (Harvard), Nan Jokerst (RTNN/Duke), Andrea Tao (UC San Diego/SDNI), Maria Huffman (Univ. of Washington), Shamus McNamara (Louisville), Steven Koester (MiNIC/UMN), Mary Tang (Stanford), David Dickensheets (Montana State Univ.), Oliver Brand (SENIC)

5.6. Building the User Base Subcommittee

The Building the User Base (BUB) subcommittee revisited the BUB stated goal of disseminating best practices for sites and NNCI as a whole to increase the user base, with an emphasis on non-traditional users. A non-traditional user may be defined based on: (1) Research areas that do not typically use nanotechnology facilities, (2) demographic groups - women and under-represented minorities, (3) users from non-R1 institutions, (4) small companies, and (5) students and teachers from K-12 and community colleges.

In 2021, the BUB subcommittee conducted a survey among NNCI sites to collect information specifically on the non-traditional user base, interactions with Research Communities, and user success stories (for use as a qualitative measure of success in addition to quantitative metrics). The results of the survey are as follows.

1. **Best strategy(ies) that has worked in attracting new users –** 1) word of mouth, 2) excellent service and networking through existing users and 3) robust, active, and targeted engagement with potential various user groups.

2. **Free/subsidized user access programs** have largely been effective in attracting new, first-time users. But in the case of returning users, it has been successful with industry users and with some non-traditional user groups, e.g., medical schools.
3. **Intentional engagement with Research Communities** (understanding their needs, priorities etc.) may be a potential avenue to attract new and diversity of users, primarily from non-traditional areas.
4. **Major non-traditional area(s) -** Biomedical sciences – medicine, biomedical devices, biotechnology, synthetic biology, pharmacology etc.
5. **Work with NNCI Metrics subcommittee** to broaden the definition of user and new user success metric that captures Impact**.**

In 2022, the BUB subcommittee discussed with the Metrics subcommittee about broadening the definition of "user" and user success metrics that capture impact. Both committees jointly discussed:

1. Can we broaden the definition of "user"? What are the other types of users, other than research users? Classes, courses, centers etc.
   a. Redefine who is a "user" and who is a "traditional user"
   b. E/O participants may be counted as users, particularly remote users, REUs, RETs, community college, students in lab classes
   c. Research/user training is a growth area with major emphasis going forward with CHIPS and Science Act – Recommended as separate category
   d. Discussed multiple classifications of users – research, training, educational, outreach, consultation etc.
2. Will it be useful to focus on Impact from success stories (center-level grants/SBIR, venture investments, jobs etc.); Are there other ways to showcase impact, diversity of users, interaction between sites etc.
   a. Combine powerful stories with data, namely SBIR contracts, successful spin out companies etc.; Economic impact data, if possible/available
   b. How to quantify level (as metric) of interactions between sites? – work further with Metrics subcommittee.

Members: Shyam Aravamudhan (SENIC, North Carolina A&T State University), Trevor Thornton (NCI-SW, Arizona State University), Todd Miller (NNI, Oregon State University), Sanjay Banerjee (TNF, University of Texas, Austin), Mark Allen (MANTH, University of Pennsylvania), Mitsu Murayama (NanoEarth, Virginia Tech), Lara Gamble (NNI, University of Washington), Andrew Cleland (SHyNE, University of Chicago)

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 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, (2) particular process technologies, such as lithography or characterization (although these are only examples of possible topic areas), and (3) education and outreach activity. Most of these working groups began in Year 1, while new ones were added in Years 2 and 3. 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 or as support for an NNCI Outstanding Staff Award. During 2021, leadership the working groups was examined, and some changes implemented, and all working groups were opened to new members from NNCI staff.

Table 8: NNCI Working Groups (2022)

Working Group Topic	Working Group Lead(s)
Network Support Working Groups	
Equipment Maintenance	Jeremy Clark (Cornell)
Vendor Relations	Charles Veith (Univ. Pennsylvania)
Environmental Health & Safety	Andrew Lingley (Montana State Univ.)
Technical Working Groups	
E-Beam Lithography	Devin Brown (Georgia Tech) Stanley Lin (Stanford)
Etch Processing	Vince Genova (Cornell)
Atomic Layer Deposition	Michelle Rincon (Stanford) Mac Hathaway (Harvard)
Photolithography	Pat Watson (Penn)
Imaging and Analysis	David Bell (Harvard)
Education and Outreach	
K-12 and Community	Jim Marti (Univ. Minnesota)

Workforce Development and Community Colleges	Andrew Lingley (Montana State Univ.)
Evaluation and Assessment	Jessica Hauer (NCI-SW)
Technical Content Development	Daniella Duran (Stanford) Eric Johnston (Penn)
4-H	Lynn Rathbun (Cornell)
Societal and Ethical Implications (SEI)	Jameson Wetmore (Arizona State)
Innovation and Entrepreneurship (I&E)	Matt Hull (Virginia Tech)

During NNCI Year 7, sites or groups of sites hosted seminars and technical workshops related to fabrication, research, or education topics (see Section 10.1). 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, although the pandemic has continued to restrict many meetings to virtual formats this past year. When travel is available, the Coordinating Office provides financial support (up to $1000 travel funding each for 5 attendees) to encourage staff participation. Recent events include:

- NNCI Etch Symposium, April 21-22, 2022 (Univ. of Pennsylvania)
- NNCI Advanced Lithography Symposium, July 15, 2022 (Stanford) [Lithography Working Group met on July 14]
- NNCI Education Symposium, Nov. 5-6, 2022 (UC San Diego)

<u>Received reports of current working groups, as provided by the leads, are presented below.</u> SEI and I&E activities are described within the Associate Director reports (Section 4).

6.1. Equipment Maintenance

Communication within the Equipment Maintenance working group has continued to occur primarily through email exchanges. The group's efforts remain focused on the collection and sharing of our tacit knowledge regarding the troubleshooting and maintenance of vacuum and RF process equipment. Most of this information continues to not be available directly from vendors and is often difficult to relay in public forums. Some of our discussions covered how we might better share and reference detailed information within the community.

Looking forward, we are hoping to create more opportunities to share our learnings with each other, particularly notes on alternative sourcing of OEM parts, pros and cons of software upgrades, as well as critical reviews of newer equipment companies.

Members: Jeremy Clark (Cornell), Mary Tang (Stanford), Bob Geil (UNC-Chapel Hill), Jesse James (UT-Austin), David Nguyen (UW), Tony Whipple (Univ. Minnesota), Patrick Driscoll (UCSD), Jeff Wu (UCSD), Ahdam Ali (UCSD), Sarice Jones (UW), Darick Baker (UW), Mark Brunson (UW), Steven Crawford (JSNN), Thomas Johnson-Averette (Georgia Tech).

6.2 Vendor Relations

In the past year the Vendor Relations working group has concentrated on maintaining a healthy, U.S.-based, vendor support organization. Suppliers that make up this organization have provided bids for lab material that reflect high quality, short lead times, and reasonable cost. These suppliers enthusiastically support academic nanotechnology research.

Successes include:

- a program to identify new vendors of expendable lab items, resulting in a 33% reduction in cost when compared with standard university processes of record. Members from one site member, MiNIC, have determined that 12% of the costs of a typical research lab are expendable items, so substantial savings may be realized through this exercise.
- an effort to identify local vendors of lab materials, thereby reducing environmental impact.
- This working group became aware, through its interactions with other universities and government labs, that electropolished stainless steel tubing (essential to the installation of new nanofabrication equipment) was in very short supply. By acting quickly, this group was able to find a vendor that could support much of our tubing needs.

In the future, the vendor relations working group will concentrate on the following areas:

- To continue to find new vendors who will assist us in supporting research at lower cost. (i.e., photomask manufacturing from Advanced Reproduction Corporation)
- Act as a point of contact for expanding partnerships between vendors, like last year's successful business agreement between the Transene Corporation and Zeon Chemicals, who together supply research-sized quantities of electron beam resists to academic centers in the U.S.

Members: All 16 NNCI sites are invited to inform, to lead efforts to lower supplies costs, and to build stronger relations with vendors in order to support NNCI Research. Working Group members come from the following sites: Harvard, Cornell, U. Penn, U. Louisville, Georgia Tech, Virginia Tech, UT-Austin, Arizona State U., UC-San Diego, Stanford, U. Washington, Montana State U., and U. Minnesota.

6.3. Environmental Health & Safety

The EHS working group met virtually twice in 2022. In September, we discussed the results of a COVID survey, which was sent in May 2022 as a follow-up to an initial COVID survey sent by Mary Tang of SNF and Ron Olson of CNF in May 2020. The updated survey asked about the status of COVID rules, policy changes, staffing, training, and compliance issues. There were 9 responses. All responses indicated that there were no major shutdowns after the March-June 2020 timeframe and that facilities no longer required health checks or health attestations. Some facilities still had restrictions in place, including some that will permanently require face masks in the cleanroom. As of May 2022, 5 facilities reported having a vaccination requirement for entry, and 4 did not. Almost everyone reported effectively using videos to improve their training and that they intend to continue to use these tools. Also, several individuals reported that telework and hybrid policies were effective, and one reported that COVID allowed time to expand their YouTube footprint.

Next, the EH&S group is continuing to explore an NNCI-wide, shared document for recording and anonymously disseminating safety incidents in NNCI facilities. Our list currently has 7 incidents. We have removed dates and identifying information but are still discussing how best to summarize and distribute the list. This list is not intended to provide detailed corrective actions but instead to help reinforce safety training, improve compliance, and prevent future incidents. Additionally, in collecting these incidents, our group has found the primary utility to be kick-starting discussions. For example, when discussing a chemical spill, we learned that there are at least three different ways NNCI labs handle cleanroom pressure when responding to a gas detection incident. We also discussed gas detection for equipment like PECVD and LPCVD tools and how these systems may miss potential inhalation risks due to chemical spills outside of fume hoods.

Another major advance for our group is developing a formal relationship with SESHA (sesha.org), the premier EH&S association dealing with semiconductor and high-tech safety. In our December meeting, Troy McCuskey and Jay McCroskey from SESHA joined us to relay the mission and goals of SESHA and to discuss options for collaboration. SESHA provides comprehensive online training, free webinars, and has an annual symposium where attendees go through a semiconductor safety bootcamp. Troy intends to join our future EH&S Group meetings as a technical expert.

Finally, our group has discussed RF safety, sound mitigation strategies for pumps, metal-ion-containing developers as alternatives to more dangerous metal-ion-free developers (experiments are underway), TMAH inhalation risks in unexpected situations, molecular beam epitaxy and related safety and contamination issues, safety showers and modesty concerns, and chemical gloves with clever solutions to wafer handling issues.

Members:

Name	**Affiliation**
Andrew Lingley	MONT (Mont. State U.)
Nasir Basit	SHyNE (Northwestern)
Mahdi Fahim	SENIC (JSNN)
Hang Chen	SENIC (Georgia Tech)
Philip Infante	CNF (Cornell)
Shane Patrick	NNI (UW)
Mark Walters	RTNN (Duke)
Philip Barletta	RTNN (NCSU)
Darick Baker	NNI (UW)
Mary Tang	nano@stanford (Stanford)
Grant Shao	nano@stanford (Stanford)
Brian Olmstead	MiNIC (U. Minnesota)
Julia Aebersold	KY Multiscale (U. Louisville)

6.4. E-Beam Lithography

We are an active working group that aims to host at least two meetings per year. With the return to normalized operations and business resumed in all our NNCI sites, we moved to hosting one online meeting this year. However, we were able to garner interest for an in-person meeting next year, a survey was sent out to members, and plans are currently being discussed for when and where for a site location. One major consideration is whether we should tack on an NNCI EBL working group meeting to an existing event, or if this should be a separate meeting. The pros and cons of attaching the meeting to a longer conference may cause members to be overly tired and not be engaged for another day away from home.

Our first meeting this past year was on May 26, 2022 with 11 tool owners in attendance. Each member in attendance provided highlights of new tools or new research. The overall feeling is that EBL is getting an uptick in interest by users in all locations. Two NNCI facilities, Duke and NC State, are reporting hiring new professors that are using EBL in their research. Therefore, some smaller NNCI facilities like NC State and Univ. Nebraska-Lincoln are looking for funding to upgrade their existing EBL capabilities. Some larger institutions, such as Stanford and Univ. Pennsylvania, have already moved to upgrade EBL tools. Many of these upgrades are necessary as current tools in service are a decade or more old and seeing hardware failures.

Another discussion point was the effectiveness of remote servicing of the EBL tools as there is a fast response time from field service engineers to log in remotely as opposed to having to fly to the location. EBL staff on-site can use video conferencing to be the hands-and-feet of the remote service engineers.

We also updated the membership noting those that resigned from their sites and their replacements.

We also encouraged any of our members to consider serving as a co-chair. Devin will continue to serve until someone takes up the mantle. This has shown to be a great responsibility that site management likes to see as it provides the sites with great NNCI visibility. This also helps with personal career growth.

Overall, our EBL working group had a successful year with one meeting and fruitful discussions with a bright outlook on EBL research and support each NNCI site has to offer. We anticipate the network's growing capabilities as newer state-of-the-art equipment become available within our facilities. Our working group is well attended with 14 sites, and everyone willingly participated in discussions.

Members:

NNCI Site	Institution	Tool Owner
SENIC	Georgia Tech	Devin Brown
	JSNN (NCAT/UNCG)	Steven Crawford
RTNN	NC State	Greg Allion Backup: Saroj Dangi
	Duke	Talmage Tyler Backup: Jay Dalton
	UNC Chapel Hill	Amar Kumbhar Bob Geil

MANTH	U. Penn	David Jones Hiro Yamamoto Sam Azadi
CNS	Harvard	Yuan Lu Backup: Jiangdong Deng
CNF	Cornell	Alan R. Bleier Roberto Panepucci Giovanni Sartorello
KY MMNIN	Univ of Kentucky	Brian Wajdyk
SHYNE	Univ of Chicago	Peter Duda
MiNIC	Univ. of Minnesota	Kevin Roberts
NNF	Univ of Nebraska-Lincoln	Anandakumar Sarella
TNF	UT Austin	Bill Ostler
NCI-SW	Arizona State Univ	Kevin Nordquist
SDNI	UC San Diego	Maribel Montero Backup: John Tamelier
nano@stanford	Stanford (SNSF Spilker)	Rich Tiberio Stanley Lin Grant Shao
NNI	Univ. of Washington	Brant Hempel

6.5. Etch Processing

The objective of the Etch Working Group is to provide an interactive forum for 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/technologies. 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. An updated (December 2021) NNCI Dry Etch Capabilities listing has been uploaded to the NNCI website (https://nnci.net/node/5514). This listing identifies each site's dry etch based equipment. In addition to the above referenced tool set listing, we have composed and updated (December 2021) the listing of common and various NNCI plasma etch technologies among the network sites and specific platforms that support those processes. This document of supported processes will also assist users who seek etch process capabilities when requirements cannot be satisfied at a specific university fab and which need to be fulfilled on a specific etch platform.

The 2022 NNCI Etch Symposium, **Advances in Micro- and Nanoscale Etching for Novel Electronic, Photonic, and Quantum Based Device,** was held on April 21-22 at the University of Pennsylvania and hosted by the Singh Center for Nanotechnology. Due to overwhelming interest, the symposium offered a hybrid format so that those who couldn't attend in person could do so virtually. The NNCI encourages these network-wide events to bring together technical experts within a specific fabrication area. A principal objective of this symposium was to bring together etch professionals in an interactive forum where collective knowledge on etch processes and their application to state-of-the-art devices can be shared.

Day 1 featured talks by NNCI sites on the status of their etch equipment, including any new acquisitions and newly developed processes. In addition, Day 1 featured technical presentations and exhibits by etch equipment vendors including Oxford Instruments, Plasmatherm, and SPTS, highlighting etch capabilities for electronic, photonic, and quantum devices. These specifically included:

- Russ Renzas (Oxford Instruments) – "Atomic Layer Etching for Low Loss Quantum Devices"
- David Lishan (Plasmatherm) – "Low Temperature Plasma Technology for Advanced Packaging Applications"
- Josh Perlstein (SPTS) – "Endpoint Detection for Plasma Etching"

Day 2 featured invited and contributed talks by scientists from academic and corporate labs including:

- Tony Zhou (MIT) – "Quantum Applications Build on Creative Nanofabrication"
- Troy Olsson (Penn) – "Etching of AlScN Materials"
- Ben Davaji (Northeastern) – "Role of Artificial Intelligence in Nanofabrication"
- Rebecca Cheng (Harvard) – "Lithium Niobate Nanophotonic Platform for Non-linear and Quantum Optics"
- Daniil Luken (Stanford) – "Quantum and Non-linear Photonics in SiC"
- Christian Reimer (Hyperlight Corp.) – "Faster and Lower Power Solutions via Thin Film Lithium Niobate"
- Sid Ghosh (Northeastern University) – "Photonic Waveguides and Acousto-optic Devices on AlN"
- Lidan Zhang (Penn State) – "Fabrication of Silicon, Silicon Nitride, and InGaP Optical Metasurfaces with Dry Etching"
- Demis John (UC Santa Barbara) – "Ruthenium Hard-masked Silicon Dioxide Etching"
- Matteo Rinaldi (Northeastern) – "Applications of AlN and AlScN Devices"

The symposium had more than 60 on-site attendees from academic and corporate sites. The academic attendees came from sites within and outside of NNCI. The participating NNCI sites included Cornell, Harvard, Stanford, Minnesota, Georgia Tech, University of North Carolina, UC-San Diego, Penn, Nebraska, U-Chicago, and Washington. Non-NNCI institutions included Princeton, MIT, UC-Santa Barbara, Yale, Purdue, Michigan, Penn State, and Northeastern.

Special thanks to the vendors for their sponsorships at the gold, silver, and bronze levels, making the event possible, including: Oxford Instruments, Plasmatherm, SPTS(KLA), Samco, TedPella, and RFVII. The symposium was organized by Vince Genova (Cornell), Ling Xie (Harvard), Eric Johnston (Penn), and Jason Tower (Stanford).

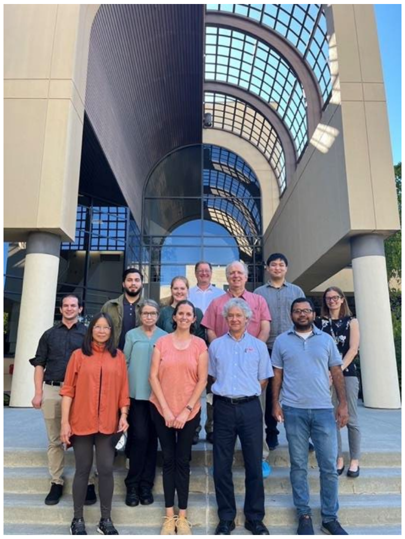
The current communication paths for the etch working group include a LinkedIn-NNCI Etch Group and an NNCI Etch listserv, where etch questions can be posed to the NNCI etch technical staff. There is also an Etch Working Group page on the NNCI website (https://www.nnci.net/working-groups). This page contains 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, in addition to the NNCI etch tool and capabilities listings.

Members:

Cornell University (V. Genova, T. Pennell, J. Clark, G. McMurdy)
Harvard University (L. Xie, K. Huang)
Stanford University (J. Tower, L. Mandyam)
Georgia Institute of Technology (T. Averette, H. Chen, M. Thomas, T-V. Nguyen, A. Gallmon, D. Gajula)
University of North Carolina (B. Geil), UNC Greensboro (Q. Dirar)
University of Louisville (E. Moiseeva, J. Beharic)
University of Minnesota (T. Whipple, P. Kimani)
University of Nebraska (J. John)
University of Pennsylvania (E. Johnston, H. Yamamoto, S. Azadi)
University of Texas-Austin (J. James,)
University of Washington (M. Morgan, M. Brunson)
Arizona State University (S. Ageno, S. Myhajlenko)
UC San Diego (X. Lu,)
Montana State University (J. Heinemann)
Virginia Tech (D. Leber, M. Hollingsworth)
University of Chicago (P. Duda, S. Kaehler)

6.6. Photolithography

The NNCI Photolithography Working Group is composed of representatives from 12 institutions (from 10 NNCI sites and UC-Berkeley). Our mission is to share photolithographic techniques, processes, and experiences with members and with the larger research community.



In 2022 we returned to an in-person annual meeting. Stanford University hosted the event on July 14, coinciding with SEMICON which began earlier in the week and the Advanced Lithography Symposium held at Stanford on July 15. The 14 attendees came from Washington, Stanford, UC-Berkeley, Minnesota, Cornell, and Penn. Four of the attendees are new members of our community.

We chose topics of interest and planned for the in-person meeting via email. As in previous years, the morning session was dedicated to presentations by a representative from each site; we described our capabilities and outlined a particular lithography problem that was encountered. In the afternoon, discussions were held that included lessons learned in obtaining lithography materials when confronted with supply chain and other problems, sharing capabilities, and precision alignment capabilities of direct write tools. The full schedule is shown below.

NNCI Photolithography Working Group Meeting Agenda			
8:30 AM	0h 30m	Coffee	Courtesy of Stanford!
9:00 AM	0h 30m	Introduction	
9:30 AM	0h 15m	Cornell	
9:45 AM	0h 15m	Washington	
10:00 AM	0h 15m	Minnesota	
10:15 AM	0h 15m	Stanford	
10:30 AM	0h 15m	Break	
10:45 AM	0h 15m	UCB	
11:00 AM	0h 15m	Penn	
11:15 AM	1h 0m	Presentations and Discussion - Materials for Lithography (in Trying Times)	Presentations from UCB, Cornell, Penn.
12:15 PM	1h 30m	Lunch	Courtesy of Stanford!
1:45 PM	0h 30m	Presentations and Discussion - Sharing Capabilities	mix and match between sites, training materials, CHIPS Act funding opportunities
2:15 PM	0h 30m	Presentations and Discussion - Experience with Optical Direct Writers and Projection Tools	Alignment capabilities and comparison with steppers? mix and match tools?
2:45 PM	1h 30m	Cleanroom Tour, Nano@Stanford Facility	
4:15 PM	0h 15m	Wrap up, Action Items	
4:30 PM	2h 0m	Adjourn - Happy Hour and Light Dinner	Thanks to Vendors

Stanford organized an in-lab tour of their direct-write and other lithography tools to complement the discussions in the afternoon. Stanford also described their investigation into operating in a non-cleanroom environment using benchtop clean spaces.

Some travel expenses for the participants were paid for by funds from the coordinating office. Meals were provided by Stanford University and some of the vendors who presented at the Direct-Write Symposium the next day.

Members:

Harvard Univ.	Guixiong Zhong
	Christine Yi-Ju Wang
Stanford Univ.	Grant Shao
	Shivakumar Bhaskaran
	Swaroop Kommera
	Phil Himmer
	Mahnaz Mansourpour
	Mary Tang
	Rich Tiberio
	Stanley Lin
	Cliff Knollenberg
	Sara Gillian Ostrowski
UC San Diego	John Tamelier
	Xuekun Lu
	Shu Xiang
Univ. Louisville	Curtis McKenna
Georgia Tech	Tran-Vinh Nguyen
Cornell Univ.	Garry Bordonaro
Univ. of Nebraska	Jiong Hua
Univ. of Minnesota	Paul Kimani
	Kevin Roberts
	Mark Fisher
	Laura Parmeter
	Emma Jory
Univ. of Pennsylvania	Gyuseok (Q) Kim
	Eric Johnston
	David Jones
	Pat Watson
	David Barth
Univ. of Washington	Brant Hempel
	Sarice Jones

	Jean Nielsen
UC-Berkeley	Allison Dove
Univ. of Kentucky	Brian Wajdyk

6.7. K-12 Teachers/RET, Students, and Community Outreach

The K-12 Teachers/RET, Students, and Community Outreach working group (hereafter, "K12") did not meet regularly over the past year. In early 2022, Jim Marti stepped down from the K12 working group leadership after six years. Marti worked with NNCI Education Director Quinn Spadola to recruit a new K12 group leader, but no one stepped forward before Dr. Spadola herself left the NNCI in late summer 2022. Thus, the K12 working group is presently in need of new leadership. It is hoped that this person can be recruited from among the several new education coordinators that have recently joined the group

The K12 working group began the year by attempting to redefine its role and mission within NNCI. A reorganizational meeting was held in late fall of 2021 to consider a new or retooled mission for the group. During this reorganizational meeting, members suggested several areas that the group could choose to focus on in the coming year. Among these areas were:

1. Ensuring that the great catalog of nano education materials generated by NNCI (and NNIN) are more convenient and useable for teachers and can be more easily integrated into existing STEM curricula.
2. Targeting our curricular materials and support efforts to K-12 teachers, rather than students.
3. Using our experiences developing remote classes during the pandemic lockdown to expand remote learning resources, virtual tours, etc.
4. Focusing on teacher professional development to expand knowledge of nanoscience and technology.

Working group members generated several specific efforts that may be undertaken by the K12 group in the coming year. Among them:

1. Make our library of nanotech lessons more useful by organizing them by national and state science standards, and by designing them to be smaller and more modular so they can be incorporated into existing classes.
2. Make our education products more scalable by making them more virtual. Examples include live virtual tours of labs and facilities, recording NanoSIMST teacher training sessions for use in teacher professional development, training other teachers to carry out NanoSIMST or similar teacher training programs, and exploiting the RAIN network for more remote learning experiences.

It is hoped that these ideas may provide the new working group leadership with a list of potential new initiatives to pursue.

Members:
Dan Ratner, University of Washington (NNI)
David Mogk, Montana State University (MONT)

Yves Theriault, University of California San Diego (SDNI)
Sheryl Singerling, Virgina Tech (NanoEarth)
Phillip Strader, North Carolina State University (RTNN)
Daniella Duran, Stanford University (nano@stanford)
Jim Marti, University of Minnesota (MiNIC)

6.8. Workforce Development and Community Colleges

The Workforce Development and Community Colleges working group met virtually twice in 2022. To kick off a discussion, we used the American Semiconductor Academy's Vision Paper and the key challenges it identified for addressing workforce readiness: 1) an invisible industry, 2) costly/inconsistent training, 3) industry academic silos, 4) dated curriculum, 5) pipeline inequality, and 6) talent retention.

To address the issue of an invisible industry, we discussed outreach to undergraduate-level engineers and scientists. For an initial attempt, MONT facilities gave short lectures to electrical and chemical engineering students in 100-level introductory courses, totaling about 70 students. These lectures were given with a portable, glass-walled tabletop sputter tool and were followed by cleanroom tours for over 30 interested students.

To address the issue of industry/academic silos, most working group participants said one of their major goals was to find tangible ways to increase engagement with industrial partners. One solution we discussed was having industry-sponsored employment in NNCI Core Facilities. Several sites are in discussions with industrial partners to help pay students to work while they attend classes. We also participated in the MNT-EC Business Industry Leadership Team (BILT) by helping to recruit several new companies. Cait Cramer from MNT joined to talk about the BILT, which helps define and refine KSAs primarily for microsystems fabrication and process technicians. She emphasized that employability skills are always the highest on the list of attributes that the BILT advocates.

To address 2), 5), and 6) above, we discussed various ways that NNCI sites employ students from four-year institutions and community colleges. For example, Daniella Duran from Stanford described their multi-year internship program. The students are hired as a cohort and work together to increase cohesion and community, as demonstrated in their Instagram account. This program is a win-win for the facilities and the students. Interns work directly with staff, who train them on tools and processes. The internship duration is substantial and is paid to increase competitiveness and to increase the value to the students and staff. Learn-to-earn models create a more equitable environment, and the flexibility of the work allows students to manage their schedules effectively during the academic year. We also intend to send a survey in 2023 to determine how many students the NNCI employs in different categories, including short-term internships (<3 months), longer-term internships (>3 months to 1 year), and long-term employment (> 1 year). This survey will ask what management strategies each facility employs to develop technical and professional skills and thus improve retention. It will ask about on-boarding procedures, meeting types and frequency (e.g. staff meetings vs one-on-one meetings), feedback strategies, and professional development plans. Regarding utility to the facilities, we also will ask what types of work student employees are given, ranging from menial tasks to operations, accounting, ordering, simple maintenance, process development, or complex equipment troubleshooting.

Similarly, the Evaluation and Assessment working group sent out a survey for the second year about non-REU undergraduate internship programs. The participation was low, so the Workforce group discussed options for increasing participation next year. We discussed having more personal follow-ups from mentors, using follow-up phone calls in addition to emails, doing surveys at staff meetings, ensuring up-to-date emails are used, and potentially having a raffle with a small prize for a lucky student worker. We also discussed using LinkedIn groups to track former interns and employees.

Members:

Andrew Lingley (MONT)
Maude Cuchiara, Phillip Strader (RTNN)
Kristin Field (MANTH)
Dave Mogk (MONT)
Tonya Pruitt (NanoEarth)
Allison Weavil (SENIC)
Julia Aebersold (KY Multiscale)
Tom Pennell (CNF)
Trevor Thornton (NCI-SW)
Daniella Duran (nano@stanford)
Micah Glaz, Dan Ratner (NNI)
Steven Wignall (NNF)
Sylvianne Velasquez (NanoEarth)

6.9. Evaluation and Assessment

Beginning in Year 6, the NNCI Workforce Development and Community Colleges working group collaborated with the Evaluation and Assessment working group to create and distribute Workforce Development Surveys for non-REU related undergraduate internship programs, ie, student workers, mentees, empower scholars, and interns. Surveys were also sent to industry mentors affiliated with the NNCI site and facility labs. The objectives of these Workforce Development Surveys were to evaluate the interns' performance and seek recommendations on how the sites can better prepare their students through separate online surveys sent to both the interns and their mentors/supervisors, respectively. Arizona State University's College Research and Evaluation Services Team (CREST) assisted the working groups with developing, distributing, and analyzing surveys.

For Year 7, the working groups have repeated this process, again relying on support from CREST. Surveys were gathered May-July of 2022. CREST evaluated responses from the 2021-22 NNCI student workers, mentees, empower scholars, interns, and industry mentors, as well as follow-up survey responses from the 2020-21 cohort of student workers, mentees, empower scholars, and interns.

- CREST reached 106 students from the 2020-21 student list. Of these students, 18 started the survey, and 17 completed at least some part of the survey, for a response rate of 16%.
- The list of the 2021-22 industry mentors provided to CREST contained contact information for 49 individuals. Of these, 24 completed at least some questions on the survey for a response rate of 49%. Of the respondents, 96% of mentors identified as being faculty/staff, and 1 respondent identified as a graduate student.
- A third survey was sent in July 2022 to a list of 135 previous student workers from the 2020-21 cohort. Of the 135, 14 completed at least some portion of the survey for a response rate of 10%.

Due to low response rates, these data cannot be broken down by NNCI sites without potentially compromising anonymity. The Evaluation and Assessment working group reviewed the full survey results. Our goal for Year 8 is to improve response rates of these workforce development surveys so that we can analyze and share impact results with each NNCI site for Year 8. We also aim not to overburden students with different surveys asking for the same information. Our committee will try to improve survey response rates by:

- Working with the Education and Outreach coordinators to help gather personal emails and contact information of student workers, mentees, empower scholars, and interns at the end of each semester.
- Communicating and planning the dates of survey distribution to align with the availability of NNCI staff to make personal contact with students in the form of emails, texts, phone calls, and in-person conversations to encourage and remind students of the value of the surveys to our programs.
- Developing awareness of the importance and impact of student input on program development. This can be accomplished in many ways, such as by hosting in-person presentations as a 'lunch and learn' to inform the importance of evaluation.
- Using site-based social media accounts to create collaborative spaces and encourage new NNCI students to join the space, for example a LinkedIn group. Staff can then send notices and reminders of the survey to the group.

Members: Jessica Hauer (NCI-SW), Carolyn Plumb (MONT), Sylvianne Velasquez (NanoEarth), Tonya Pruitt (NanoEarth), Ana Sanchez Galiano (KY Multiscale), Wendy Barnard (NCI-SW), Dan Ratner (NNI)

6.10. Technical Content Development

The Technical Content Development working group has a goal of developing and sharing educational materials to support existing users, potential users, and non-traditional users in order to lower the barriers to entry in our facilities and improve foundational knowledge.

In the previous year, the working group solicited the NNCI member institutions for training resources on tools, as well as outreach and educational content. This was compiled into a spreadsheet that was added to the NNCI Technical Resources webpage including links. There are currently 250 entries that cover the following topics:

Analysis
Deposition
Etch
Safety and Orientation
Lithography
Metrology
Microscopy
Oxidation
Wet Bench Processing
Sample Prep
Software
X-Ray

In an effort to make this spreadsheet more useful, the committee sent out a questionnaire to the NNCI sites asking whether the NNCI Technical Resource page is being used and which learning media are preferred. The results indicate that:

- The current spreadsheet form of the resource page is extensive but challenging to use.

- There is potential to provide a useful resource if it is more accessible and easier to navigate.
- Step-by-step and video are the preferred formats.

While the Technical Content working group plans to continue expanding training resources, the committee intends to focus on putting the preferred formats (step-by-step and video) on a more easily accessible platform, which has yet to be determined.

Members: Daniella Duran (Stanford), Eric Johnston (Univ. of Pennsylvania), Phillip Strader (RTNN), Kathyrn Dean (SHyNE), Tom Pennell (Cornell), Mac McMurdy (Cornell)

7. Research Communities

Research Communities are groups of faculty, students, and staff from NNCI sites organized around a particular research topic, national priority, or grand challenge, many of them based on NSF 10 Big Ideas. In contrast to NNCI working groups which are focused on a particular tool or process with the objectives of sharing best practices, the Research Communities are more outward facing helping to develop products that benefit the larger scientific and engineering communities. The current Research Communities are shown in Table 9 along with the lead and participating sites. In 2022, a new community focused on Microelectronics and Semiconductors was added, as a partial response to increasing national interest in this area. The Research Communities provided an overview of their past and planned activities at the 2022 NNCI Annual Conference, and these can be viewed along with other resources on the Research Community page of the NNCI website.

Table 9: NNCI Research Communities

Research Community	Leader(s)
Nanotechnology Convergence	Jacob Jones (RTNN)
Nanoscience in the Earth and Environmental Sciences	Trevor Thornton (NCI-SW), Mitsu Murayama (NanoEarth), David Mogk (MONT)
Nano-Enabled Internet-of-Things	Mark Allen (MANTH)
TransformQuantum	Andrew Cleland (SHyNE), Robert Westervelt (CNS), Steven Koester (MiNIC)
Understanding the Rules of Life	Vinayak Dravid (SHyNE)
Microelectronics and Semiconductors	Sanjay Banerjee (TNF), Philip Wong (nano@stanford), Trevor Thornton (NCI-SW), Shyam Aravamudhan (SENIC)

Activities of the communities may include:

- NNCI-sponsored symposia/workshops/webinars
- Road-mapping exercises
- Identifying future infrastructure needs

These groups will address questions such as (a) What infrastructure capabilities are needed to support the research topic? (b) What are the challenges of current fabrication infrastructure for the specific research area? In addition, they can provide opportunities for networking among faculty and students working on similar themes. They also can be used to convey information about tools, capabilities, and expertise within the wider NNCI network to researchers who may not typically look outside their own local site or who are not part of an NNCI institution.

Each Research Community provided a summary of past activities and future plans for this report.

7.1. Nanotechnology Convergence

The NNCI Research Community for Nanotechnology Convergence is a collaboration between the RTNN, SDNI, KY, and NCI-SW sites. Major individual contributors in 2022 included: Jacob Jones (RTNN), David Berube (RTNN), Maude Cuchiara (RTNN), Trevor Thornton (NCI-SW), Kevin Walsh (KY Multiscale), Ana Sanchez Galiano (KY Multiscale), Phillip Strader (RTNN), Anne Njathi (RTNN), Yuhwa Lo (SDNI), Yves Theriault (SDNI), and Elaine Hubal (EPA, NNCI External Advisory Board member).

In 2018, NSF announced their **10 Big Ideas**, one of which is Growing Convergence Research. NSF said this about Growing Convergence Research: "*The grand challenges of today -- protecting human health; understanding the food, energy, water nexus; exploring the universe at all scales -- will not be solved by one discipline alone. They require convergence: the merging of ideas, approaches and technologies from widely diverse fields of knowledge to stimulate innovation and discovery.*" [1]

The NSF-accepted definition of convergence research is that it fulfills two primary criteria [2]:

1. The research is driven by a specific and compelling problem, and
2. It involves deep integration across disciplines, often involving the integration of theories, methods, data, and research communities and the creation of new frameworks or paradigms.

Growing Convergence Research is a process-oriented Big Idea. It involves *how* the research is conducted, not necessarily the vehicle of the research. In Convergence Research, researchers who are intellectually diverse come together and develop effective transdisciplinary communication methods and create common frameworks or new scientific languages in the pursuit of highly complex or vexing problems, ideally problems of which are of great societal significance. Historical examples of disciplinary convergence can be found, e.g., in bioinformatics, bioengineering, and nanotechnology. It is important to note that the concept of Convergence Research extends beyond the converging of disciplines to include, e.g., the convergence of stakeholders, economic sectors, different categories of educational institutions, and the public-private sectors.

While many researchers work in convergent fields today, e.g. nanotechnology and bioengineering, the process of converging has not been widely studied. Therefore, there isn't a lot known about best practices for converging disciplines or convergence research. In a recent report [3], for example, this was emphasized by saying "*…given the newness of the Convergence Research literature, most of our references are to the antecedents of Convergence Research*." Nevertheless, the opportunities that Convergence Research presents, particularly in addressing high complex and societally-relevant problems, outweigh the dearth of insight into how to pursue it.

In the area of nanotechnology, Roco and Bainbridge [4] reinforce the idea of a convergence-divergence cycle. At the beginning of convergence for nanotechnology, the disciplines, materials, sectors, tools, and methods came together in an effort to control matter at the nanoscale, a phase that lasted decades. After four nanotechnology generations, they evidence divergence by spin-off disciplines, new business models, new products and applications, and new expertise and decision making.

The premise of the **Research Community for Nanotechnology Convergence** is that nanotechnology facilities of the future will play central roles in tackling wicked [5] and global challenges that require convergence approaches and, in many cases, facilities may require major adaptation to facilitate convergence. This can occur, for example, at the interface of nanotechnology with agriculture, health, or advanced manufacturing.

The Research Community goal is to bring together researchers and staff from diverse disciplines and perspectives, facilitate their collaboration, and work toward a common vision and public report for the future design and role of university open-access facilities in specific research areas. To phrase this more informally, the Research Community seeks to answer the question, "*How do we use our Nanotechnology Infrastructure, currently supported by the NNCI, to converge and advance research on complex and compelling problems?*"

A specific Research Community topic around nanotechnology convergence is selected for each year, enabling the Research Community to be dynamic and respond to emerging opportunities.

The 2021 topic was **Convergence in Nanotechnology for Food and Nutrition Security**. A major activity in 2021 involved an event designed to bring stakeholders together and learn more about research community needs. The event, held March 9, attracted ~150 registrants and >100 participants who were from academia, industry, government agencies, NGOs, consortia, policy fellows, etc. The team had IRB approval to record transcripts of the break-out rooms for purposes of conducting research. A social science team led by David Berube has completed analysis of all content from the meeting and conducted additional follow-up interviews with experts. The material is being integrated to produce an article on convergent needs in Agriculture-Nanotechnology areas. The authors will include students and is scheduled for publication in 2023.

The 2022 topic was **Convergence in Nanotechnology and Additive Manufacturing**. Convergence in this area was discussed at a National Academies Workshop and perspectives were published in a 2022 NAE Workshop Proceedings report [6]. Some needs identified in the report include integration of nanoscale additive manufacturing into larger-scale additive manufacturing, the development of in situ diagnostics, updates to our paradigm for education to a 'convergent education model,' and offering cross-training opportunities for students e.g. through bootcamps. A major activity in 2022 was the NSF NNCI Nano+Additive Manufacturing Summit held on August 9-10, hosted by KY Multiscale and contributed by many additional sites. This 2-day conference attracted over 260 participants from across the US and brought together a diverse group of micro/nanotechnologists and additive manufacturing researchers from academia, industry, and government. Keynote presentations were given by 5 nationally-renown speakers, at least three of which pushed the boundaries of convergence, e.g., through topics on neural interfaces, entrepreneurship, and additive manufacturing for the medical field. The Summit was hosted jointly with the annual NSF NNCI REU Convocation, which added 60 top undergraduates from leading universities all over the country, integrating education and workforce development into the meeting, consistent with the recommendations from the NAE report [6]. The Summit also contained 38 Technical Presentations in 2 parallel sessions,

113 Research Posters, 20 Vendors and Sponsors, an engaging Career Panel session, tours of the UofL micro/nano/additive core facilities, and several networking opportunities. In the feedback to survey questions after the meeting, it was noted that 19 self-identified disciplines of respondents included bioengineering, computer science, organic materials, and safety and health, which could be considered non-traditional areas in additive manufacturing. Moreover, many respondents self-reported "Additive Manufacturing" as their discipline, which may be an early indicator of convergence during which Roco and Bainbridge [4] state that the disciplines, materials, sectors, tools, and methods come together, e.g. as we saw many decades ago for nanotechnology.

The 2023 topic of the Research Community is **Convergence in Nanotechnology for Addressing Climate Change**. The topic is inspired and informed by the NSF Engineering Research Visioning Alliance (ERVA) report, "The Role of Engineering to Address Climate Change" [7] and the National Nanotechnology Initiative (NNI) Nano4EARTH Challenge [8]. The initial activity planned for 2023 is a virtual community event aimed at identifying and building consensus on the key R&D needs and opportunities to help address climate change using nanotechnology. The event, to be held Feb. 21 from 1:00-3:00 PM Eastern Time is titled, "Help Identify Critical Nanotechnology Opportunities for Addressing Climate Change!" This virtual community event targeting the basic science, fundamental research, and convergence needs is being held a few weeks after the complementary commercialization-focused Nano4EARTH Kick-off Workshop in Washington, DC. Attendees will meet in small groups to provide important stakeholder perspectives on a variety of specific questions. Discussion topics are broken down according to the categorization in the ERVA report and include nanotechnology for: i) energy storage, transmission, and critical materials, ii) greenhouse gas capture and elimination, iii) resilient, energy-efficient, and healthful infrastructure, and iv) water, ecosystems, and geoengineering assessment. Event information can be found here: https://www.rtnn.ncsu.edu/nano-climate-change/.

References:

[1] https://www.nsf.gov/news/special_reports/big_ideas/convergent.jsp
[2] https://www.nsf.gov/od/oia/convergence/index.jsp
[3] Frechtling, Gajaray, Schnell, Desai, Silverstein, Misra, and Wells, "Exploring Convergence Research: An Initial Examination of What it Means and What it Hopes to Accomplish," Westat - Clarivate, April 30, 2021.
[4] Roco and Bainbridge, J. Nanoparticle Research, 15, 1946 (2013)

[5] Head, B. "Wicked problems in public policy," Public Policy 3, 101–118 (2008)
[6] National Academies of Sciences, Engineering, and Medicine. 2022. Convergent Manufacturing: A Future of Additive, Subtractive, and Transformative Manufacturing: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/26524
[7] https://www.ervacommunity.org/visioning-report/visioning-event-report/
[8] https://www.nano.gov/nano4EARTH

7.2. Nanoscience in the Earth and Environmental Sciences

The second **Nanoscience in the Earth and Environmental Sciences Research Community** (Nano EES-RC) workshop was convened May 16-18, 2022 (virtual, hosted by NanoEarth). Lead institutions for this event were: NanoEarth (Tonya Pruitt, Mitsu Murayama), MONT (David Mogk, David Dickensheets), NCI-SW (Paul Westerhoff, Trevor Thornton), Nano@Stanford (Kate Maher). The Science Education Resource Center at Carleton College (Monica Bruckner), a MONT partner, provided tremendous logistic and data collection support.

The 2022 Nano EES-RC workshop was targeted towards researchers in non-traditional fields in nanoscience and nanotechnology including environmental, agricultural, water, and geosciences. The workshop content was designed at a level that would be accessible to both nano-novices and those with significant prior experience. Following up with the successful 2021 workshop, and the continuing unpredictable epidemic situation, the 2022 workshop was also offered in virtual format, and programed by two NanoEarth core faculty member geoscientists, Marc Michel and Madeline Schreiber, as well as NanoEarth instrument specialist, Dr. Sheri Singerling. The workshop activities were built around two case studies. Day 1 focused on sediment samples containing iron (Fe) and manganese (Mn) nanominerals that were collected from a local reservoir system. Day 2 focused on nanoscale mineralogical features in a meteorite. The goal for both case studies was to show the participants how these samples are prepared for different types of imaging, spectroscopic, and scattering methods, how data are collected, analyzed, and interpreted, and how the findings can be integrated together. A unique aspect of the workshop that resonated with multiple participants based on feedback was the field sampling demonstration that included using suspended sediment traps and a coring apparatus in the reservoir. The workshop content was delivered via live presentations and panel discussions with Q&A, and pre-recorded talks and instrument demonstrations. We felt that this format was more suitable for participants that may have limited background in nanoscience and nanotechnology and know relatively little about the tools and what they can offer. We would like to acknowledge Dr. Lowell Moore, Cecelia Wood and a few other Virginia Tech grad students who volunteered to take on EPMA operation and reservoir sampling demonstrations. The workshop program also included an invited lecture given by Professor Susan L. Brantley (Penn State Univ.), a National Academy of Sciences member and world-famous geochemist. The virtual format allowed for greater participation and inclusivity for diverse audiences and reached an international audience. All workshop presentations and video demonstrations are posted on the program webpage.

The workshop was attended by 65 participants. The optional *Office Hours with Experts* follow-on served as "consultancies" with experts in topics of interest (via a pre-session registration form). These meetings were mainly one-on-one or small group interactions between participants and session leaders to talk directly about research interests, and to solicit advice and feedback. Nineteen participated in the optional Office Hours session, as either discussion leaders/experts or as participant attendees. Assessment of the workshop by the SERC Evaluation Team demonstrates the profile of participants by institution type, professional role, ethnicity, race, gender, and discipline. We also note that the workshop materials posted on the SERC website continue to make an impact, as indicated by analytics data tracking website traffic. For example, from April to December of 2022 the 2022 Nano EES-RC page received nearly 1,000 page views, 356 downloads, 316 engaged visitors, and 192 intensive visitors.

The workshop was advertised broadly through numerous professional listservs (AGU, GSA, MSA, GSA, the National Association of Black Geoscientists (NABG), Association of Women Geoscientists (AWG), among others), and we did indeed attract a broad audience from Earth and Environmental Sciences, as well as a variety of other disciplines and fields of research (see below). In terms of diversity as measured by ethnicity, race, and gender, the workshop attendees included ~10% who identified as Hispanic or Latinx, 13% as Native American or Alaska Native and Black or African American, and nearly half (46%) as female. These numbers are encouraging, but clearly continuous work needs to be done in terms of advertising and recruiting a more diverse cohort of nanoscience researchers, especially from industry. The workshop was well-received by the participants with aggregated review scores of 3.5-4.0 on a 4-point Likert scale. Many of the 56 respondents to the End-of-Workshop Survey prepared by SERC provided detailed feedback and comments on their workshop experiences. In general, the respondents were extremely positive in terms of the facilitation, communication, design, and active learning aspects of the workshop. They also reported finding new opportunities to build collaborations, understand how sampling and analysis can answer broad science questions, realize new data, services, and tools for research, as well as new opportunities through NNCI.

A webinar was presented on November 1, 2022, as a collaboration between the Rules of Life and Earth and Environmental Science Research Communities: "The Convergence of Biology and Earth Sciences." This webinar was sponsored by MONT and supported with logistical and web services by SERC. The webinar had 38 attendees (out of 60 registrants), representing numerous STEM disciplines, mostly from academic institutions (faculty and graduate students). Details of this webinar are posted on the SERC website. Four invited speakers presented on a variety of topics at the interface of life and Earth science: Rachel Spietz (Assistant Research Professor, Dept. Microbiology and Cell Biology): Reductive biomining of pyrite by methanogens; Christine Foreman (Professor, Dept. Chemical and Biological Engineering): Exploration of microbes in icy environments; Stephan Warnat (Assistant Professor, Dept. Mechanical and Industrial Engineering): Detection of Microbes in Ice Using Microfabricated Impedance Spectroscopy Sensors; and, Chelsea Heveran (Assistant Professor, Dept. Mechanical and Industrial Engineering): From bones to stones: engineering living building materials. A following breakout session allowed participants to "Chat with the Experts". End of workshop evaluation by SERC showed that the webinar was well-received by the participants.

Additional web-based resources were developed to support the workshop (since last year):

- A Nano EES-RC listserv has been established with 225 members who attended any of the series of workshops convened with NNCI support. This listserv is open to new members and is intended as a forum for participants to submit queries and to solicit advice from experts in the Nano EES-RC.

- Additional "primers" or tutorials on Instruments and Analytical Methods Common to Nanoscience have been posted (e.g., Auger Electron Spectroscopy; X-ray Photoelectron Spectroscopy), and additional webpages (e.g., Transmission Electron Microscopy, FTIR) are being solicited to expand this collection.
- A new Registry of Analytical Instruments available in the NNCI and collaborating laboratories commonly used in EES research has been developed. This is designed to be a clearinghouse service a) for lab managers who are seeking to build their user base; b) for researchers, instructors and students to gain access to analytical equipment to support their scholarly work; and c) to build capacity by optimizing the use of existing analytical equipment to support excellence in science and the training of geoscientists. This is more than a list of instruments. Essential information about each instrument and lab is provided including contact information, instrument type, capabilities and limitations, sample requirements, typical applications, and related resources to help a novice user to make informed decisions about whether or not to pursue collaborations. The current NNCI listing does not have a search category for EES, so this new search instrument has the potential to reach a targeted set of new users from across the EES community. The Registry has a simple template for lab managers to enter information specific to their lab and instruments and search capabilities for new users to discover instrumentation available by instrument type or free text searches.

Next Steps for the Nano EES-RC

Due to COVID -19 restrictions, planned face-to-face activities have been delayed or canceled. As public health considerations allow, we plan to implement:

- Week-long technical staff exchange program among the participating NNCI nodes
- A joint REU program with both in-residence components at the NNCI sites and coupled with shared virtual experiences for students among the participating sites

The White House Office of Science and Technology Policy (OSTP) and the National Nanotechnology Coordination Office (NNCO) announced on October 7, 2022, the inaugural National Nanotechnology Challenge, Nano4EARTH. Nano4EARTH will leverage recent investments in understanding and controlling matter at the nanoscale to develop technologies and industries that address climate change. As a member of the National Nanotechnology Initiative, the research community will stimulate support of nanotechnology-enabled solutions for addressing global issues. On behalf of the network, Matt Hull (NanoEarth/Coordinating Office) will serve as a panelist for the Nano4EARTH Kickoff Workshop (hybrid, Washington DC) on January 24-25, 2023. The Nanotechnology Convergence Research Community shares a common interest with this topic, and the two research communities plan to host a joint workshop in 2024.

Preparations are in progress for the third annual workshop for the Nano EES-RC led by NCI-SW, building on the successes of the previous year. The workshop is currently scheduled for April 5-6, 2023, with two focused topics: Emerging Nanoscience Research for 1) Water Purification, Nano-Enabled Treatment Processes versus Nano/Microplastics; and 2) Agriculture and Elemental Cycling.

7.3. Nano-Enabled Internet-of-Things

NNCI partners at CNF, SENIC, MANTH, NNF, and KY-NNIN have created a **Nano-IoT Research Community**. It is our conjecture that many devices and applications for the Internet of Things will be enabled by nanotechnology.

publicdomainvectors.org

- The IoT 'things' may in many cases comprise small-scale structures, sensors, and actuators (MEMS)
- The IoT 'things' may need to process and collect data, requiring on-board electronics
- The IoT 'things' will need to communicate with the Internet, requiring communication protocols in multiple bands exploiting a diversity of modalities

Our vision is that the ubiquitous sensing potential of the Nano-Enabled Internet of Things (Nano-IoT) will:

- provide the input necessary for data mining/big data processing to understand complex system behavior
- augment the interaction environment in future workplaces
- be the transducers that can monitor living things from agriculture to medicine
- catalyze the convergence of researchers from many intellectual backgrounds

Nano-IoT encompasses several of the themes of the NSF Ten Big Ideas, including: Future of Work, Growing Convergence Research, Understanding the Rules of Life, and Harnessing the Data Revolution.

This Research Community held its second Symposium (hybrid) in August 2022, hosted by CNF. The meeting was organized by participants from each member site through online discussions. The one-day workshop began with the following in-person invited presentations given by academic and business leaders:

- Abraham D. Stroock, Gordon L. Dibble '50 Professor, Smith School of Chemical and Biomolecular Engineering; "*Programmable Plants and the Internet of Living Things*"
- Mark Poliks, Center for Advanced Microelectronics Manufacturing, Binghamton University; "*Flexing, Bending and Stretching Toward Advances in Electronics for Medical and Industrial Applications*"
- Scott Miller, Ph.D., Director of Technology, NextFlex; "*Hybrid Electronics Process WiFi Enabled Controllers*"

In the afternoon, research overviews were given by the representatives of each of the 5 member sites. Finally, a discussion panel was held that responded to the following topics:

- Defining future Nano IoT research directions.
- How will nanotechnology transform the IoT?
- What does a facility have to have to support IoT, heterointegration, start to finish?

- What processing technologies will be needed for smaller versatile devices so we can move to the internet of everything?

Workshop registrant statistics:

43 people registered

- 24 from Cornell University
- 8 from Nano IoT RC sites
- 5 from industry
- 5 from other universities
- 1 from a government lab

21 attendees signed in for most of the day via zoom and 15 attended in person

Based on a limited exit survey, 100% of feedback respondents rated the content excellent/good and 100% approved of the format of the meeting. A video recording of the event is available.

In a follow-up discussion with members, it was decided to hold the next Nano-IoT research community meeting (hopefully) in-person on the Nebraska campus in 2023, hosted by site member NNF.

7.4. TransformQuantum

Overview: The **TransformQuantum Research Community** was established in 2020 to organize and systematize considerations of how the NSF-supported National Nanotechnology Coordinated Infrastructure (NNCI) and its community of users could better prepare for and respond to the needs of the ongoing quantum revolution and its demands for quantum-relevant fabrication capabilities. This report provides an update to the TransformQuantum (TQ) activities over the past twelve months.

TransformQuantum comprises members from each of the 16 NSF NNCI sites as well as members from a handful of other institutions both in the U.S. and internationally. Most of the members represent academic institutions, all with nanofabrication facilities, sharing a common interest in the development of specific quantum-related nanofabrication processes that enable and improve the performance of a range of quantum technologies. There are also some representatives from government-supported research labs and research facilities.

With key players from theoretical, computational, and experimental backgrounds, our focus areas are:

- Collating and distributing information about quantum-relevant nanofabrication infrastructure and expertise,
- Formulating scalable designs for intermediate-scale and large-scale quantum computation,
- Developing theory and experimental methods for quantum communication over short- and medium-range networks,
- Investigating and implementing realistic methods for error detection, correction and mitigation,

- Developing materials science-based approaches for higher fidelity qubits and quantum information storage,
- Developing realistic roadmaps for quantum computation and quantum communication.

There are a wide variety of different technologies that are being pursued related to quantum information. These include atomic systems (neutral atoms; Rydberg atoms; ions); atomic-like solid state systems (color center defects in semiconductors; spins in semiconductors; rare earth ions in glasses); photonic systems; and solid-state systems such as qubits based on superconductors, and on quantum dots in semiconductors. There are also more exotic systems, such as developing acoustic phonons as quantum information carriers, or developing qubits based on electrons on liquid helium or solid neon, that are being pursued as well, but are not currently represented in this research community, due to their small size. However, we are open to supporting these activities as well.

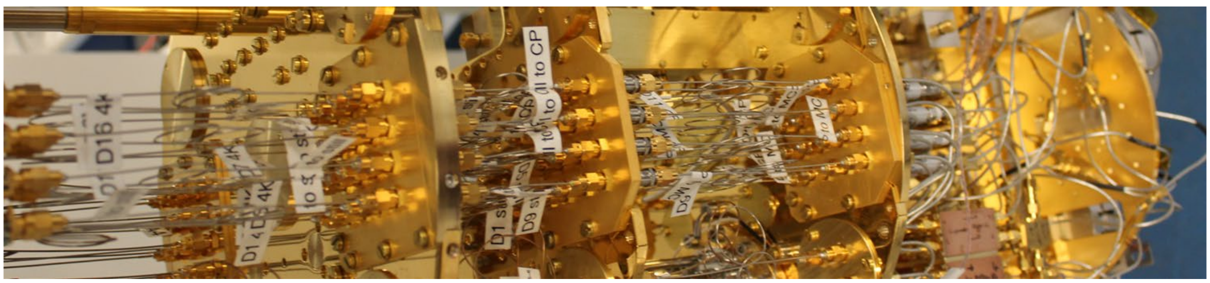


Figure 10: A cryogenic system suitable for characterizing low-temperature quantum systems such as color center quantum communication platforms and superconducting quantum computing or quantum sensing platforms.

Each of these hardware paradigms face different challenges: For example, atomic systems rely on qubits occurring naturally, but require highly sophisticated means to interface those qubits to the optical, electrical and magnetic signals used to control and measure the qubits. Photonic systems require large numbers of nearly lossless optical elements such as beam splitters, mirrors and photodetectors to entangle and process the photonic qubits, and these optical elements most likely will rely on nanofabrication to allow the necessary scaling in number and complexity. Solid-state superconducting and quantum dot qubits are amenable to nanofabrication but face challenges related to materials loss, materials interfaces, and scaling to large numbers of qubits. Solid-state color centers such as nitrogen-vacancy or silicon-vacancy defects in diamond, or atomic-like phosphorous donors in silicon, do not currently allow controlled placement of qubits with the required level of positional precision, but can be significantly advanced by integrating optical and radiofrequency control and readout signals into the solid host for these qubits.

Our overall approach is to rethink current methods to develop **quantum-specific** best practices relevant to each of these platforms:

- **Materials processing & characterization** to promote quantum performance
- **Materials interface** preparation, treatment and characterization
- **Systems integration** of quantum devices
- **Packaging** technologies

Figure 11 illustrates the range of different platforms and the cross-cutting technologies that impact their development and performance. The different needs of each of the hardware platforms demonstrates that distinct approaches with different emphases are need, such that each nanofabrication facility can meet the needs of a range of different platforms, but likely cannot meet all requirements.

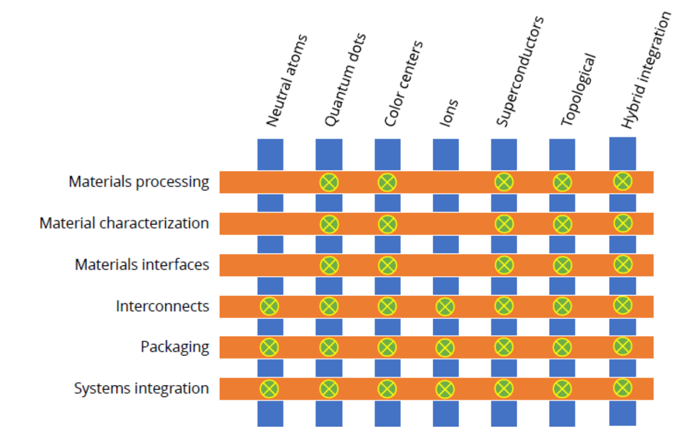


Figure 11: Cross-cutting needs for technologies needed for advancing quantum (horizontal rows), for each of the quantum information hardware platforms (vertical columns). Note that while, for example, each hardware platform will need interconnect technology, the specific technology needed will likely differ from platform to platform.

Considerations of these challenges guide us to the following principles:

- NNCI fabrication facilities must balance needs of specific hardware platforms with general-purpose useability.
- Access to key materials will be vital for future success (this includes e.g. Si/SiGe heterostructures; materials for color centers such as diamond and SiC; and assembled 2D material stacks; some of these preferably isotopically pure or with isotopically pure epitaxial layers).
- Better mechanisms to preserve & propagate quantum-related processes, developed by individual research groups but needing cataloging and distribution.
- Uniform and accepted characterization methods for quantum devices.

Website: TranformQuantum has put together an information-centric website, hosted at the University of Chicago: https://hbar.uchicago.edu/tq. This website provides an introduction to TransformQuantum; links to our partner institution websites; and some information regarding recent and upcoming workshops. We have plans to expand the information available on this website as the research community matures.

Annual Update: To provide a communication center and organizational structure, TQ has pursued the following activities over the 2022 calendar year:

- Maintaining the TQ website mentioned above.
- Participation in an NSF-funded AccelNet program Global Quantum Leap (GQL) (PI: Steven Koester)
- The Global Quantum Leap AccelNet program has itself made a number of significant contributions:
  - Linked seven international networks focused on quantum materials and sciences, including the ML4Q Cluster of Excellence in Germany; Nanoplatform Japan; QCS Hub in the United Kingdom; two Europe-wide network (EuroNanoLab and the European OpenSuperQ); the Chicago Quantum (with partners in the US, Australia, and the Netherlands); and the Challenge Institute for Quantum Computation based at UC Berkeley.

- Organized a highly successful International Research and Training Experience (IRTE) with the Global Quantum Leap partners at NIMS Japan, that was active in summer 2022. Two students and one postdoc performed research on quantum materials. A summary of participant experiences is available on the GQL website.
- Is in the process of organizing two IRTE programs for summer 2023, one to be hosted by NIMS, Japan and the second by ML4Q partners in Aachen, Germany.
- Organized direct student exchanges, with a web-based solicitation resulting in four direct supervised student exchanges that were successfully engaged in over the summer and fall of 2022.
- Co-sponsored NSF-funded workshop "Building a Nanofabrication Facility for Quantum Science and Engineering" at CU Boulder. Provided travel support for international participants and advertising.

Roadmapping: TransformQuantum is participating in developing a quantum roadmap, led by the Global Quantum Leap Accelnet program. This effort includes specific roadmapping for each hardware platform. Led by Chris Olber (Cornell), Vlad Pribiag (UMinn), and Steven Koester (UMinn), we have identified a panel of experts in each of five hardware platforms and are working to build a larger panel covering more areas. The goal is for the panel to generate a first draft roadmap by 2023 and develop a more complete and comprehensive roadmap by 2025. The plan is to publish the roadmap in an archival journal to make it accessible to a broad range of researchers and program managers. An initial coordination meeting was held in April 2022, and a range of quantum platforms considered for this exercise (superconducting; topological; trapped ions; spins; color centers). We included researchers from each topical area in the discussions. The outcome was a decision to refocus the target audience for the roadmapping exercise to fabrication facilities and the funding agencies and institutions that support these, and a redirection of the scope, towards fabrication and assembly/integration for early & mid-stage quantum platforms.

Future Workshops: We plan to hold additional workshops in the coming months, including:

- **Workshop on Quantum Engineering Infrastructure II**: Follow-up to 2021 event will help to drive road-mapping activities. Tentatively planned for Spring 2023.
- **Winter School on Quantum Technology:** Prof. Tony Low (Minnesota): Quantum effects & technology school. In collaboration with Kyung Hee University (South Korea)
  - Bootcamp focus on fundamentals of quantum phenomena
  - Fabricating functional quantum devices
  - First cohort with students from Kyung Hee University
  - Expand to include more students (summer 2023)

7.5. Understanding the Rules of Life

Rules of life (RoL) is one of NSF's "big ideas", akin to a rallying cry for the community to address and harness for intellectual merit and broader impacts in this technical theme. However, unlike most other big ideas (e.g., quantum information systems, Nature of Work, etc.) RoL is clearly a complex and multifaceted theme that is unusual and unconventional under the typical infrastructure settings, like the NNCI network. RoL is, on one hand, a bit eclectic and diverse theme about understanding life itself and how living organisms work at a fundamental molecular level. On the other hand, RoL also encompasses how life affects the surrounding ecosystem and also how surroundings influence life across many levels and hierarchical connectivity. Thus, the scale and scope of RoL can be overwhelming and all-encompassing unless we attempt to contextualize RoL in the spirit and stage of NNCI as an infrastructure network.

Defining the RoL RC within NNCI: The initial meetings and discussions on RoL RC revolved around how best to define the opportunities in RoL within NNCI and focused on a handful of key initiatives that can provide impetus for generating network and infrastructure context to RoL RC. SHyNE Resource has been undertaking discussion and discourse to formulate the RoL RC theme within NNCI, given its emphasis on "soft" and "soft-hard" (hybrid) interfaces and structures.

The RoL RC is meant to facilitate interactions between member institutions and partners, and provides an avenue for collaborations, joint projects, and information exchange. Much of the earlier discussion and discourse within RoL RC theme revolves around defining a few targeted themes that may resonate broadly in the research community as well as align with the mission and goals of NNCI at large.

The NNCI RoL RC has identified three major themes for focus for the wider future activities. These include:

1. "Synthetic Biology (SynBio)"; with a focus on "road-mapping" for infrastructure and facility needs for SynBio. Here the focus is analogous to SRC roadmap activities to identify and target "metrology" needs for SynBio and help define performance needs and attributes.
2. "Seeing and Sensing the Invisible"; i.e., encompassing broad and relevant length-scales for "imaging", spanning sensing, diagnostic and imaging fields. This is an obvious and relevant RoL theme that aligns firmly with NNCI goals and activities.
3. Outreach and Workforce Development as they relate to RoL RC. There is ample diversity and scale/scope of RoL RC and has potential global societal impact through business and commercial opportunities. Thus, workforce development is naturally relevant and timely opportunity to target education, professional development and outreach related to RoL.

RoL RC Activities and Plans: During this year of initial RoL RC formulation, most of the meetings and discussions revolved around identifying (and narrowing) the aforementioned technical themes and ensuring that these are broad enough to fulfill RC criteria. Yet, they also need to be focused and targeted to enable monitoring of progress and relevance as well as alignment with NNCI mission, objectives, goals, and activities.

Given the complexity and diversity of RoL themes, the RC members are happy to have identified three key themes that the broader NNCI community can rally around and highlight, plan and anchor their RoL related activities. During the course of these meetings, ample opportunities were offered to participating network nodes to elaborate their RoL related activities and plans.

The participating members of this RC on RoL highlighted their own site's research and outreach efforts related to broad RoL theme as well as three defined sub-themes that NNCI committee identified. SHyNE Resource shared their research activities related to integrating molecular and synthetic biology on top of microelectronic and microfabrication platform for sensing and diagnostics. SHyNE also shared the details of the i-Nano event that brought together regional (ANL, UC and NU) players under the RoL theme that addressed emerging theme as in: *"Convergence of Synthetic Biology with Data Science:- Promises, Prospects and Perils".*

This event and thematic coverage represent shared example of RoL activity that not only addresses scholarship and intellectual merit but also serves as a vehicle to disseminate educational information and thought-provoking ideas that straddle boundaries of excellence, ethics, empathy and related DEI considerations. As a trial regional activity, RoL RC participated in the November 2022 M^3S meeting in Chicago region held at Baxter Healthcare in Deerfield, IL. In attendance were scientists from Chicago-based industries, including Baxter, researchers from universities and national labs in the Midwest, and vendors including Hitachi, JEOL, Gatan, Leica, ThermoFisher, and numerous others.

Similar experience and ideas were shared by other members. For example, CNF has partnership with the Cornell Center for Biotechnology. The Center's imaging capabilities led to the creation of the Cornell Imaging and Visualization Partnership which has tools for non-destructive 3D imaging. As part of their biannual Technology at the Nanoscale (TCN) Short Course, they offer hands on training in microfluidic device production and CNF has a capability in house for fabrication and testing of such devices, which are used in some of the noted highlights below. An interdisciplinary workshop is planned in 2023 with the Cornell Center for Biotechnology on the use of nanofabrication in life science studies. As part of their creation of the New York State Nanofabrication Network, a consortium of like-minded schools with capabilities in nanobiotechnology in the region. Some of the initiatives under ROL related to life sciences include the creation of micro-robotic swimmers controlled by ultrasound for exploration of cellular media and targeted delivery of drugs, studies of cancer cell transport in confined environments, new nanophotonic methods for DNA sequencing and water pressure sensors for digital agriculture.

These representative examples are meant to convey that the RoL RC is evolving and taking shape that would identify broader NNCI-wide activities and plans as well as anchor local RoL related activities under the RC RoL umbrella.

By way of another such example, two community college interns started in RTNN this year have almost exclusively been working in sample preparation for bio and bio-EM and both have an interest in the area of study. This serves as a potential workforce development; 3rd pillar of the NNCI-wide technical foci. A new NSF ERC center (PreMiEr) was awarded and supported at RTNN. A 5-year $26 million ERC grant was awarded in summer 2022, and is led by Claudia Gunsch, Professor of Civil and Environmental Engineering at Duke University. Partners are North Carolina A&T, UNC Chapel Hill, UNC Charlotte, and NC State University. PreMiEr aims to develop diagnostic tools and engineering approaches that promote building designs for preventing the colonization of harmful bacteria, fungi or viruses while encouraging beneficial microorganisms.

In 2023, we will further strengthen collaboration and convergent research crossing multiple levels of organizations within NNCI network addressing key questions in the life sciences. We will develop ideas for research tools and infrastructure to further Rules of Life Research and strategies to leverage RoL such as vendor/webinar events, workforce training, outreach/SEI. The RoL RC quarterly meetings are planned and set in the calendar. We expect that RoL RC will continue to grow and diversify across the NNCI networks in the year ahead.

7.6. Microelectronics and Semiconductors

The global semiconductor market is currently over $600B, with an annual growth rate of ~10%, and will drive a $3T electronics market by the end of decade. The US share of this market has fallen to less than 10%, which has clear economic and defense ramifications. This was the impetus for Congress to pass the $52B CHIPS legislation to encourage in-shoring of semiconductor fabs.

An NSF NNCI-sponsored workshop was held on Sept. 8, 9, 2022 to discuss how academia could contribute the CHIPS program. Dr. Brand from Georgia Tech and Dr. Goldberg from NSF discussed the NSF National Nanofabrication Coordinated Infrastructure (NNCI), which sponsored this workshop. Since NNCI is a successful geographically diverse network of sixteen universities and partners in the US which provides cleanroom access to internal and external academic and industrial users, it may make sense to use CHIPS funding to build on the NNCI model to expand the capabilities and geographical reach of NNCI, and build an "NNCI on steroids."

The first day of the workshop was devoted to invited talks by industry leaders who discussed the state of the art in their respective fields, and research challenges, highlighting opportunities for academic research. Dr. Kavalieros from Intel focused on advanced transistors for logic applications, Dr. Ramaswamy from Micron discussed advanced memory architectures, and Dr. Narayanan from IBM educated the attendees about heterogeneous integration (HI) as the next paradigm in Moore's law and Dennard scaling. Some of the common themes that emerged are the move toward next-generation 3D devices such as nanosheet transistors, and 2.5D and 3D HI of chiplets of CPU, GPU, high bandwidth DRAMs, and non-volatile memory using hybrid bonding with sub-10 micron pitch for applications such AI/ML using neuromorphic computing. Power management becomes a huge challenge in such 3D systems.

Dr. Chudzik from Applied Materials discussed equipment challenges for 300 mm tools which need to handle a wider set of materials, semiconductors beyond Si such as SiC and GaN, and advanced packaging. Dr. Moroz from Synopsys and Dr. Banerjee from Ansys discussed TCAD and EDA challenges, respectively. Moroz pointed out the need for more *ab-initio* simulation methodologies such as density functional theory (DFT) for structure calculations, coupled with non-equilibrium Green's function (NEGF) methodologies for electronic transport, which go beyond the usual drift-diffusion based simulators. Dr. Banerjee pointed out the need to do multi-physics simulations for HI, involving coupled heat and charge transport, as well as high speed simulation of Maxwell's equations to handle parasitics.

The workshop also discussed workforce development and academic infrastructure. For CHIPS legislation to be impactful, there must be significant renewal of aging academic microelectronics, R&D infrastructure, and a doubling of graduates in this field to feed into the ecosystem of 300,000 workers in this field in the US. Dr. Liu from Berkeley talked about the proposed American Semiconductor Academy which would marshal the resources of universities and community colleges to fill the pipeline for college graduates and technicians needed by industry, and provide them with the multi-disciplinary training in device physics, materials science, circuits, and architectures to perform device technology co-optimization (DTCO) and system technology co-optimization (STCO) that will be increasingly needed in the future. Intel provided an industry perspective of future workforce needs. Case studies of what academia has started doing in this area were discussed by Purdue and Cornell.

A key question that this workshop attempted to answer was how to revamp the aging academic cleanrooms. For example, what wafer size should universities target in the future, and how would these more expensive facilities be maintained? Dr. Del Alamo from MIT discussed a “business model” for new academic facilities and suggested that 200 mm (CMOS + X) may be the “sweet spot” for academia. State-of-the-art 300 mm tools would be prohibitively expensive to maintain, while tools handling wafer sizes smaller than 200 mm may not be supported by the equipment manufacturers. However, to sustain these academic cleanrooms, the university needs to have an annual research portfolio comparable to the infrastructure investment, which may limit the number of such facilities that the US can justify. A slightly contrarian view was expressed by Dr. Plummer from Stanford who felt that universities should focus on TRL-1 type exploratory research and not invest in expensive 200 mm CMOS capabilities.

Plans:

During the next year, the Microelectronics and Semiconductors Research Community will address the key question about how to revamp aging academic cleanrooms. For example, what wafer size should universities target in the future, and how would these more expensive facilities be maintained? It may make sense to use CHIPS funding to build on the extremely successful NNCI model to expand the capabilities and geographical reach of NNCI. The current consensus is that academic cleanrooms should not invest in 12-inch capability because of the expense of the equipment and operating costs. 8-inch may be the “sweet spot” where leading edge tools can be acquired and maintained at a sustainable cost. However, smaller wafer sizes such as 6-inch may also be a viable option for TRL 1 level work done by universities.

8. NNCI Network Promotion

8.1. 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 provided 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)

Continuous internal marketing should include:

- 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

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

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.* While normally the Coordinating Office would have hosted a booth at conferences such as TechConnect or MRS, this activity was suspended in 2020 and 2021 due to pandemic-related travel restrictions. NNCI was represented at TechConnect 2022 through invited oral presentations by Matt Hull and David Gottfried.
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 2018-19 but decreased in 2020-21. 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 listserv 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 140 subscribers to this email list with approximately 50-70 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.* While this was discussed within the Coordinating Office, it was felt that sites were better positioned to disseminate news and events information to their local users.

8.2. 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 Years 3-5.

The NNCI Introduction Video was produced at the end of 2017 and publicly released in February 2018. It was posted to the NNCI home page with the 2019 upgrade. The YouTube URL is https://youtu.be/72ZXh-ESt3U. As of Dec. 31 2022, the video had been viewed more than 2,000 times. During 2021, the NNCI YouTube channel was added to the home page, and more details on this are provided later in this report.

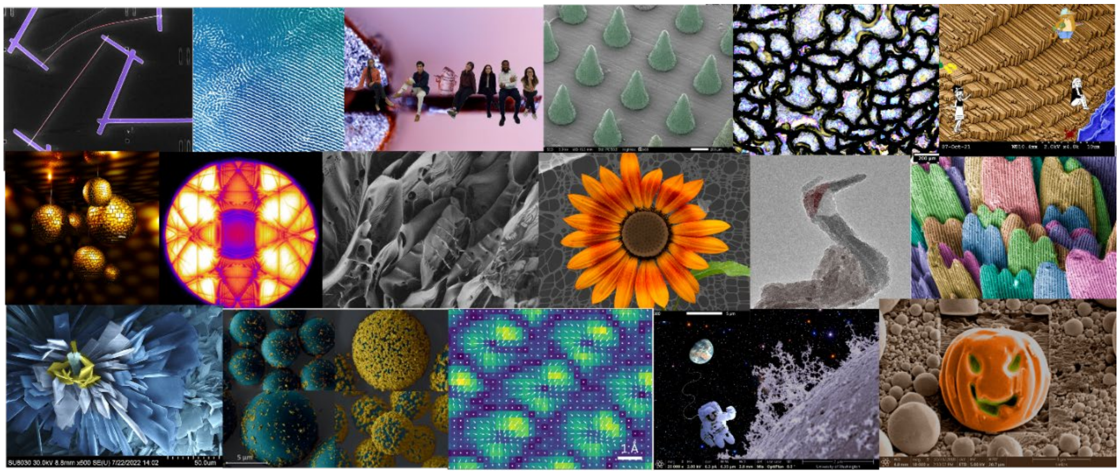
Since the original launch, new content and updates have been uploaded regularly including:

1. News items on the blog (7 news items in 2022)
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 Research Communities and Audio/Video content
7. Home page news spotlights
8. Updates to site pages
9. Backend improvements, changes, and bug fixes

During the past year (Year 7), the most significant upgrade made to the NNCI website was the addition of pages on the “Innovation Ecosystem.” This section was added to the “Learn” menu, with additional pages about:

- Nanotechnology Entrepreneurship Challenge (NTEC)
- Research AND Entrepreneurship Experience for Undergraduates (REEU)
- Entrepreneurs-in-Residence (EiR)
- Commercialization Resources

In celebration of National Nanotechnology Day 2019 (October 9), the NNCI website hosted the first “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. This contest has been repeated each year since, with public voting open this past year during Oct. 6-13, 2022 in categories “Most Stunning”, “Most Unique Capability”, and “Most Whimsical”. These images (and winners) are now archived as part of the Education pages on the website and further details are described in the Education and Outreach report in Section 4.1.



Google analytics for www.nnci.net indicate that in calendar year 2022 there were more than 54,000 visitors to the website, a 9% decrease over the prior year. As in previous years, a large spike in visitors was observed in October, primarily to participate in the image contest voting. For the year, 91% were new visitors with 46% from the United States (up from 43% the previous year). There were more than 102,000 pageviews, which is also a 9% decrease from the prior year. The average session duration was slightly more than 1 minute, with an average of 1.6 pageviews/session, comparable to 2021. During this time period, the top ten pages visited are shown in Table 12 below. Significant differences this year include a large increase in views of the Home page, but significant decreases in most of the other popular pages compared to 2021. In general, the top pages include the education-related pages ("careers", "what is nano", and "how small is nano" pages), consistent with previous year's observations. Other significant increases in pageviews were seen for the Events (+45%) and RET (+116%) pages.

Table 12: NNCI Website Page Visits (2022)

Page	# Pageviews in 2022	%Change from 2021	% Pageviews in 2022
/	18,083	+17.00%	17.65%
/careers-nanotechnology	7,847	-24.68%	7.66%
/what-nano	7,020	-16.65%	6.85%
/how-small-nano	4,787	-59.67%	4.67%
/plenty-beauty-bottom	4,363	-5.09%	4.26%
/research-experience-undergraduates	3,177	-4.34%	3.10%
/sites/view-all	3,004	-0.23%	2.93%
/nature-helps-nanotechnology	2,603	-27.17%	2.54%
/about-nnci	2,172	+1.88%	2.12%
/search/tools	1,767	-5.00%	1.72%

Since the NNCI website's debut in late 2016, the growth in annual visitors and pageviews is shown in Figure 11 below and appears to have reached a plateau in annual usage.

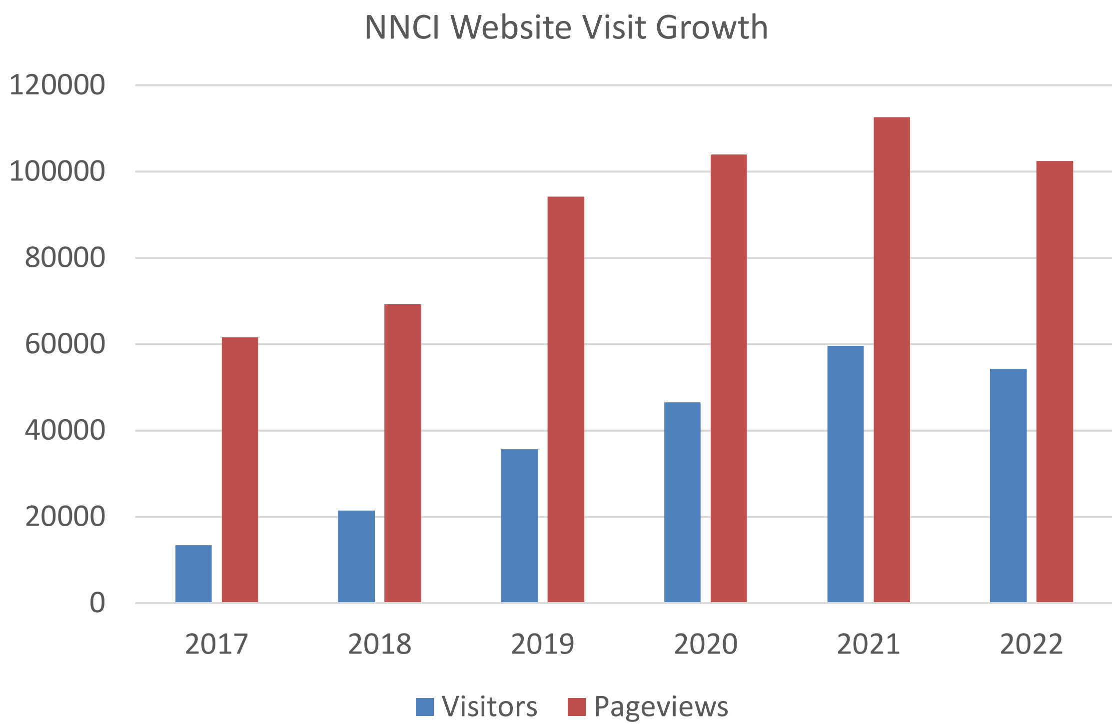


Figure 11: Growth in Annual NNCI Website Usage

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 12). The organic search rate of 56.0% showed a significant decrease this year after several increasing years (67% in 2020) while direct acquisition jumped to 37.8% (from 25.2% in 2020). Both modes showed increases in overall number of visitors compared to the previous year.

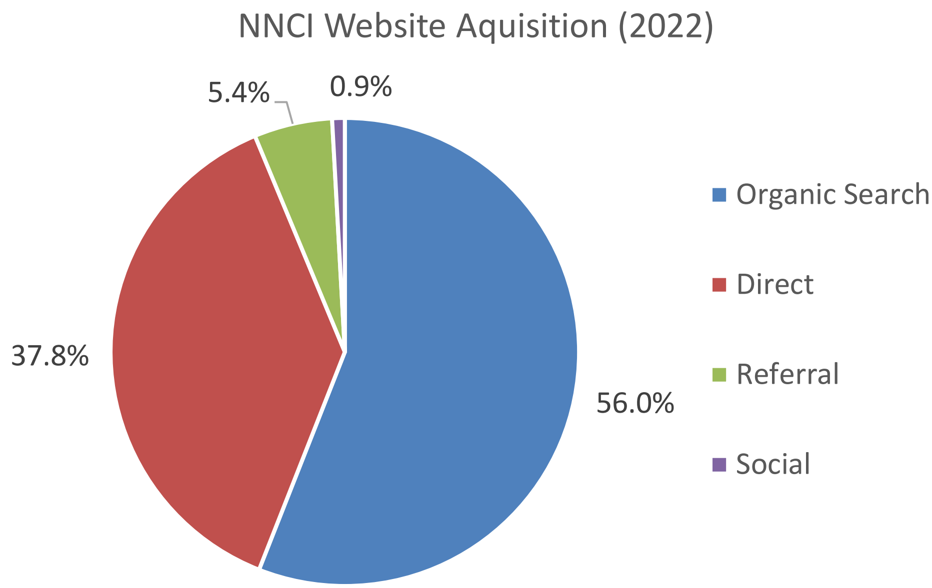


Figure 12: Site Acquisition (how visitors get to the website) for www.nnci.net (2022)

The geographic distribution of visitors to the website is illustrated by the map in Figure 13 below indicating the nearly complete global reach. The top ten locations of visitors are shown in Table 13.

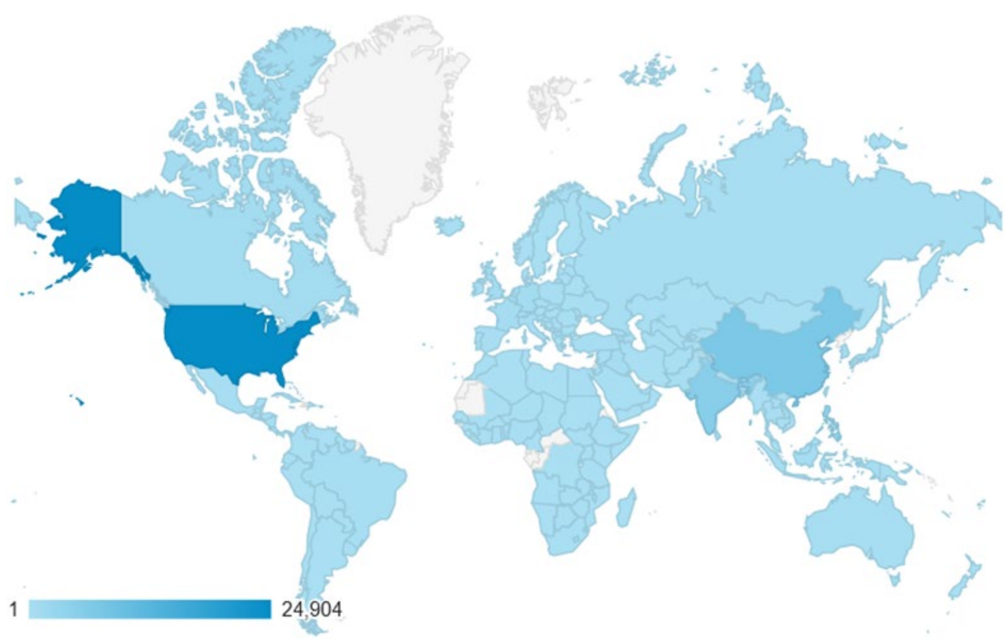


Figure 13: Geographic Distribution of Visitors to www.nnci.net (2022)

Table 13: NNCI Website Visitors by Location (2022)

Country	# Visitors	% Visitors
United States	24,904	45.82%
China	6,904	12.70%
India	5,042	9.28%
Philippines	3.269	6.02%
Germany	967	1.78%
Canada	931	1.71%
United Kingdom	762	1.40%
France	675	1.24%
Iraq	483	0.89%
Japan	479	0.88%

A further examination of the US locations of website visitors (Figure 14) not surprisingly reveals that the highest densities are in states with NNCI facilities (California, Virginia, Washington, Texas, and New York are the top 5, slightly different than in 2021) although all 50 states are represented.

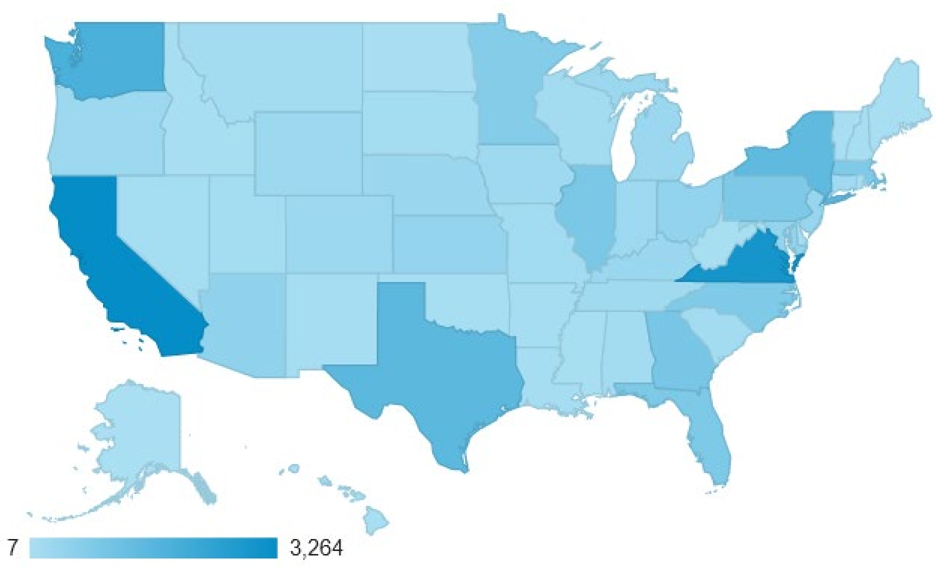


Figure 14: US Distribution of Visitors to www.nnci.net (2022)

8.3. User Satisfaction Survey

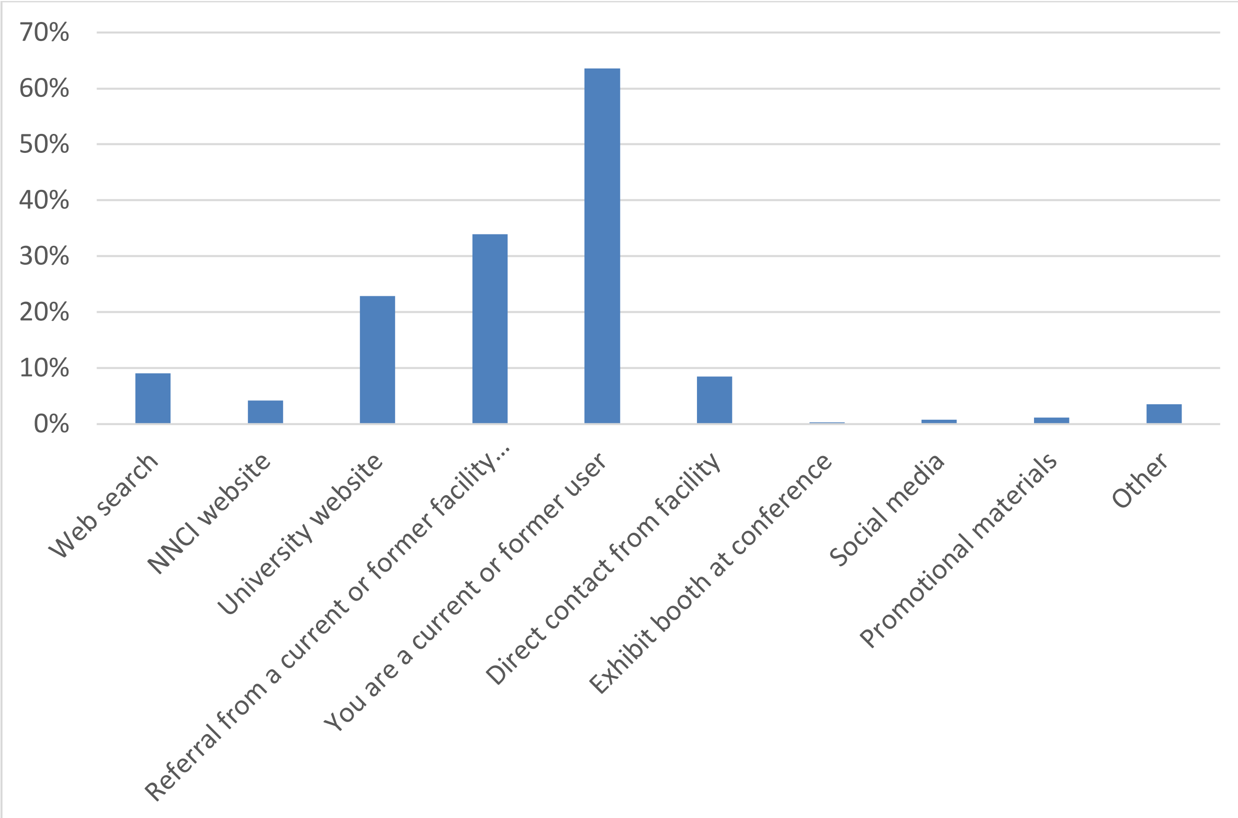
As a result of site director discussions, as well as recommendations from the Advisory Board, the Coordinating Office created a User Satisfaction Survey for implementation throughout the NNCI network. Using a *Survey Monkey* platform, the survey was first made available to sites for forwarding to their 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). This same survey was used for 2020, with the addition of a new question regarding use of resources specific to the COVID-19 pandemic, and this version was very slightly modified in 2021, and a question about civility was added to the 2022 survey shown below. All sites were encouraged to use the common survey vehicle when possible, and 14 sites had respondents to the common survey while the remaining two sites provided their own data for inclusion (N=970). Not all data were combined from the survey data submitted by these two sites, so the N is reduced for those questions. The site-specific filtered results, with comments, were provided to individual sites for identification of action as needed.

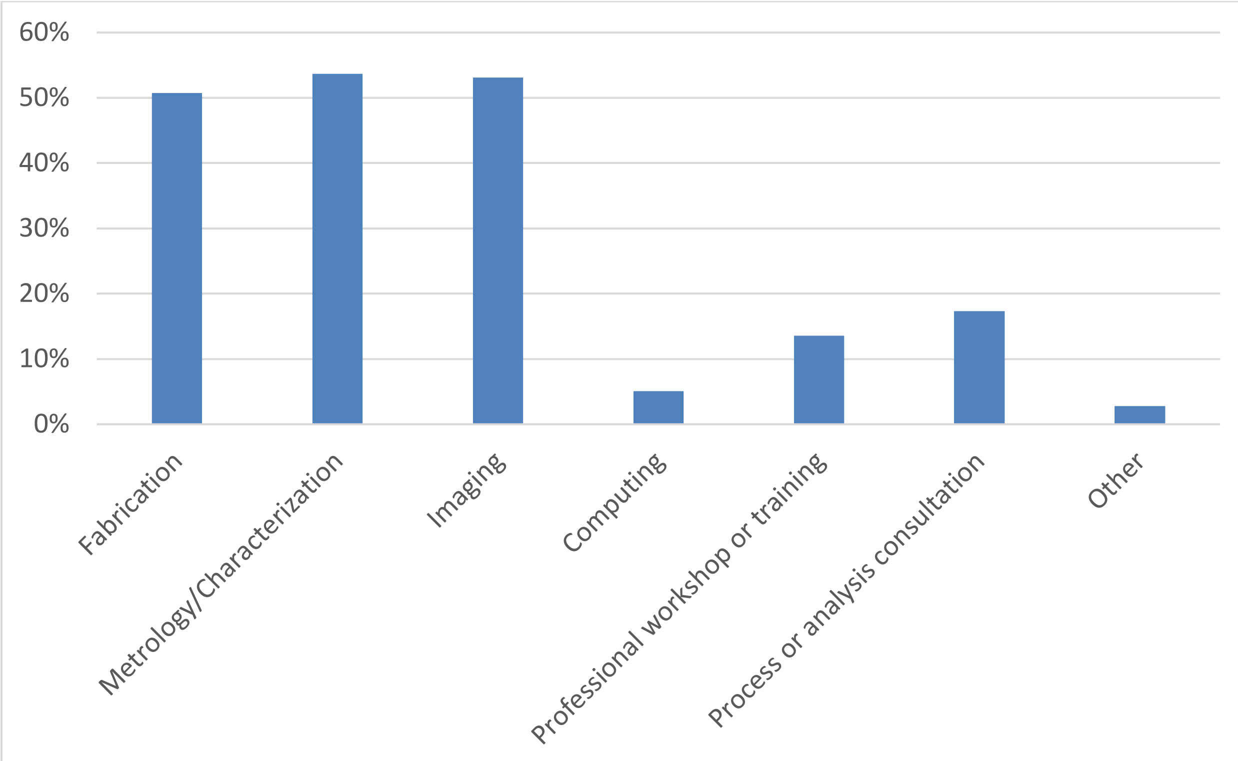
<u>The NNCI facility that was primarily used during the previous 12 months.</u>

The number of responses from each site varies from 11 to 239 (mean=60.6). 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. In addition, users were not asked to identify specific universities or facilities within the NNCI site which were accessed.

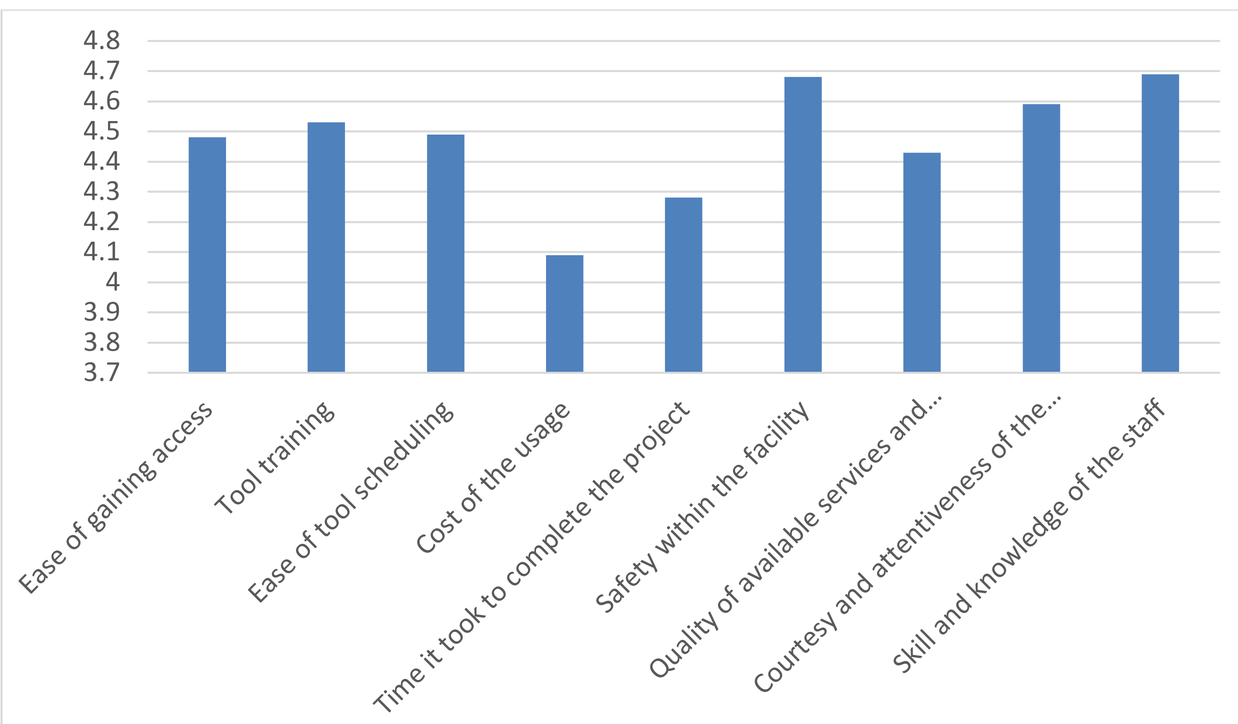
How did the user find out about the NNCI facility? (N=669)



Which services were used at the NNCI facility? (N=907)

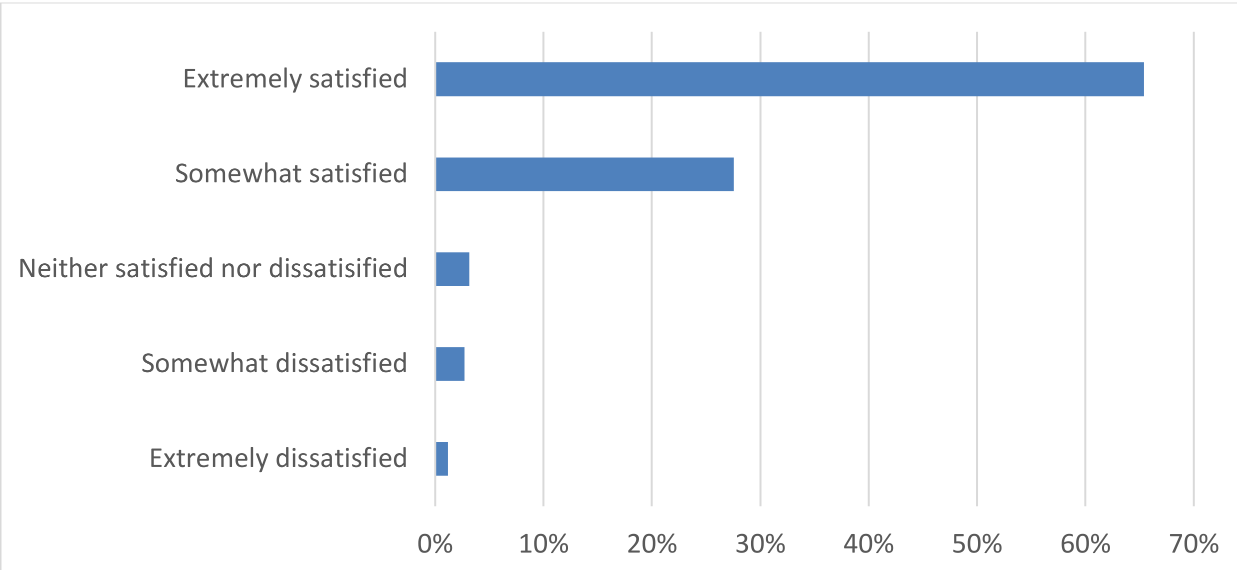


Regarding this NNCI facility, rate your satisfaction with the following (N=669; Scale=1-5, 1=extremely dissatisfied, 5=extremely satisfied)



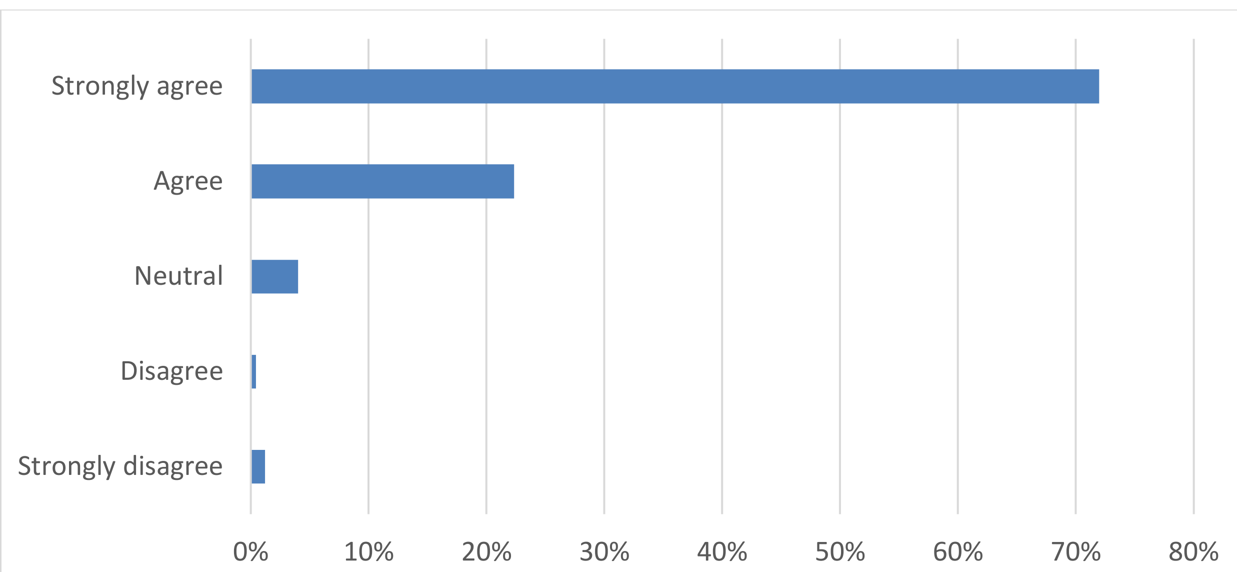
Rate your overall satisfaction with this NNCI facility (N=970)

For all NNCI sites, the average overall satisfaction rating is 4.53/5. For the common survey (N=671), the detailed ratings are as indicated below, with 93.0% of respondents indicating either somewhat or extremely satisfied.



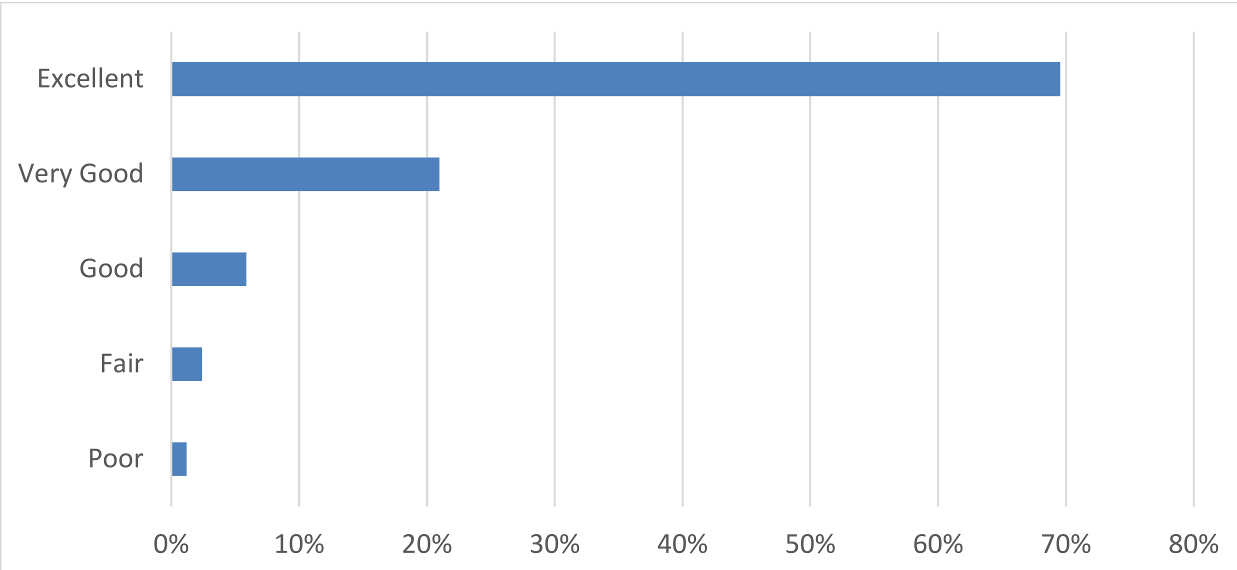
Rate your agreement with this statement: This NNCI facility has had a positive impact on my project goals or research activities (N=671)

This question was first asked in 2021, with 94.5% of respondents agreeing or strongly agreeing with the statement. In 2022, 94.3% agreed or strongly agreed.



<u>How would you describe the level of civility (professional engagement and mutual respect) in your interactions at this NNCI facility? (N=663)</u>

This question was newly added in 2022, at the request of the Diversity subcommittee, as a follow-up to previous specific assessments of environment and culture within NNCI facilities. Less than 4% of respondents rated the level of civility as Fair or Poor, although more than 120 comments were also provided so sites would be aware of any specific issues that might exist.



<u>Would you recommend this NNCI facility to a colleague? (N=812)</u>

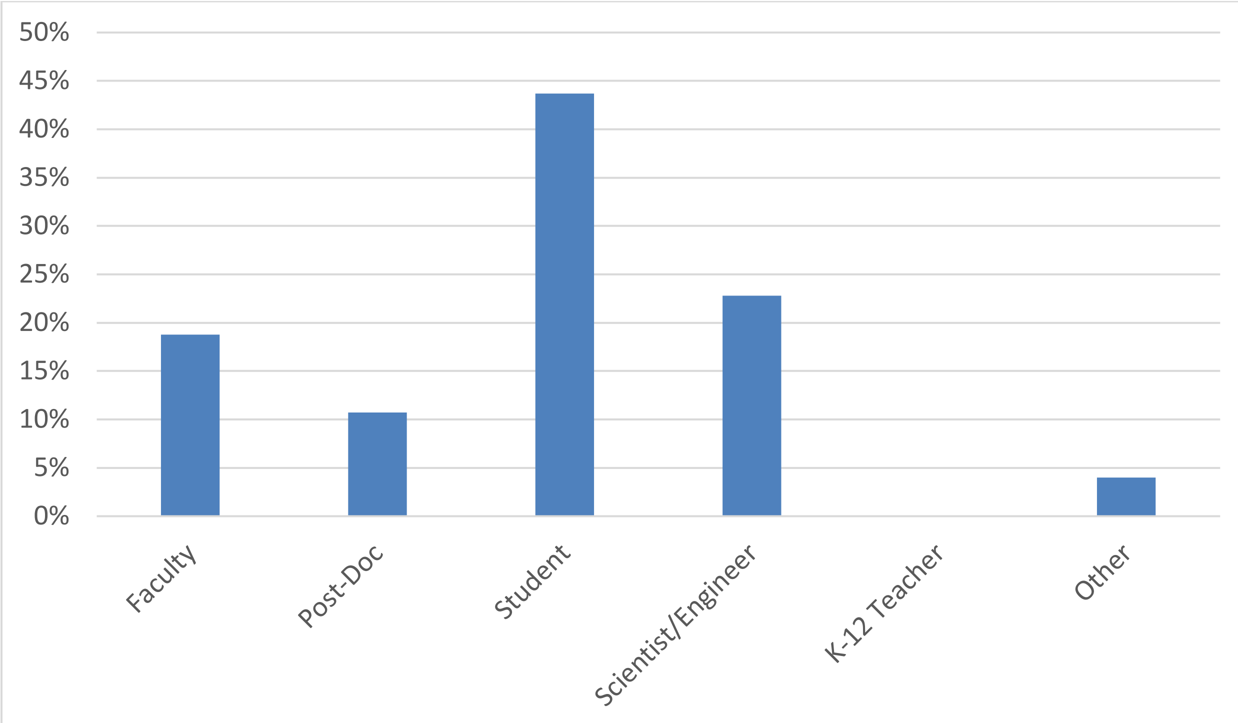
Yes: 97.9%

No: 2.1%

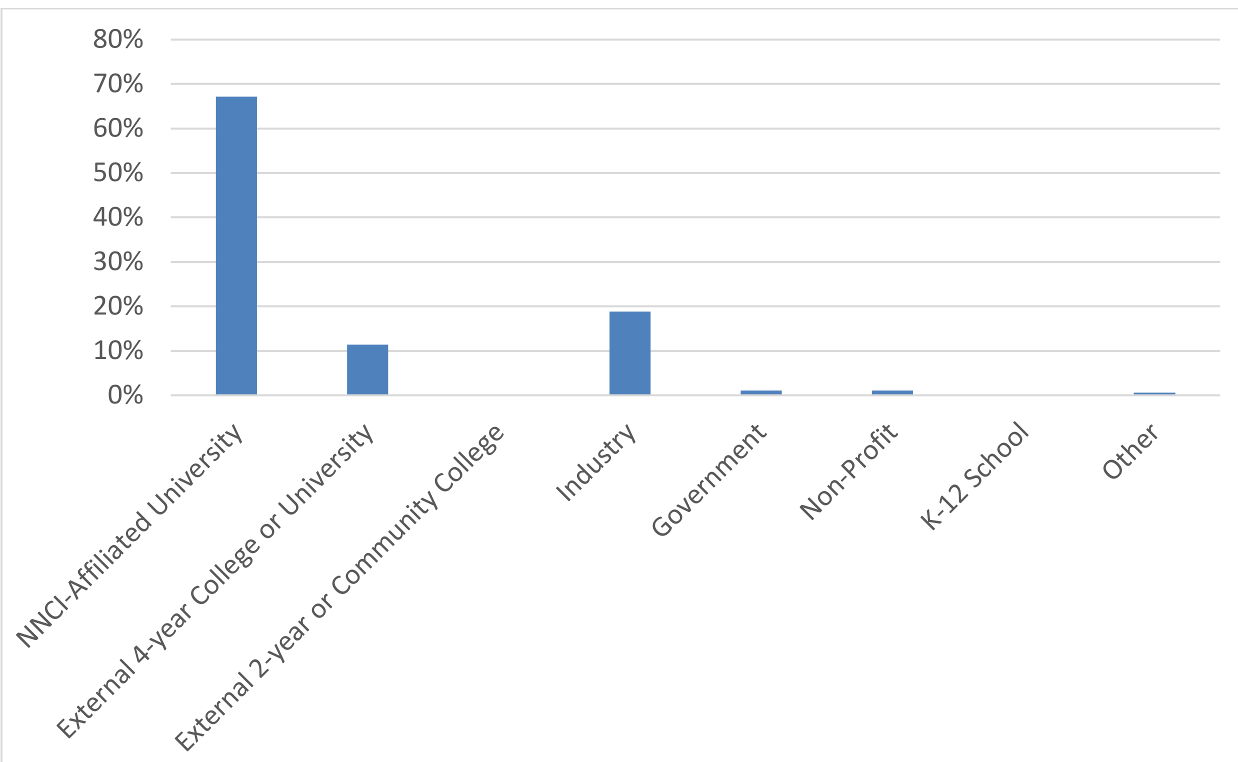
<u>If you have any recommendations for specific new tools or services at this NNCI facility, please indicate them.</u>

More than 150 suggestions were received and provided to the sites. Examples include characterization tools like TEM, Cryo-EM, FIB-SEM, XRD, and XPS, as well as fabrication tools such as direct write, lithography, lithography stepper, ion milling, redundant etching systems, MOCVD, newer E-beam lithography, and laser machining. In addition, replacing old and outdated tools, as well as additional standard tools (light microscopy, hot plates, oven) were also suggested. Finally, users suggested more remote work options, improved scheduling system, revamped training, and increased staff.

User Position (N=671, this question was only asked on the common survey)



User Affiliation (N=671, this question was only asked on the common survey)



Note that this distribution somewhat mirrors the actual user affiliation distribution for the NNCI network as a whole (see Section 11.1, Figure 26) suggesting that the survey is probing a statistically similar cross-section of NNCI users.

In addition to responses to the survey questions noted above, nearly 70 individual free-text comments were provided, both positive and negative, and a selection of these is provided here (specific facility names removed):

The … Facility is a national treasure (as are all of the NNCI facilities as well, I'm sure.)

As a user from industry, I very much appreciate that the … facility is available for my use, works to remove any roadblocks to my usage of the facility, and is open practically 24/7 which makes it easier for me to perform my work.

This facility needs more emphasis on user safety conduct. Staff needs to also be more attentive to safety concerns and be held to a higher standard in terms of resolving these safety concerns. Tooling also needs to have a higher standard of process control.

This facility provides many opportunities to faculty, postdocs and students to work with a variety of advanced scientific instrumentation.

Our access was severely restricted during the pandemic, with a large impact on our ability to conduct work and complete projects.

Instruments are well maintained and perform well with very little downtime. The staff and users are knowledgeable and friendly; it is a pleasure to learn from and work along side them. I feel lucky to have the opportunity use such a facility and work with those who use and run it.

For industrial users doing research projects, especially small start-ups such as my company, it would be fantastic for budgeting if there was an option for a flat monthly rate for cleanroom access.

… staff are incredible in terms of depth of knowledge and customer service. The equipment has high availability and the facility is a tightly run ship from fab through computing and characterization. I'm extremely satisfied with my experience and highly recommend this site to any early stage start-up with wafer fab needs.

9. NNCI Annual Conference (October 2022)

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."

After holding the 2020 and 2021 Annual Conferences virtually, the 2022 meeting was held in-person (with virtual options) at Cornell University on October 19-21, 2022. The 2.5-day event had a registration of 116, including senior representation from every site (all 16 site directors); 7 of 8 advisory board members; NSF officials including NNCI Program Officer Dr. Larry Goldberg; Dr. Branden Brough Director of the NNCO and Dr. Quinn Spadola, Deputy Director of the NNCO; as well as invited speakers.

This year's program included a ½-day Workforce Development Program, with invited guest speakers and a panel discussion on education needs, equipment needs for teaching, workforce development with community colleges, diversity in the student body, veterans, and other topics. Invited speakers were:

- Om Nalamasu (Applied Materials)
- Michelle Williams-Vaden (SEMI Foundation)
- Griselda Bonilla (IBM)

The agenda also featured:

1. Separate meetings for those interested in Education/Outreach, SEI, and Innovation and Entrepreneurship were held during the afternoon before the main conference.
2. Remarks from Dr. Larry Goldberg (NSF Program Manager for NNCI) and Dr. Branden Brough (Director of the National Nanotechnology Coordination Office, NNCO).
3. Presentations by the Director and the four Associate Directors of the Coordinating Office with an NNCI Overview and Reports on Education & Outreach, Societal & Ethical Implications, Computation, and Innovation and Entrepreneurship.

4. Short site reports from each of the 16 NNCI sites. Each site was requested to answer one or more of the following questions related to their activities over the past year:
    - What new program have you introduced recently? What issue/objective does this program address? What are the benefits of this program?
    - What impactful research emerged from your site during this past year? How can the results of this research be translated and applied?
    - What steps has your site taken to expand access of your site facilities and expertise to underrepresented students, faculty, and research disciplines?
    - What steps has your site taken to reduce the environmental impact of your facilities? How are you tracking these impacts?
    - Do you see potential to accelerate your site's growth? If so, what opportunities do you see? If not, what challenges do you face?
    - How do you measure economic or commercial impact of your site?

To assist attendees, supplementary information including site user statistics, research, education, SEI, and computation highlights, and impact were provided as PowerPoint files in an online accessible format.

5. Site presentations were grouped into 4 topical areas, with panel discussions featuring the site directors and attendees.
    - Microelectronics and the CHIPS+Science Act
    - Visions for the Next Network
    - Approaches for Undergraduate Engagement
    - NNCI Impact and How to Measure It
6. Research communities provided summaries of their past and planned activities:
7. Staff awards were presented with details provided in Section 10.5 below.
8. A meeting between the site directors and the coordinating office, to discuss plans for ongoing and Year 8 activities.
9. 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 14.1.

The Coordinating Office presentations, site reports, and research community summaries are provided, along with the full meeting agenda, on the NNCI website https://nnci.net/nnci-annual-conference-2022.



The next NNCI Annual Conference is scheduled to be held at Stanford University (nano@stanford) on October 25-27, 2023.

10. Network Activity and Programs

10.1. 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 resulting in shared reports and best practices
5. Participation in National Nanotechnology Day Activities. Thirteen NNCI sites submitted 35 entries for the "Plenty of Beauty at the Bottom" image contest in 2022.
6. Attending NSF Nanoscale Science and Engineering Grantees Conference. The December 2022 conference was held virtually, chaired by Dan Herr (SENIC), with co-chairs Junhong Chen (SHyNE) and Paul Westerhoff (NCI-SW). Jamey Wetmore (NCI-SW) participated on an SEI panel.
7. Attending NNCI Annual Conference (October 2022)
8. Participating in NNCI REU Convocation (Hosted in Aug. 2022 by KY Multiscale)
9. Participating by sending students to attend the "Winter School on Responsible Innovation and Social Studies of Emerging Technologies" and the "Science Outside the Lab" programs
10. Participating in the NNCI Nanotechnology Entrepreneurship Challenge (NTEC) competition and showcase event
11. Providing content for the NNCI website
12. Participation in the NNCI Outstanding Staff Awards program
13. Discussions between site staff on equipment repair and maintenance issues
14. Dissemination and promotion of NNCI, network events, and opportunities (webinars, workshops, job postings, etc.) through electronic communications and other marketing
15. User referrals to other sites, via NNCI email list or responses to NNCI website contact form
16. Leadership of and participation in the NNCI Research Communities

Multi-Site Activities

1. Hosting and participation in NNCI supported or sponsored workshops and technical events (host site in parentheses), not including individual seminars and webinars:

a. Nanoscience in the Earth and Environmental Sciences Research Community (Nano EES-RC) Workshop, May 16-18, 2022 (virtual, hosted by NanoEarth). The workshop was designed for nano-novices in Earth, environmental, agricultural, water, geoscience, or related fields. Faculty, graduate students, post-docs, industry, and government-based professionals with a broad interest in nanoscience were encouraged to attend. The workshop demonstrated the practical aspects of applying the tools and knowledge of nanoscience to study planetary and environmental samples.

b. NNCI Nano+Additive Manufacturing Summit, August 9-10, 2022 (University of Louisville). This is an annual event dedicated to bringing together researchers in the advanced manufacturing fields of additive manufacturing and micro/nanotechnology to discuss new findings, share results, showcase capabilities, generate ideas, debate the future, and network with one another. The 2022 program served as the annual event for the Nano Convergence Research Community.

c. Nano-IoT Research Community Symposium, August 16, 2022 (hybrid, Cornell University). The purpose of this symposium is to inform and exchange ideas between NNCI users and interested researchers in Nanoscale Internet-of-Things (Nano-IoT) research. The hybrid event featured invited speakers that highlighted emerging research areas in Nano-IoT and NNCI site director overviews showcasing the work performed at their individual NNCI sites. An in-person only panel discussion defined future Nano-IoT research directions.

d. Microelectronics/Semiconductor Research Community Virtual Workshop, September 8-9, 2022 (TNF, SENIC, NCI-SW, nano@stanford). In light of recent efforts of the federal government to bolster semiconductor manufacturing in the US under the auspices of the CHIPS Act, NNCI created a new Research Community and organized an online workshop to examine how NNCI can interact with the various components of the CHIPS initiative.

e. NNCI Etch Symposium, April 21-22, 2022 (Univ. of Pennsylvania)

f. NNCI Advanced Lithography Symposium, July 15, 2022 (Stanford). The Photolithography Working Group used this opportunity to meet in person.

g. NNCI Education Symposium (Nov. 5-6, 2022): SDNI organized an education symposium with the theme "Nanotechnology Education: A Driver for Academic and Career Development". The meeting included presenters from NNCI sites (SDNI, nano@stanford, NanoEarth), NNCO, MNT-EC, Penn State/NACK network, UCSD MRSEC, and local middle and high schools. In the 2-day virtual event, people exchanged ideas and collaboration plans to promote STEM in K-12 and integrate nanotechnology to the current science curricula.

h. The NNI Nano-engineered Systems Seminar, offered weekly since 2019 as a forum for nanotechnology researchers at UW, switched to a virtual format in autumn 2020, alternating between speakers from UW and OSU. The seminar continued through the 2021/22 academic year and also featured invited speakers from other sites.

i. The UW (NNI) Distinguished Practitioners in Nano-engineered Systems Seminar has recently featured four NNCI directors: SHyNE PI Vinayak Dravid (May 11, 2021), SENIC PI Oliver Brand (November 16, 2021), MANTH PI Mark Allan (May 17, 2022), and MONT PI David Dickensheets (November 8, 2022).

2. 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 listserv, and NNCI website contact form, has become an important dynamic within the network which allows for maximizing the network's resources for the nation's benefit. Examples include:
    a. Using the NNCI website, RTNN directs users to other facilities when their work necessitates capabilities outside of the RTNN. This includes several Coursera learners; when another NNCI node may be closer to their home, RTNN directs students there for more information and potential training.
    b. NNI's WNF has been involved in remote projects with UCSB, OSU, Virginia Tech, University of British Columbia, and Montana State University.
    c. MONT had user/technical interactions with NNI (both UW and Oregon State), NNF, NanoEarth, CNS, MANTH, MiNIC, SDNI, and SENIC.
3. Staff technical interactions:
    a. MANTH hosted two staff members from CNF for a one-week visit and sent three staff to CNF for a reciprocal visit, supported by the Coordinating Office staff exchange program.
    b. The Univ. Minnesota (MiNIC) approached SDNI due to issues with line widths below 100 nm and was looking to see if the issues were design or tool related. Both sites have Vistec EBPG tools and agreed that transferring the exposure to another Vistec tool would be better than transferring the process to a different tool manufacturer. Two dose test samples were completed by the end of November 2021 and returned to MiNIC. Additional tests on working devices were performed in February and March 2022. The two sites continue to work together to deliver working devices to the MiNIC research group.
    c. SDNI reached out to other sites to gather information about their experience with wet benches vendors and available features. Mary Tang, from nano@stanford, talked with SDNI about their wet benches and shared lessons learned from the purchasing experience. A second discussion regarding hot plates for lab use was carried out with SHyNE. Discussions are still ongoing with Univ. Chicago regarding their internally designed hotplates.
    d. Georgia Tech (SENIC) continues to collaborate with Montana State University to implement facility management software at the MONT site, leveraging the extensive application development and applying it to the much smaller installation there.
4. NSF-funded Research Experience for Teachers (RET) program. Georgia Tech, (lead institution), Northwestern, Univ. Minnesota, and Univ. Nebraska. These four universities from across the NNCI network support 20 high school/community college faculty each year in a 6-week summer research experience, with follow-up support during the school semesters.
5. Partnership in the NSF AccelNet project "Global Quantum Leap" (GQL) (MiNIC is lead, with CNF, SENIC, SHyNE). GQL establishes an international network-of-networks linking the

NNCI to quantum networks in Asia and Europe. The GQL has launched a webpage (www.globalquantumleap.org), Twitter, and LinkedIn pages. The GQL has expanded to add two new international partners, EuroNanoLab and QCS Hub (UK), and has launched the first two of its international exchange programs: an International Research and Training Experience (IRTE) program at NIMS in Tsukuba, Japan and a summer internship program with the ML4Q network in Germany. The GQL also sponsored research-specific student/postdoc exchanges coordinated between members of the US and international partner networks. GQL is also organizing a Quantum Technology Infrastructure Roadmap (QTIR) and plans to have a follow-up Workshop on Quantum Engineering Infrastructure (WQEI) in 2023.

6. North Carolina Collaborations: To support outreach efforts in rural areas, RTNN collaborates with volunteers from JSNN, part of the SENIC site. Carolina Science Symposium is an annual joint symposium organized by RTNN facilities and staff with considerable collaboration/participation from JSNN (SENIC). RTNN and JSNN are both active members of the North Carolina Center for Innovation Network (NC COIN). RTNN and SENIC users have used each other facilities, when their tools have been under repair/maintenance, and JSNN staff and users have participated in RTTN and industry co-organized instrument and/or technical workshops.
7. Sharing of best practices:
    a. Regional facility networks have continued and expanded. The NNI and MONT sites initiated a joint effort to create the Northwest Nanotechnology Laboratory Alliance (NWNLA), a regional platform for exchange on laboratory experiences and best practices. NWNLA holds regional meetings for facility staff during the off-years of UGIM (University Government Industry Micro/Nanotechnology Symposium - the prime international conference for nanotech facility staff). Meeting topics and agendas are selected by polling NWNLA members with featured speakers and presentations based on group interest. NWNLA 2021 was jointly planned by UW and Montana State University and hosted online Nov. 8-9, 2021. This will be followed by NWNLA 2023 at the University of Washington, and at another Northwest nanotechnology site to be determined for NWNLA 2025. An NWNLA dinner was organized during the UGIM meeting in June 2022.
    b. Nano Summer Institute for Middle School Teachers (NanoSIMST): This weeklong workshop, originally developed by Stanford, was implemented in 2022 at Stanford, NNF, SDNI, MiNIC, KY Multiscale, and SENIC, virtually or in-person. Stanford also developed a nationwide virtual program with local teachers sponsored by CNS, MONT, RTNN, and NanoEarth. SDNI provided remote SEM assistance to the NanoSIMST program.
    c. NNF collaborated with nano@stanford to provide a virtual four-day workshop during summer 2022 for 9 Nebraska teachers to learn about nanoscience and engineering through lectures, hands-on activities, tours, and guest speakers. They also developed their own lesson plans to bring back to their classrooms. NNF is currently recruiting 10 teachers to this program for the summer of 2023.
    d. NNF collaborates with MONT and NNI by sharing synchronous lessons and activities and partner contact information, respectively.

e. 4-H Outreach: CNF, NNF, NanoEarth, and MONT are collaborating on 4H outreach initiatives, sharing activities and best practices. Material to engage 4-H Youth already exists within NNCI; using the 4-H mechanism to deliver content and training is a scalable opportunity.

f. REU Workshop and Career Panels (NanoEarth, CNF, SENIC, KY Multiscale) and Research and Entrepreneurship Experience for Undergraduates (REEU) seminars (led by Matt Hull).

8. Participation in SEI Programs:
   a. The SEI program hosted a half day workshop shortly before the NNCI annual conference in 2022 to share best practices, and the SEI leaders at the different sites have met to discuss issues and give each other feedback.
   b. Jamey Wetmore coordinates the efforts of the four primary SEI sites at NC State, Georgia Tech, UT-Austin, and ASU, to maximize the benefits of their work across the network. Each has agreed to develop a program that other NNCI sites, who may have less access to SEI expertise, can plug into. NC State and Georgia Tech are both developing complementary toolkits for assessing the impacts of NNCI sites, UT-Austin will be hosting and sponsoring an SEI engagement workshop designed to help get participants from across the NNCI up to speed on SEI efforts, and ASU is redesigning the Science Outside the Lab program to train each participant as SEI ambassadors who can take what they've learned in the program back to their home institutions.
9. NCI-SW, RTNN, NNF, SDNI, nano@stanford, and SENIC participate in the Nanotechnology Applications and Career Knowledge (NACK) Network's Remote Access Instrumentation in Nanotechnology (RAIN) coordinated by Penn State University. SDNI became the top performer within the RAIN nationwide network that includes 28 institutions.
10. Several sites (ASU, Georgia Tech, and UC San Diego) collaborated with Penn State's Nanotechnology Applications and Career Knowledge (NACK) to create the Microelectronics and Nanomanufacturing for Certificate Program. Designed specifically for US military personnel and veterans, this program was funded by an NSF Advanced Technological Education (ATE) grant. The program is developing and offering a 12-week program, where each site provides laboratory access to students from a local community/technical college.
11. Several sites participate in education programs and meetings organized by MNT-EC (Micro Nano Technology Education Center), NACK (Nanotechnology Applications and Career Knowledge) network, and MNTeSIG (Micro Nano Tech Education Special Interest Group).

Site Activity on Behalf of the NNCI

1. CNF publishes "Nanooze", and, in addition to direct distribution to classrooms, distributes it to all NNCI sites for use in their outreach activities.
2. Georgia Tech (SENIC) maintains the current NNCI website. RTNN receives requests from the Spanish language "Contact Us" form and responds to all inquiries made via this method.
3. CNF manages the iREU program that affords a second-year research experience abroad from among the highest rated REU interns from the previous summer.

4. CNF organizes the iREG program, which provides for graduate students from Nanotechnology Platform Japan to spend time in NNCI labs during a summer research experience.
5. NanoEarth continues its partnership with Jim Metzner with 5 programs developed for the "Pulse of the Planet" radio show. This year's episodes featured Karen Sorber, Chief Executive Officer and Cofounder of Micronic Technologies, discussing innovative technology for revolutionizing water treatment and recovering waste products and nanoparticles. "Pulse of the Planet" is heard on over 265 NPR radio stations by 1.1M listeners per week and is available as a podcast on Stitcher and iTunes.
6. Hosting of NNCI Annual Conference by CNF (October 2022)
7. Hosting of NNCI REU Convocation by KY Multiscale (August 2022)
8. KY MMNIN hosts the UGIM website and several NNCI staff are members of the UGIM Steering Committee (Aebersold (KY MMINI), Cibuzar (MINIC), and Tang (Stanford)).
9. David Gottfried (CO and SENIC) and Matt Hull (NanoEarth) were partners in the EU Horizon 2020 funded project NanoFabNet and Quinn Spadola (CO and SENIC) was a partner in a sister project SUSNANOFAB. Both projects aim to develop hubs for sustainable nanofabrication.
10. Washington Nanofabrication Director Dr. Maria Huffman (NNI) was selected as a member of the external advisory board of Myfab, the Swedish Research Infrastructure for micro and nanofabrication, and she was invited to Sweden for a meeting at Chalmers University in Gothenburg in September 2022. She was also invited to give a presentation about the WNF and discuss its infrastructure at Lund University through NanoLund and the Department of Solid State Physics.
11. Daniella Duran (nano@stanford) advised and provided organizational support for the NNCO-Nanoeducators Forum and also coordinates the network-wide list for educators called "NNCI Educators" to highlight nano resources across the network and beyond to K-14 educators.

10.2. Regional Facility Networks

Initiated by efforts at MiNIC and MANTH, a number of sites within the NNCI have established informal networks of regional fabrication and characterization facilities to provide mutual assistance, develop best practices, and provide staff networking opportunities. The map below (Figure 15) shows the updated geographic distribution and regional clustering of these networks, along with a brief description of each. The New Yok State Nanotechnology Network (NNN) was newly added in 2022.

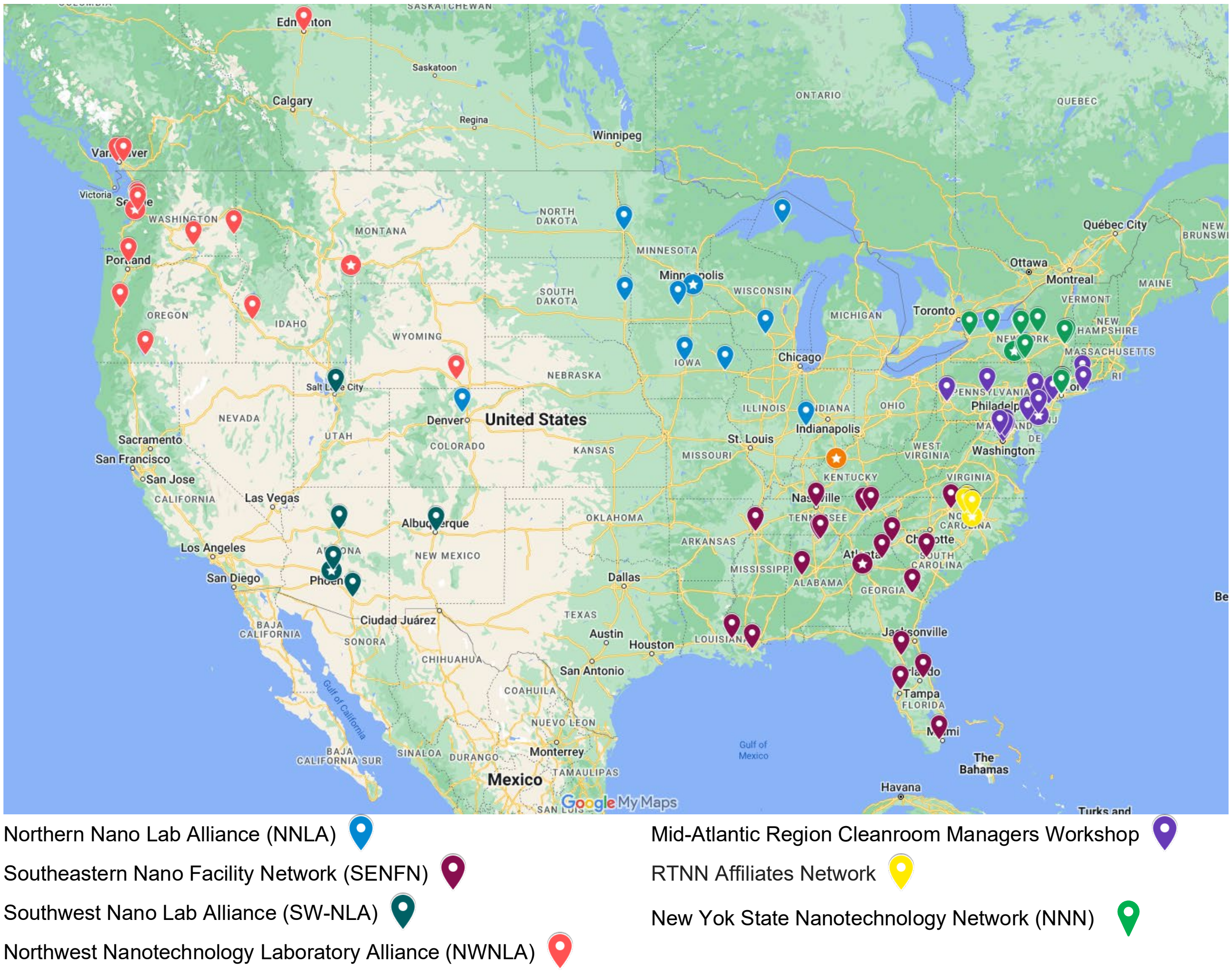


Figure 15: NNCI Regional Facility Networks

MINIC: The **Northern Nano Lab Alliance (NNLA)** is a regional network of university fabrication facilities. Its mission is to help each member improve their support of academic research in applied nanotechnology.

SENIC: The **Southeastern Nano Facility Network (SENFN)** was created in 2018 as a regional network of nanoscale science and engineering user facilities located in the SE United States. The objectives of this network are to share information on capabilities and events at each facility, discuss best-practice solutions to common challenges, and begin a process for informal staff-level technical exchanges.

MANTH: The **Mid-Atlantic Region Cleanroom Managers Workshop** began as a gathering of lab managers from the academic and government cleanroom facilities located in the triangle formed between Washington DC, Brookhaven National Laboratory in NY, and Pittsburgh, PA. The Singh Center for Nanotechnology Quattrone Nanofabrication Facility staff at MANTH created these semi-annual meetings in 2016 in order to share best practices for research cleanroom operations throughout the region.

NCI-SW: The **Southwest Nano-Lab Alliance (SW-NLA)** will disseminate best practices in cleanroom management, equipment purchasing/maintenance, and user training across the partner schools across the southwest. The association will meet annually for a one-day workshop that will rotate amongst the participating labs. The workshop will bring together at least two participants from each lab to discuss best practice for managing cleanrooms and associated multi-user facilities, on-going challenges, and future opportunities.

NNI and MONT: The **Northwest Nanotechnology Laboratory Alliance (NWNLA)** is a joint effort between the NNI and MONT sites to create a regional platform for exchange of laboratory experiences and best practices. Members of NWNLA include nanotechnology facilities in Idaho, Montana, Oregon, Washington, Wyoming, Alberta and British Columbia.

RTNN: The **RTNN Affiliates Network** connects RTNN facilities with other nano-focused university and government facilities in the Triangle. The goals of Affiliates Network are to (1) allow regional facility managers/directors to more readily connect researchers to complementary facilities needed to complete their nanotechnology research, (2) enable facility leadership and staff from across the Triangle to communicate timely information efficiently and effectively about instrumentation and other opportunities, and (3) develop strategic partnerships on emerging opportunities and technical needs that support the facilities or user base.

KY-MMNIN: The **Ohio Valley Regional Nano Network** (no members identified yet) has the objective of building a network of researchers from facilities throughout the Ohio Valley. The purposes of the network are to exchange information on operations and capabilities, host processing seminars, accelerate access to KY Multiscale core facilities, and encourage best practices and collaborative research.

CNF: The **New Yok State Nanotechnology Network (NNN)** is focused on bring together NY state universities and industry to help build local relationships, solve common problems, and grow awareness of the state's capabilities as they pertain to micro and nanotechnology. This network allows universities/colleges and industry to partner and expand technology skills and capabilities while providing synergies that are strengthening technology and the workforce in New York state.

10.3. NNCI Seminar Series

While initially created in 2021 as a way to share technical content about computation, modeling, and simulation with the greater NNCI community, the NNCI Seminar Series quickly expanded to a semi-monthly series with speakers selected by the Coordinating Office Associate Directors to highlight their specific topical areas. Information about the videos is shared with NNCI sites, posted on the NNCI website, and disseminated on social media as well as by external organizations such as the NNCO. Typical attendance during the live events in 2022 averaged around 26 (range:11-45). Video recordings are then posted on the NNCI YouTube channel (see below). The schedule of 2022 seminars is provided in Table 13.

Table 13: NNCI 2022 Monthly Seminars

Date (Topic*)	Speaker(s)	Affiliation	Title
January 26 (E)	Mike Russo, President and CEO	National Institute for Innovation and Technology (NIIT)	"The NIIT National Talent Hub: Connecting Educators, Talent and Employers in

	Robert Weinman, Director of Workforce Innovation		Strategic, Tech-based Industries”
February 23 (S)	Kristen Kulinowski, Director	Institute for Defense Analysis, Science and Technology Policy Institute	“From Wow to Yuck to Meh: The Normalization of Nano Risk”
April 27 (C)	Gerhard Klimeck, Director	NanoHUB	“Semiconductor workforce development through immersive simulations on nanoHUB.org”
May 18 (S)	Dr. Arie Rip, Prof. Emeritus of Philosophy of Science and Technology Dr. Carlo Altamirano Allende, Public Policy Consultant Dr. Ayesha Chaudhary, Consultant	University of Twente, the Netherlands Albaa Legal+Tech, Mexico City World Bank	“Science Policy Around the World in 2022: Innovations and Uncertainties in the Global Knowledge System” Moderator: Buki Makinde, School for the Future of Innovation in Society, Arizona State University
August 31 (E/C)	Azad Naeemi, Professor	School of Electrical and Computer Engineering, Georgia Tech	“Virtual Immersive Worlds for Experiential Learning of Quantum and Semiconductor Physics”
September 28 (C)	Tony Low, Professor	Department of Electrical and Computer Engineering, University of Minnesota	“Theoretical Exploration of Energy Efficient Spintronics Devices"
October 12 (I)	Miguel Urteaga, Director of Foundry Products and Services	Teledyne Scientific Company	“Lab-to-Fab: Transitioning from University Cleanrooms to Industrial Prototyping and Low-Volume Production”

*C=Computation, S=SEI, E=Education, I=Innovation

10.4. NNCI YouTube Channel

The NNCI YouTube Channel was created in April 2018 as a way to host the NNCI Introduction Video created that year. During 2021, the channel was expanded to include additional Playlists for Education Videos, Seminar Series, and Training Videos. Education videos include careers in nanotechnology content created by Jim Marti (MiNIC) and Matt Hull (NanoEarth), which are public, as well as an RET information session (which is unlisted, but used by the RET program). The NNCI seminar series (see above) videos since May 2021 are all archived on the channel and are public. Finally, the Training Video playlist was created for future content and currently holds a video on Evaporative Deposition (unlisted) which is being tested internally. Overall, the channel has 166 current subscribers (81 new added in 2022) and 3,209 views during 2022, more than twice that in 2021. Analytics of the top video content during 2022 is shown in Table 14 below, with newly-added videos in bold.

Table 14: NNCI YouTube Video Analytics (2022)

Video*	Views	Average View Duration
Careers in Nanotechnology: Opportunities for STEM Students (Jim Marti, MiNIC)	890	2:49 (20.8%)
The Evolution of Process TCAD in Semiconductor R&D and Manufacturing (Shela Aboud, Synopsys)	679	5:49 (9.9%)
What is the NNCI?	279	1:28 (40.4%)
X/Nano: The Enabling Potential of a Career in Nanoscience (Matt Hull, NanoEarth)	242	4:32 (15.5%)
The NIIT National Talent Hub (Mike Russo and Robert Weinman, NIIT)	**169**	**7:01 (11.8%)**
Simulation Software Next Door (Dragica Vasileska, ASU)	163	4:45 (7.8%)
Semiconductor Workforce Development through Immersive Simulations on nanoHUB.org (Gerhard Klimek, Purdue Univ.)	**130**	**3:36 (6.4%)**
From Wow to Yuck to Meh: The Normalization of Nano Risk (Kristen Kulinowski, Science and Technology Policy Institute)	**102**	**6:41 (11.5%)**
Virtual Immersive Worlds for Experiential Learning of Quantum and Semiconductor Physics (Azad Naeemi, Georgia Tech)	**79**	**2:25 (4.0%)**
Theoretical Exploration of Energy Efficient Spintronics Devices (Tony Low, Univ. Minnesota)	**73**	**1:58 (3.0%)**

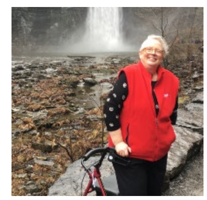
*Videos added in 2022 are bolded.

10.5. NNCI Outstanding Staff Awards

During 2022, the NNCI Coordinating Office organized the fifth 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 June 2022 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 and was recognized at the 2022 Annual Conference, with travel support provided to attend. Awardees from 2020 and 2021 were also recognized at the first in-person conference since 2019.

Education and Outreach

- Melanie-Claire Mallison (Administrative Assistant and Public Relations and Publication Associate, CNF)



"…estimated to have personally interacted with 240 CNF REUs, 153 International REUs, and 1,263 Network REUs…takes the group participants from diverse backgrounds under her wing, working diligently to ensure the best possible research and life experience…"

- Daniella Duran (Director of Education & Outreach Programs, nano@stanford)

"…extended her impactful efforts to reach various K-12, community college, and public communities beyond our network…spearheaded new partnerships…"

Technical Staff

- Bashir Jama (Electromechanical Systems Specialist, MiNIC)

"…excellence in technical proficiency, forward-looking proactive initiative. Building a positive workplace culture, and dedication to customer-focused service…a rare ability to manage several concurrent projects while also keeping track of important preventive maintenance."

- Tom Carver (Flexible Cleanroom Lab Manager, nano@stanford)

"…a tremendous resource for users during training and later advising on existing processes, troubleshooting existing and developing new processes…successfully transitioned all existing users to the new tool and in the process managed to double the user base from about 150 to 300 users!"

User Support

- Aaron Windsor (Research Support Specialist III/Senior Engineer Thin Films, CNF)

"…providing state-of-the-art, hands-on education to a diverse group of academic and industry users from around the world…interacts with users to constantly troubleshoot and develop imaginative and innovative solutions…"

- Melissa Gammon (Administrative Associate, RTNN)

"…effectively guides users through the registration process and provides responsive troubleshooting support…possesses a diverse skillset and is an excellent role model for how administrative staff can dramatically enhance the overall productivity of a research core facility."

11. 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 user programs. 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 8.3 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 10 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.

11.1. NNCI Aggregate User Data (Oct. 1, 2021 - Sept. 30, 2022)

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 12), we have not included exhaustive sets of individual site data here, but rather the aggregate for the NNCI network. In Table 15 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 15: Summary of NNCI Aggregate Usage Data (Year 7)

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users	13,348	834 (233 – 1,677)
Unique Internal Users	9,967	623 (162 – 1,424)
Unique External Users	3,381 25.3%	211 (71 – 456) 26.0% (15.1% – 46.9%)
External Academic	1,238	77 (16 – 282)
External Industry	1,882	118 (27 – 301)
External Government	209	13 (0 – 1115)
External Foreign	52	3 (0 – 17)
Average Monthly Users	5,112	319 (75 – 759)
New Users Trained	5,151	322 (54 – 649)
Facility Hours*	1,072,332	67,021 (9,142 – 179,802)
Facility Hours – External Users	253,667 23.6%	15,854 (1,630 – 66,378) 22.3% (6.7% – 51.1%)
Hours/User*	80	77 (27 –148)
User Fees Internal Users External Users	 $24.4M $20.1M	 $1.52M $1.26M

*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 attempted 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 1-7 is shown in Table 16 below. As can be seen, most metrics show significant double-digit percentage increases from Year 6 to Year 7. Of course, this needs to be taken with the context that all site facilities are recovering from reduced operations and usage seen in Years 5 and 6 due to the COVID-19 pandemic. In fact, many metrics have increased to the levels seen in Year 4, just prior to the pandemic, and the "best" year for NNCI. The exception to this recovery is in the external users, with total external users in Year 7 still approximately 12% lower compared to Year 4, and even more specifically in the external academic user metric, which remains 19% lower than Year 4. We can speculate that the ongoing pandemic has continued hurdles for travel to NNCI facilities as well as the general pressures on research funding available. Finally, it should be noted that, with the start of the second 5-year funding period, i.e. in Year 6, a few facilities have been dropped and others have been added to the network sites (see Section 1.2). The changes in internal and external users and usage hours over the first seven years of NNCI are illustrated in Figures 16 and 17. These further illustrate the improvement in Year 7 compared to Year 6, and the ongoing recovery from the impact of the pandemic when compared to earlier years of NNCI, although the recovery in external usage continues to lag that of the internal users.

Table 16: Comparison of Years 1-7 NNCI Aggregate Usage Data

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Δ Year 6 - 7
Unique Facility Users	10,909	12,452	13,110	13,355	10,501	11,242	13,348	+18.7%
Unique Internal Users	8,342	9,276	9,731	9,503	7,668	8,449	9,967	+18.0%
Unique External Users	2,567 23.8%	3,176 25.5%	3,379 25.8%	3,852 28.8%	2,833 27.0%	2,793 24.8%	3,381 25.3%	+21.0%
External Industry Users	1,413	1,669	1,870	1,961	1,529	1,619	1,882	+16.2%
External Academic Users	1,060	1,295	1,365	1,531	1,064	964	1,238	+28.4%
Average Monthly Users	4,429	4,911	5,001	5,292	3,654	4,381	5,112	+16.7%
New Users Trained	4,116	4,563	4,981	5,194	2,813	4,414	5,151	+16.7%
Facility Hours	909, 151	939,230	1,006,764	1,149,788	767,255	967,297	1,072,332	+10.8%
Facility Hours – Ext Users	173,511 19.1%	191,494 20.4%	228,441 22.7%	298,986 26.0%	197,368 25.7%	242,926 25.1%	253,667 23.7%	+4.4%
Hours/User	83	75	77	86	73	86	80	-7.0%
User Fees								
Internal	$20.6M	$23.0M	$23.6M	$23.2M	$16.3M	$21.9M	$24.4M	+11.4%
External	$13.5M	$14.5M	$16.9M	$20.5M	$13.1M	$17.8M	$20.1M	+12.9%

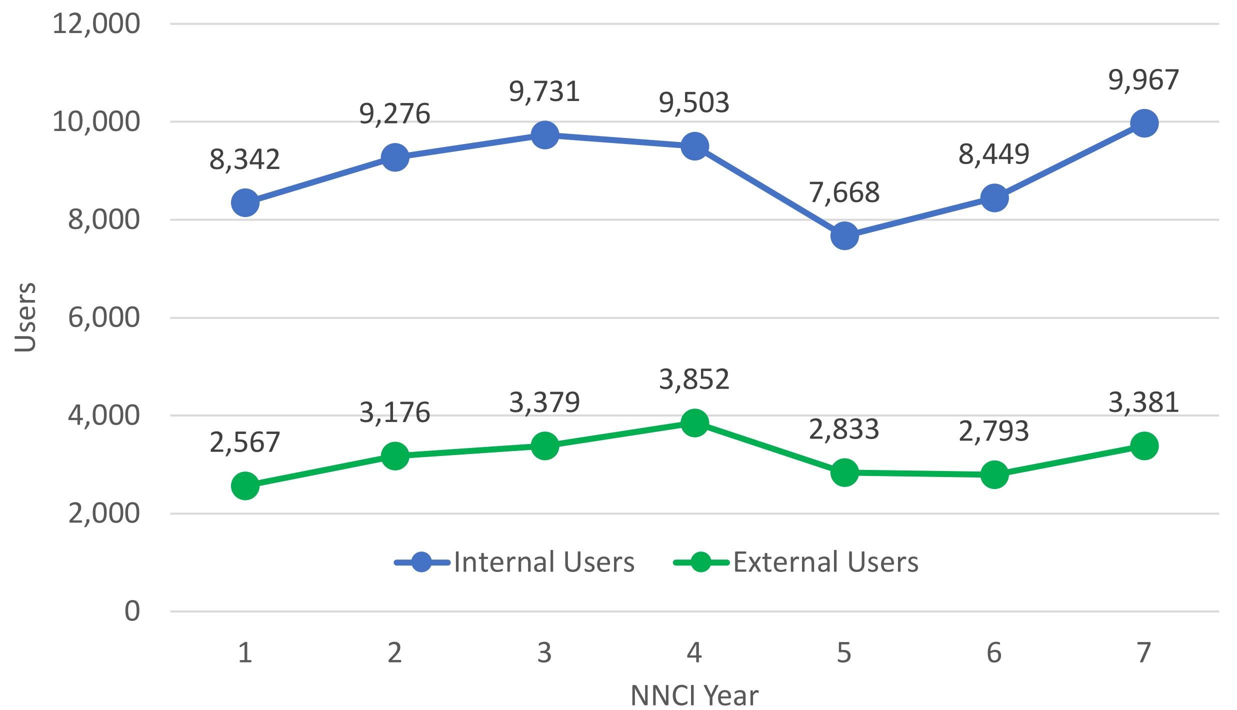


Figure 16: NNCI Users by Year

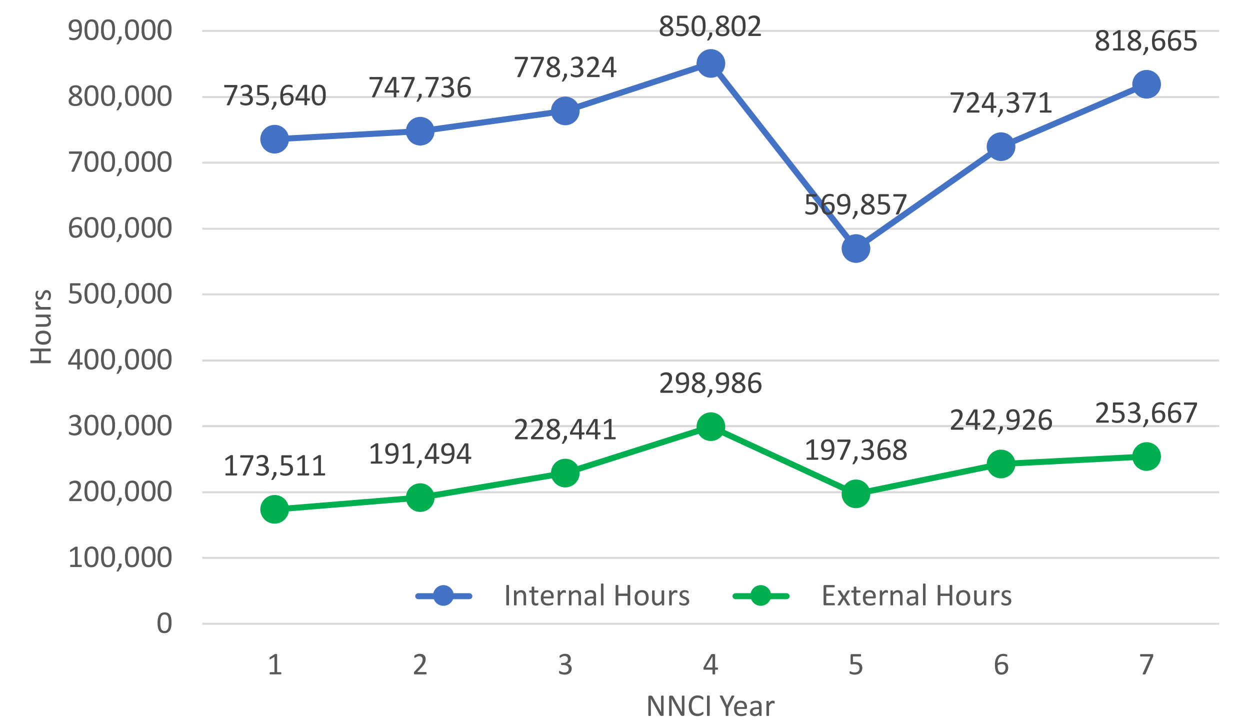


Figure 17: NNCI Usage Hours by Year

Since re-opening of NNCI facilities during the June-August 2020 timeframe, sites have continued to grow operations so that they are near normal (pre-pandemic) usage capacity, with no limits on external usage and regular training opportunities. The effects of the pandemic are most striking for external users (and training). Nevertheless, the fraction of users and hours from external sources, 27% and 26% respectively, remained relatively constant over the course of Year 5 compared to Year 4 (see Table 15) but showed a slight decline in Year 6 (25% external users and external hours), the first full 12-month pandemic period, and has remained reduced (25% external users and 24% external hours) compared to the peak achieved in Year 4.

A deeper analysis of the effects of the pandemic closures and recovery of usage is explored in the figures below. Figures 18 and 19 show the Years 4-7 monthly change in cumulative users and lab time, respectively, across all NNCI sites. It is clear that usage at the beginning of Year 5 was on a pace to match or exceed that of Year 4, but plateaued suddenly when facilities were shut down in March 2020 and only began to recover partially beginning in June 2020. The number of users began Year 6 at a lower level and grew over that year at a slightly reduced pace and were unable to reach pre-pandemic totals. However, in Year 7, total cumulative users matched that of the pre-pandemic period. Recovery in usage hours also appears robust, although not complete, with a 7% decrease in Year 7 total hours compared to Year 4. The effect on cumulative external usage is further illustrated in Figure 20 which shows the percentage of cumulative external users by month for Years 4-6. It is clear that in Year 4 (and previous years) the fraction of external users increases throughout the year, with an enhanced rate during the summer months likely benefited by REU students and other summer researchers. During Year 5, of course, this summer effort was curtailed and the overall decrease in external usage is obvious. This effect has continued into Years 6 and 7.

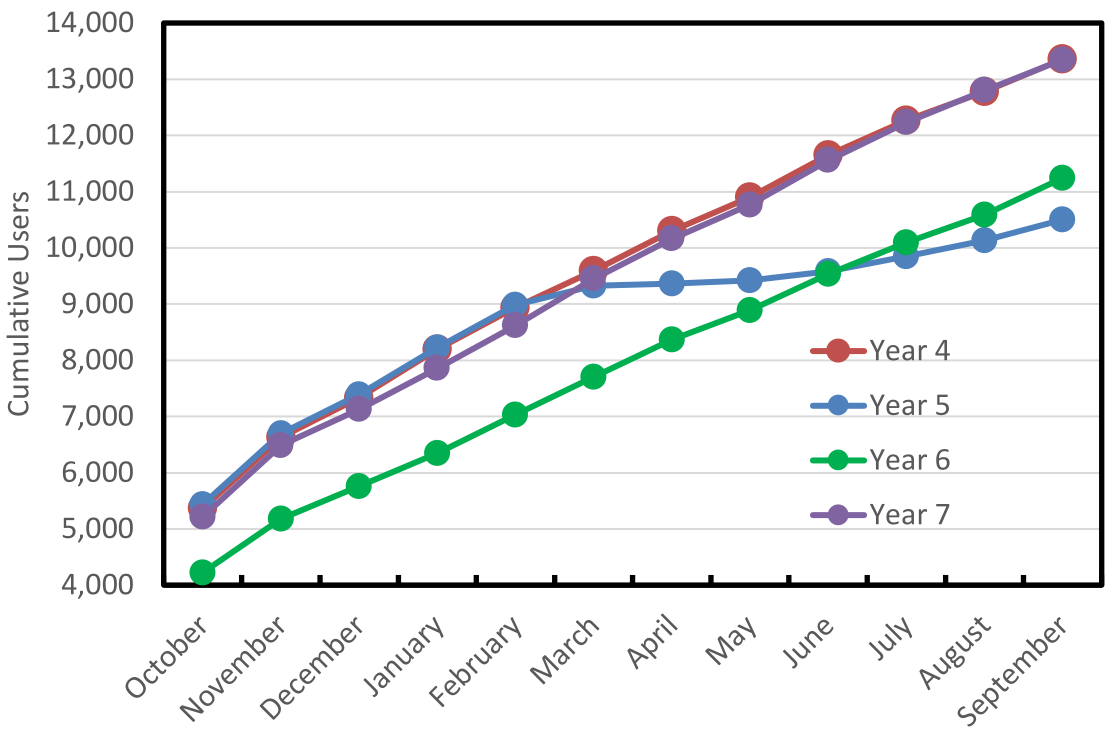


Figure 18: NNCI Cumulative Users by Month for Years 4-7

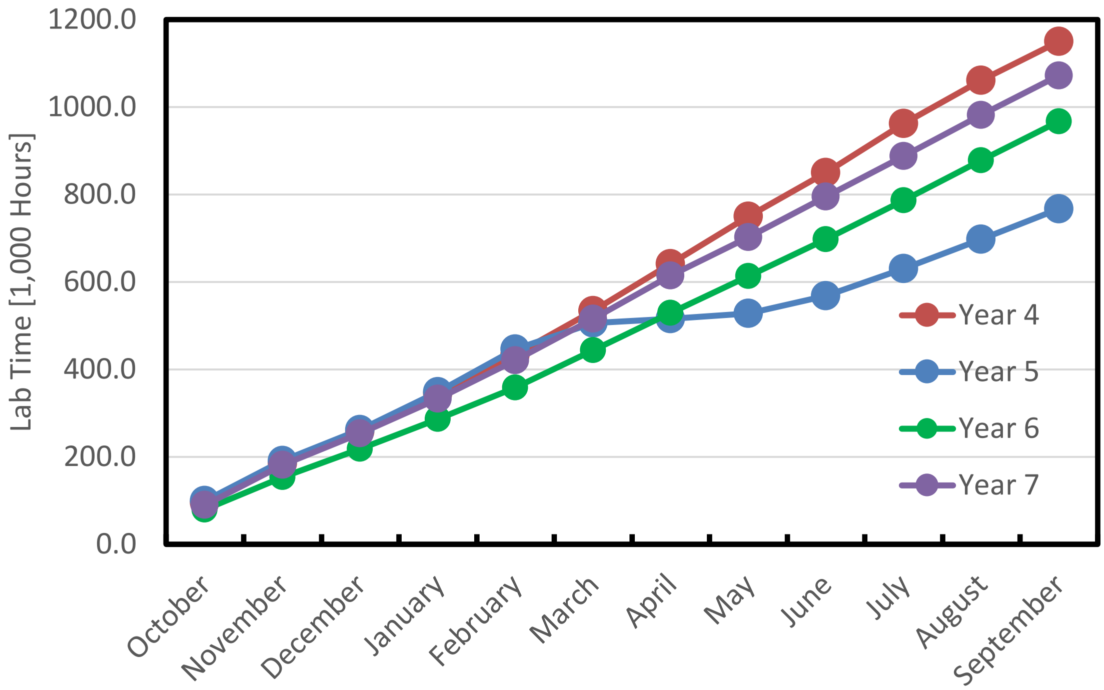


Figure 19: NNCI Lab Usage Time (1,000s of Hours) by Month for Years 4-7

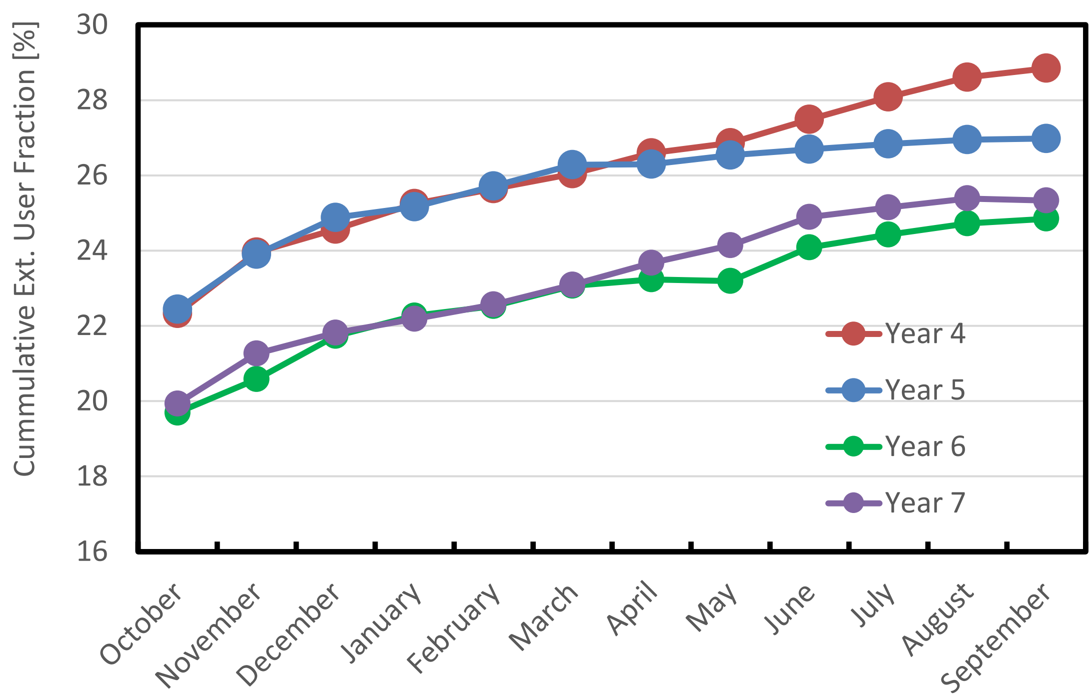


Figure 20: NNCI Cumulative External Users (%) by Month for Years 4-7

As can be seen in the figures above, at the start of Year 6 the overall external usage started off lower than pre-pandemic and failed to recover fully even with robust month-over-month increases. While in Year 7 the total usage has shown near full recovery, external usage continues to be depressed. These differential pandemic effects on usage are amplified in Figures 21 and 22, which shows the number of monthly internal and external users across the NNCI, and indicates that, during NNCI Year 7, monthly internal users reached values seen in Year 4 and the beginning of Year 5. Monthly external users at the end of Year 7 remain 7% below pre-pandemic levels, although they started the year at 15% below so some improvement over the 12 months was observed. Monthly internal users in Year 7 averaged 4,056 which is 99% of the Year 4 average (4,102), while monthly external users in Year 7 averaged 1,056, which is only 89% of the Year 4 average (1,190).

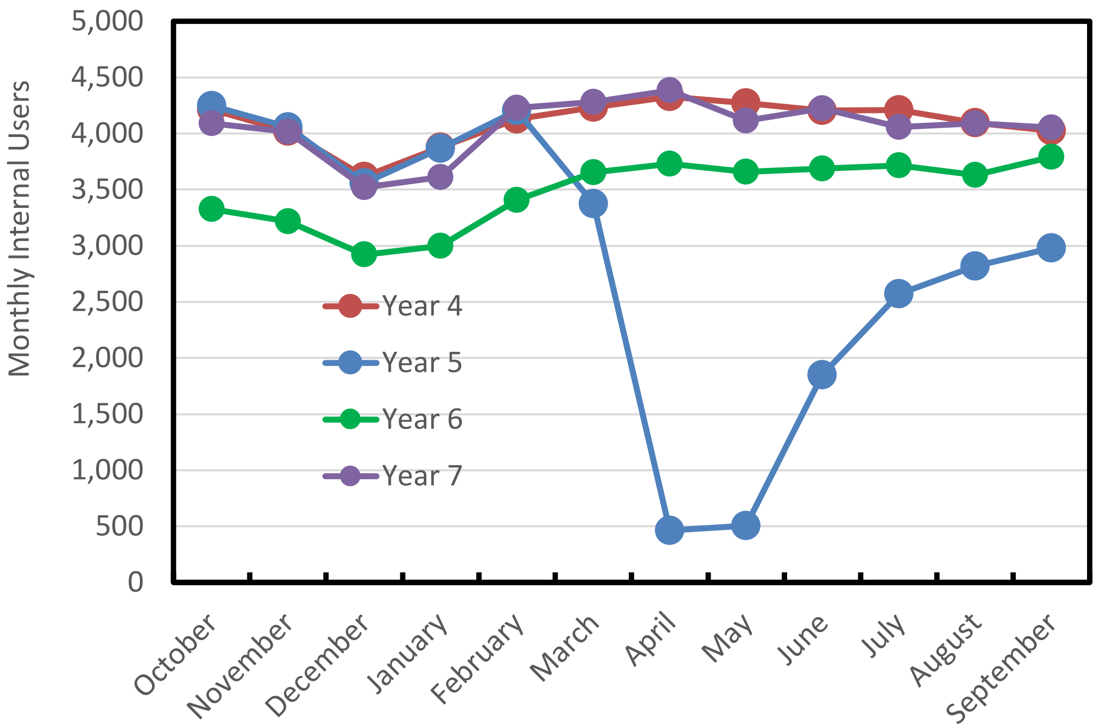


Figure 21: NNCI Total Monthly Internal Users for Years 4-7

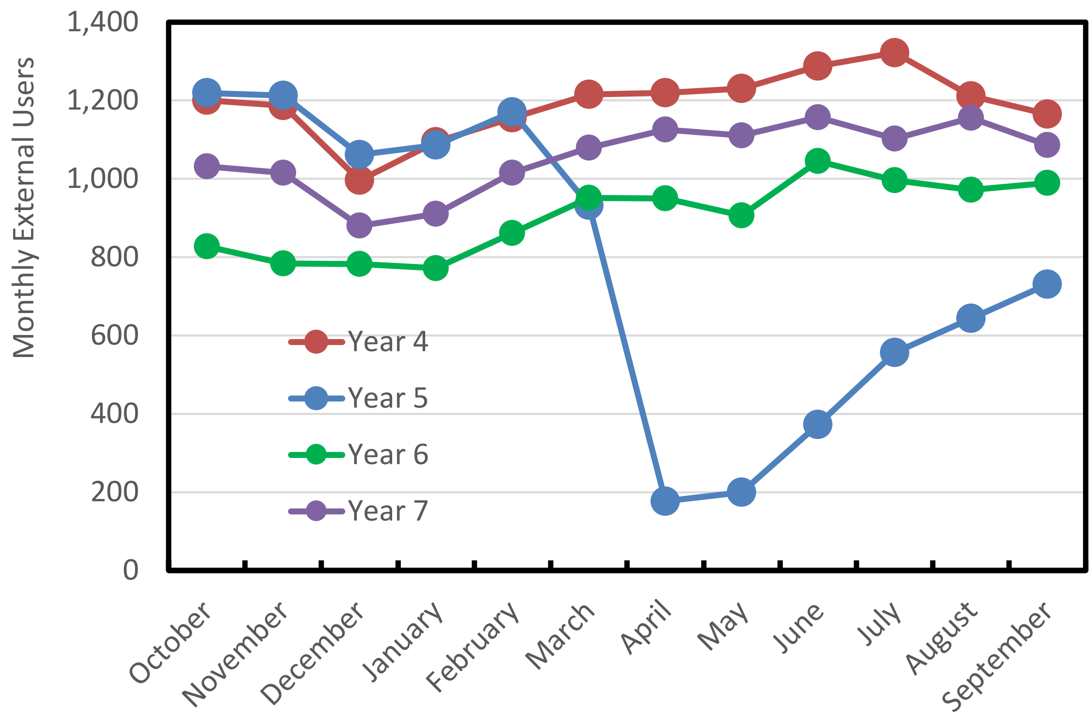


Figure 22: NNCI Total Monthly External Users for Years 4-7

Finally, the pandemic has accelerated a shift to remote usage as can be seen in Figures 23 and 24 for remote users and hours, respectively, begun in Year 6 and continued in Year 7. The assumption is that this mode of access, while more costly for users and labor intensive for facilities, avoids the hurdles associated with travel and training.

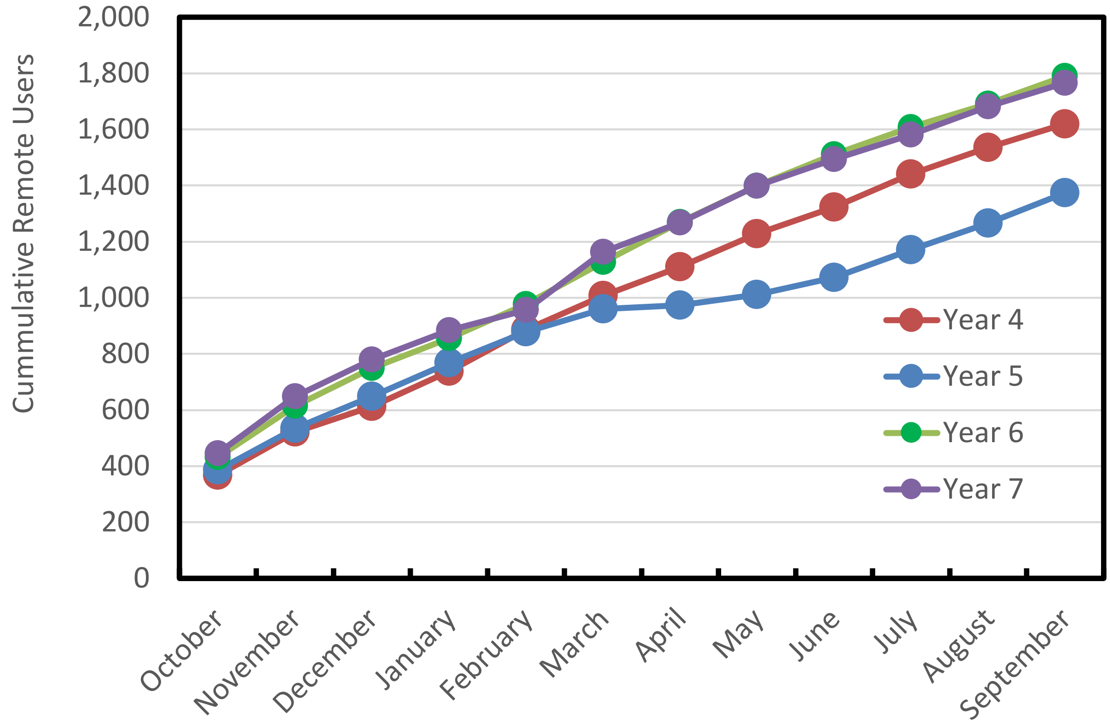


Figure 23: NNCI Cumulative Remote Users for Years 4-7

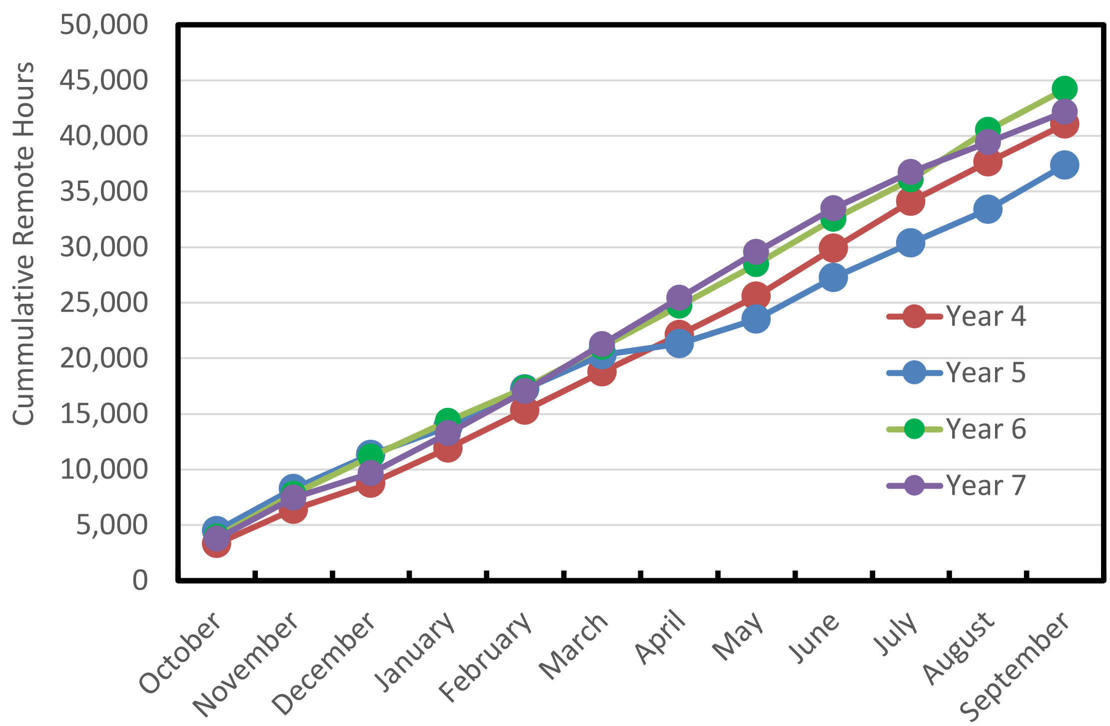


Figure 24: NNCI Cumulative Remote Hours for Years 4-7

The nearly 3,400 Year 7 external users come from 1,061 distinct external institutions (full list shown in Appendix 14.2), including 233 US academic institutions from 49 states and Puerto Rico (Figure 25), 562 small companies, 189 large companies, 17 US local/federal government organizations, 37 international institutions (from Europe, Asia, Africa, North America, and Australia), and 23 other institutions (museums, hospitals, K-12 schools, and other non-profits). 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 99 companies, 5 government organizations, and 1 foreign entity that remain anonymous due to contractual requirements with one NNCI site and may or may not overlap with those listed in the appendix.

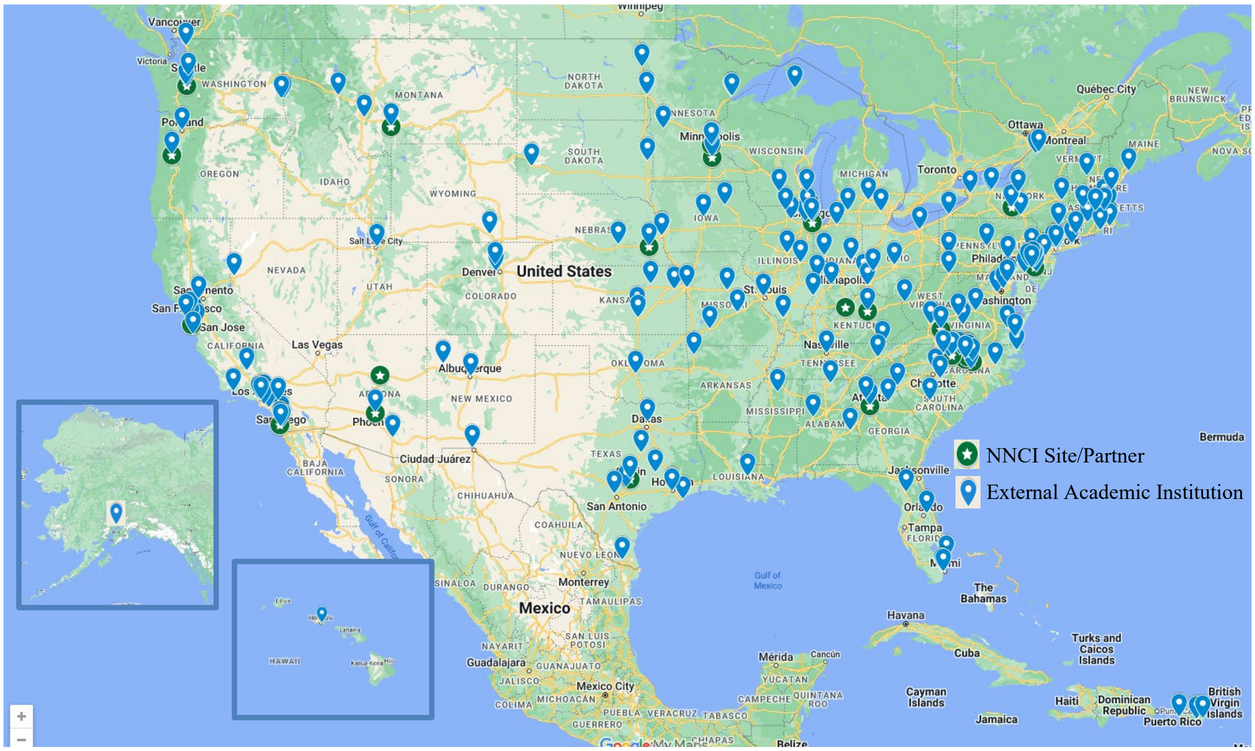
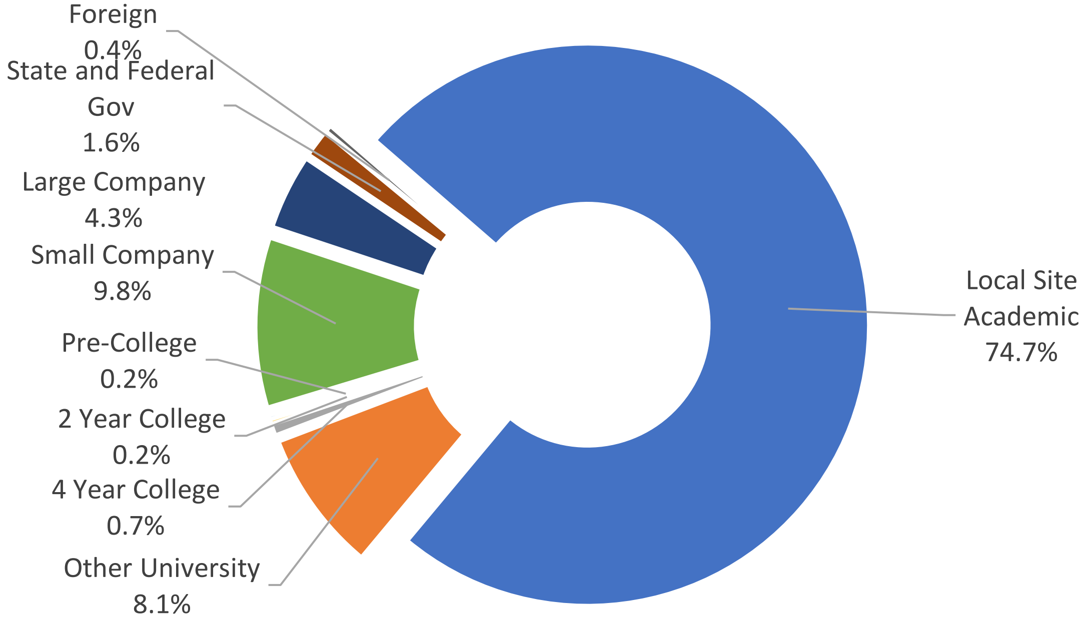


Figure 25: NNCI Year 7 US Academic Institutions (233 External)

Figure 26 shows the distribution of users and lab hours by affiliation for the entire network. Individual affiliation plots are shown for each site in the data of Section 12 below. External users make up 25.3% of total users and external hours are 23.7% of total hours. This difference between external users and hours (1.6%) is slightly larger than was observed in Year 6. The greater fraction of external users compared to their hours has been ascribed as likely due to the proximity and ease of access of internal users to the facilities, which provides them opportunities for greater overall use. This difference between percentage of external users and external hours has been trending downward since the start of NNCI (see Table 16 above), with the smallest difference observed during Year 6.



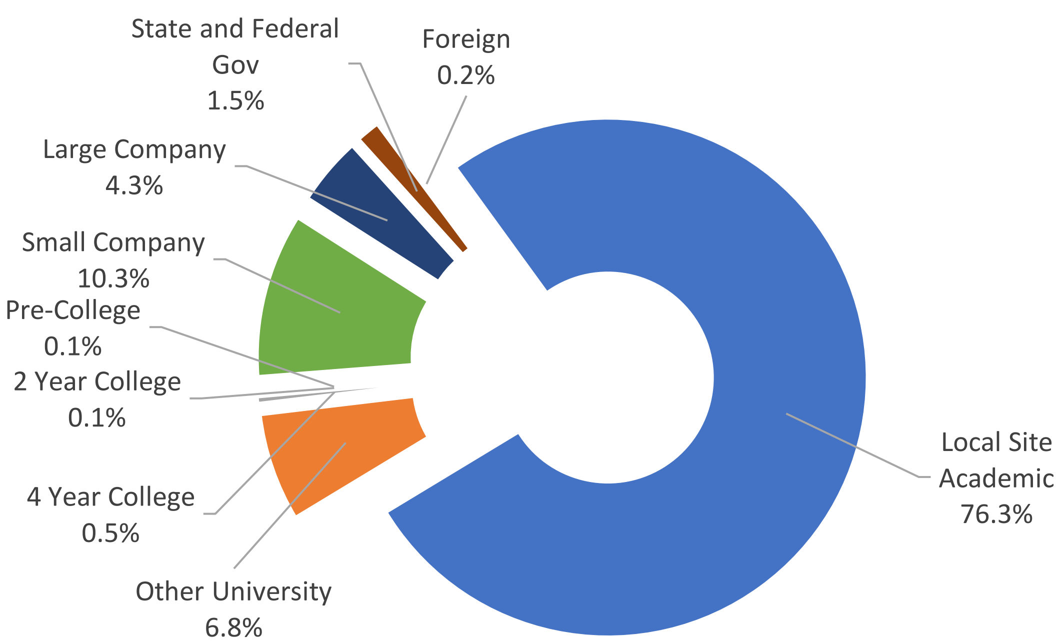


Figure 26: NNCI Users (top) and Usage Hours (bottom) by Affiliation (Year 7)

A comparison of Year 7 cumulative users (by affiliation) by site is provided in Figure 27 for all users and Figure 28 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 were part of the NNIN program, others were not; some have a large number of facilities, tools, and staff, others do not. Thus, it can be difficult to draw conclusions from a site-to-site statistical comparison.

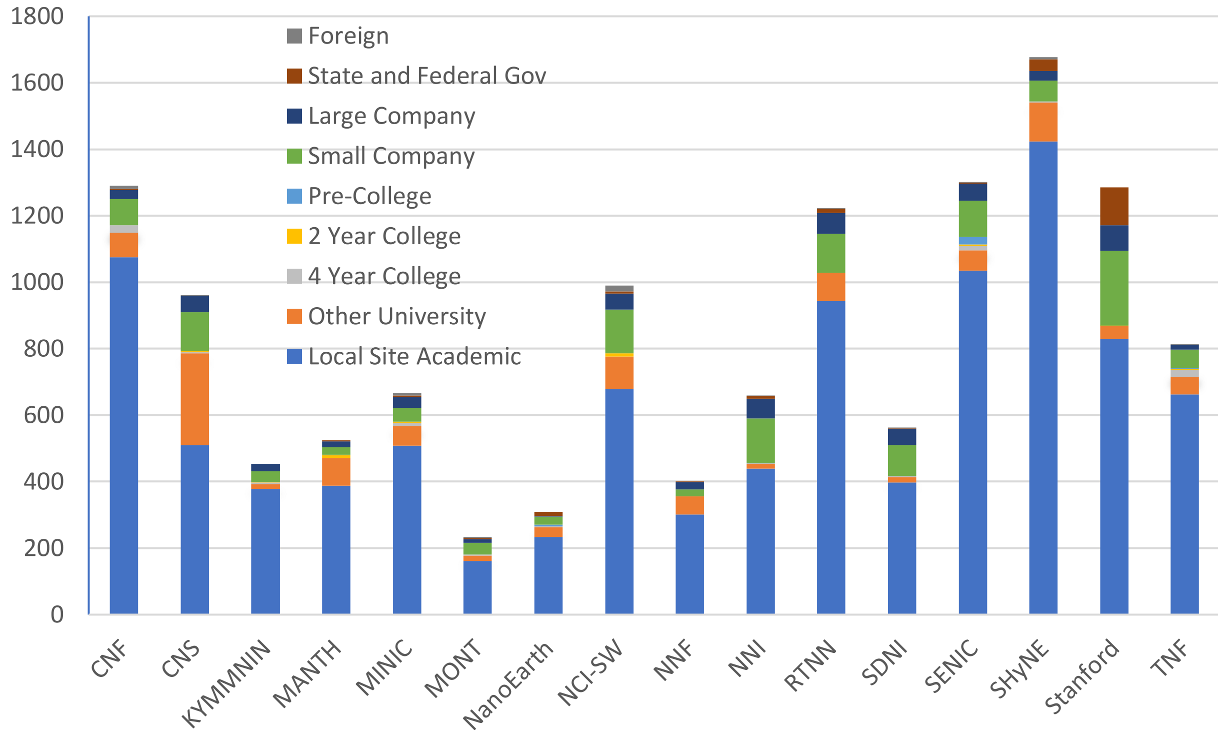


Figure 27: NNCI Cumulative Users by Site (Year 7)

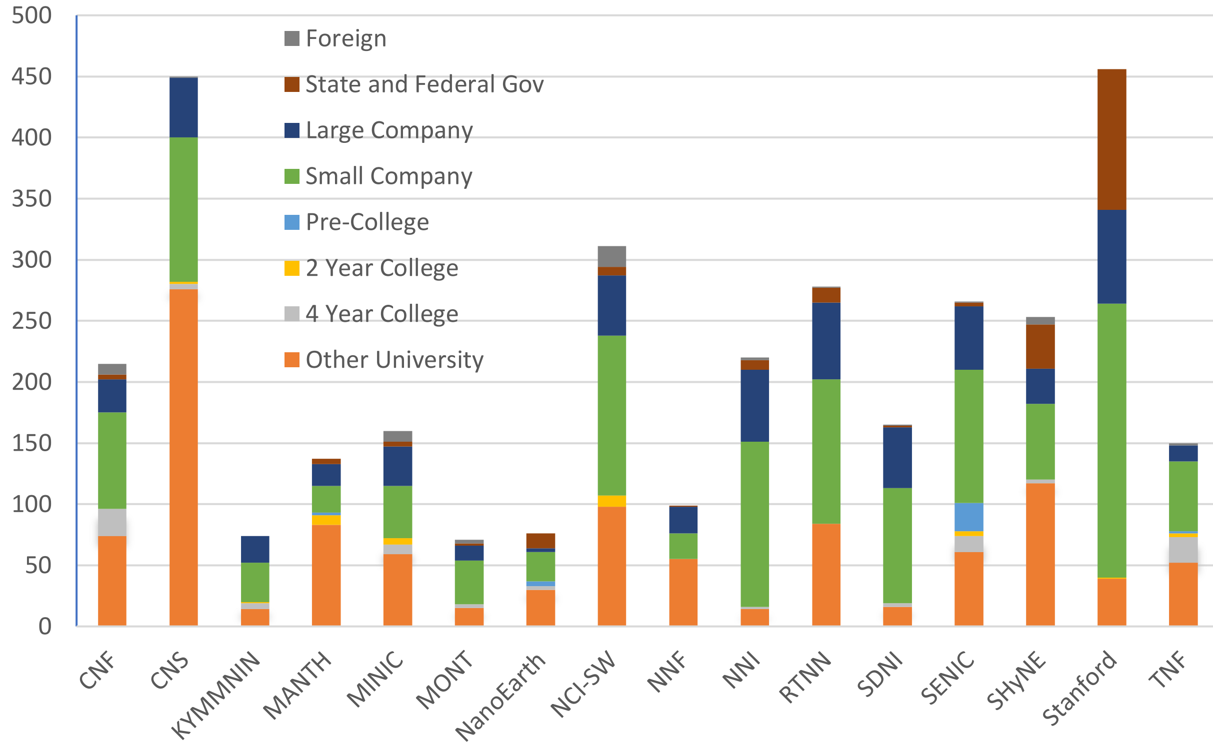


Figure 28: NNCI Cumulative External Users by Site (Year 7)

For academic institutions a network map showing the NNCI nodes and associated US colleges and universities (from 49 US states and Puerto Rico) is shown in Figure 29 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, 43 in Year 7) are labeled in Figure 29, including four institutions (Kansas State Univ., NC State Univ., Univ. of Wisconsin, and Yale Univ.) with projects at four different NNCI sites. Year 1 had 296 linkages between institutions, and this increased each year reaching 395 in Year 4, but fell to 307 in Year 5 due to the pandemic-related decrease in usage and has risen to 349 in Year 7. In addition to the academic usage depicted by the figure, it was also observed that approximately 40 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.

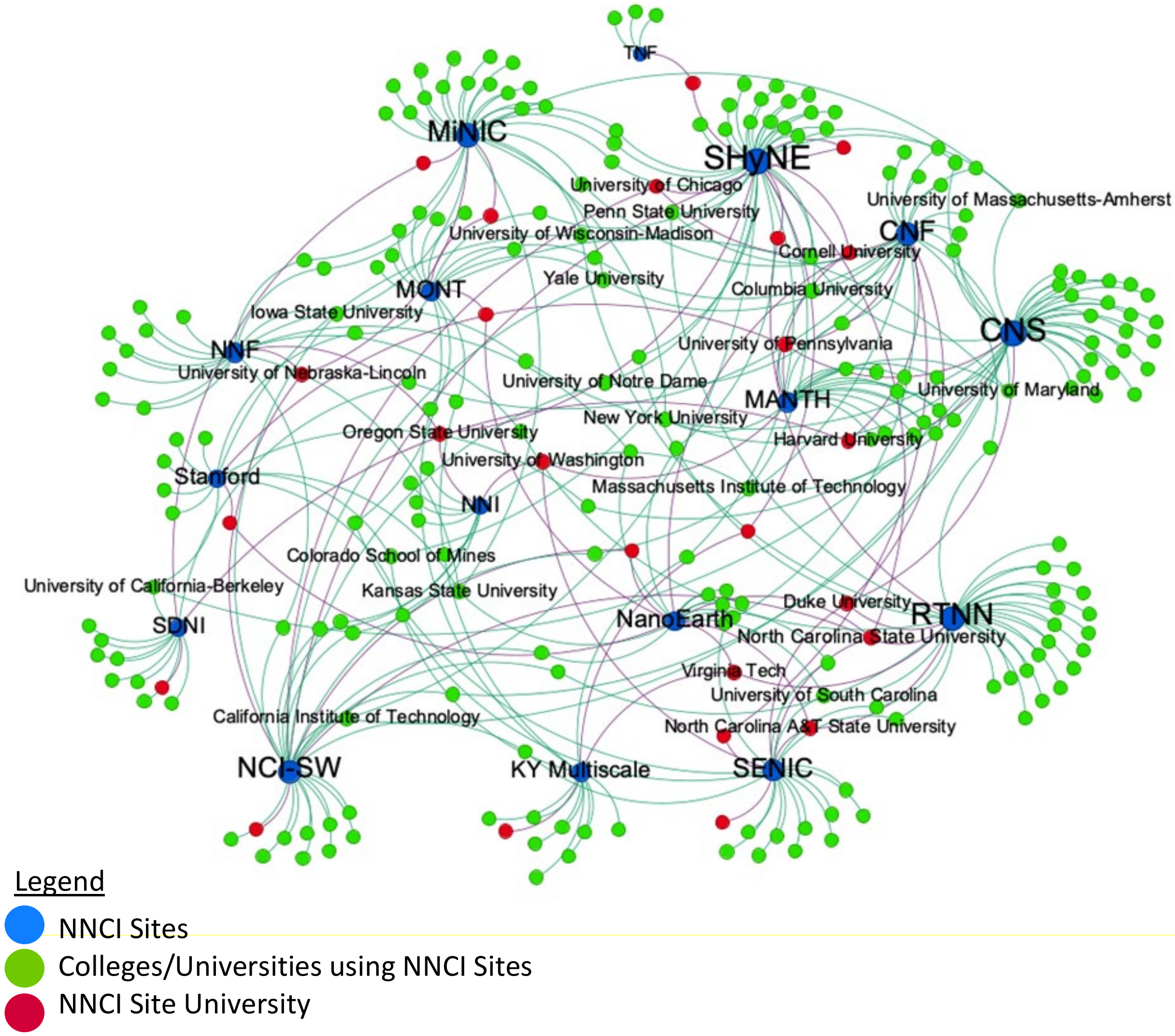


Figure 29: NNCI Academic User Network Map (Year 7)

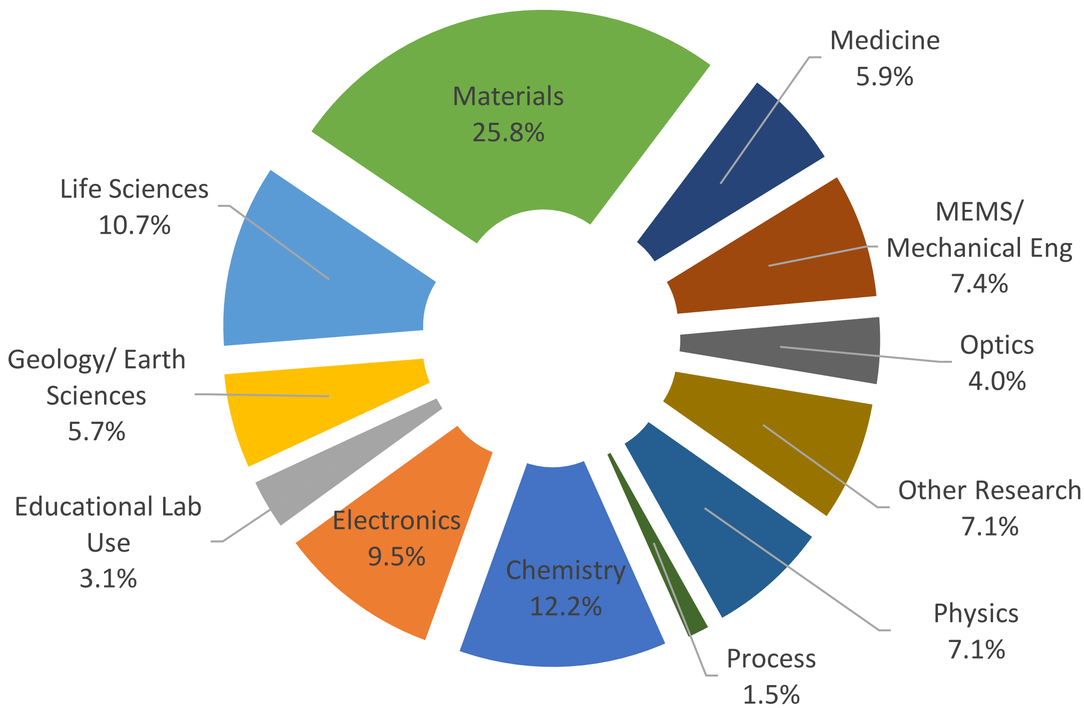
11.2. Non-Traditional Users

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). In addition, the Building the User Base subcommittee has indicated that non-traditional users may come from the following categories:

1. Research areas that do not typically use nanotechnology facilities; these are identified using the disciplines described in more detail below.
2. Demographic groups, such as women and under-represented minorities; information on minority serving institutions is provided below.

3. Users from non-Research I educational institutions; data on 2-year and 4-year colleges are provided in the affiliation statistics above.
4. Small companies; data on small company users are provided in the affiliation statistics above.
5. K-12 students, community college students, and teachers; affiliation data is provided for pre-college users and more information about outreach to this category is provided in Section 4.1.

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, may reflect the user's home department or their specific area of research, and these may be different from each other. Figure 30 illustrates the distribution by number of users and usage hours in specific disciplines. Furthermore, Figure 31 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, physics, and process development tend to require more lab usage by researchers, but with Geology/Earth Sciences also among the hours/user leaders. The usage distributions by discipline are similar to previous years, continuing the rapid growth in Geology/Earth Sciences users (5.7% in Year 7 compared to 2.4% in Year 1) and usage hours (6.7% in Year 7 compared to 1.2% in Year 1), and this is also reflected in the hours/user for that discipline. Overall, users from Geology/Earth Sciences, Life Sciences, and Medicine now comprise 22% of all NNCI users. The annual changes in number of users in each discipline are graphically displayed in Figure 32 (with "Educational Lab Use", "Process", and "Other" removed for clarity).



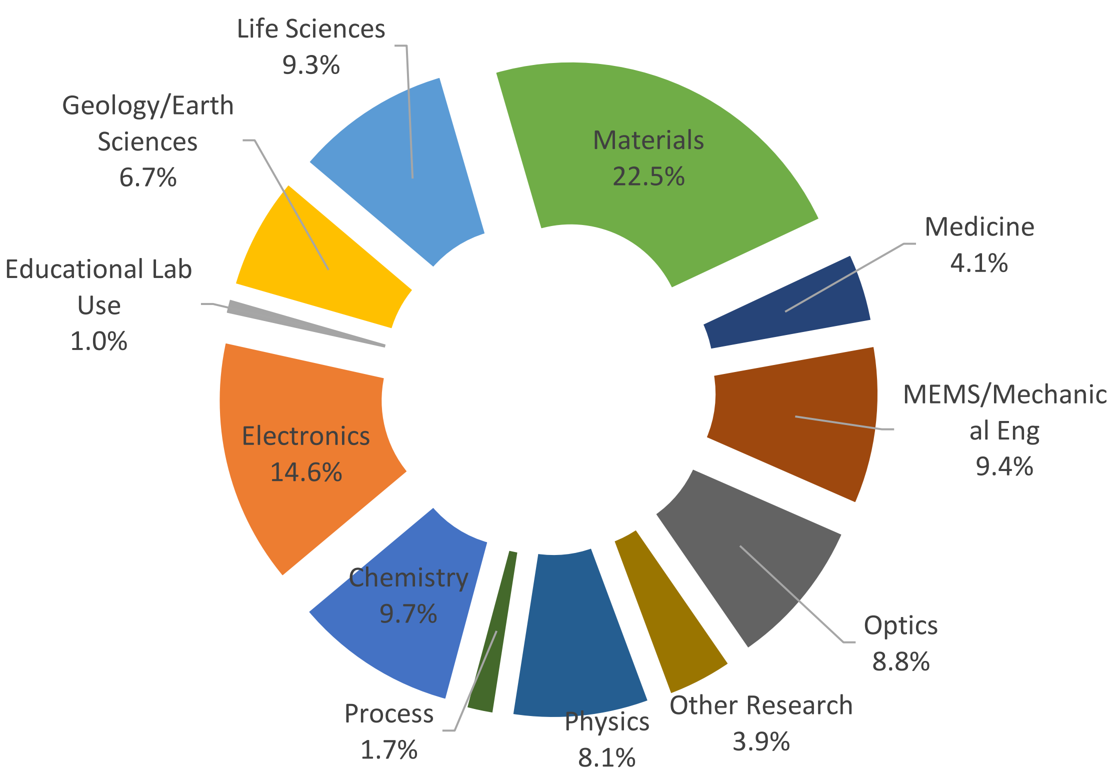


Figure 30: NNCI Users (top) and Usage Hours (bottom) by Discipline (Year 7)

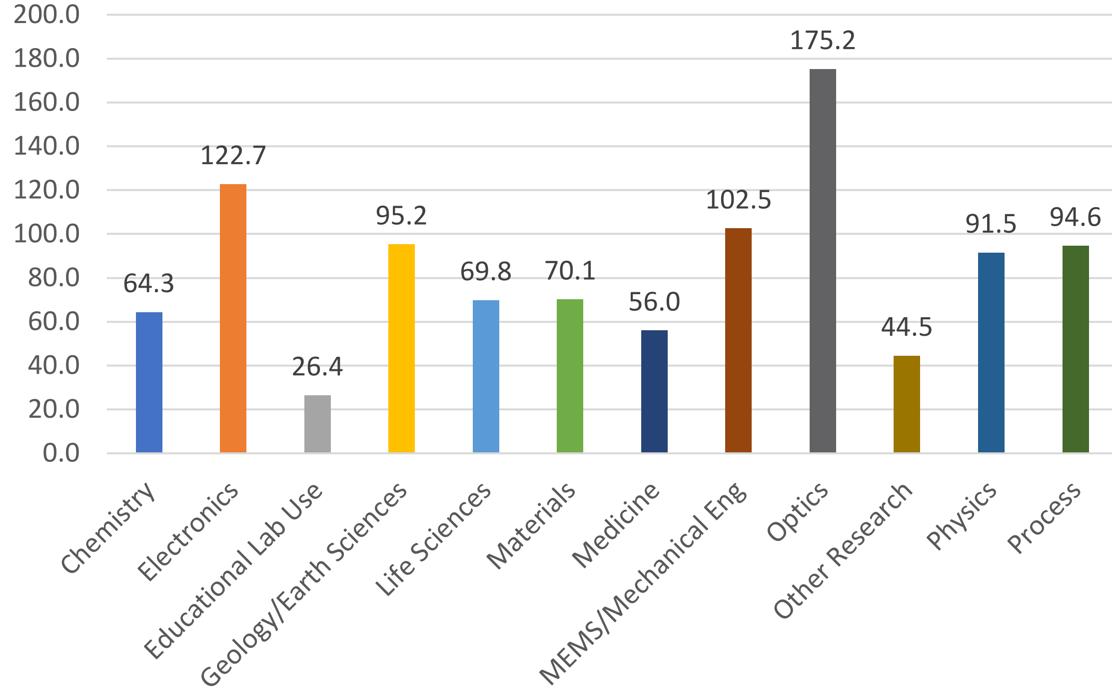


Figure 31: NNCI Hours/User by Discipline (Year 7)

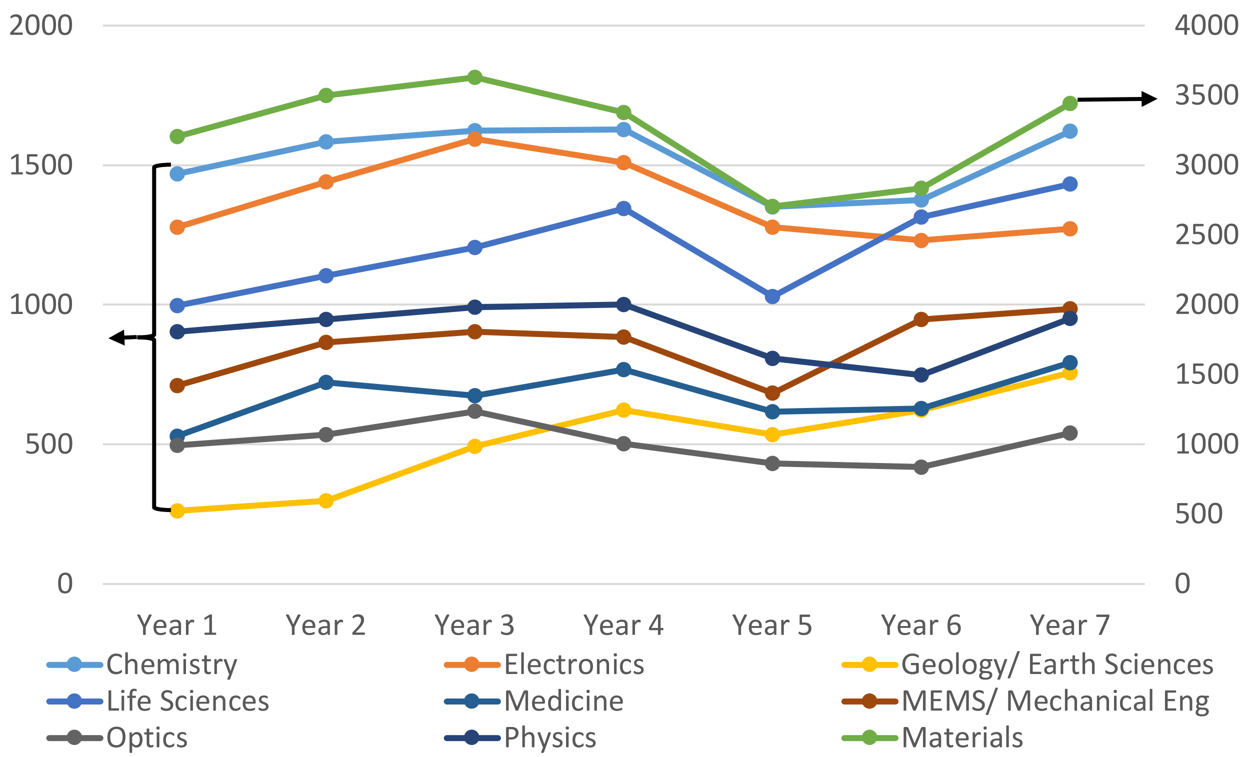


Figure 32: NNCI Yearly Users by Discipline ("Materials" indicated by the right Y-axis for comparison purposes.)

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 17 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 increased significantly and has continued to be the dominant population of users, although the relatively proportion of non-traditional usage hours decreased temporarily during pandemic Years 5 and 6.

Table 17: Usage by Traditional and Non-Traditional Disciplines

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
# of Users							
Traditional*	5,386 (51%)	6,063 (50%)	6,384 (50%)	5,997 (47%)	4,791 (47%)	5,148 (47%)	5,893 (46%)
Non-Traditional**	5262 (49%)	6044 (50%)	6383 (50%)	6750 (53%)	5408 (53%)	5,804 (53%)	7,046 (54%)
Hours of Usage							
Traditional*	495,215 (55%)	506,393 (54%)	510,180 (51%)	543,838 (48%)	374,934 (50%)	474,876 (50%)	516,803 (49%)
Non-Traditional**	409,935 (45%)	424,855 (46%)	490,992 (49%)	588,980 (52%)	382,140 (50%)	476,194 (50%)	544,732 (51%)

* Electronics, Materials, MEMS/ME, Process

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

Since NNCI Year 2, sites have collected PowerPoint slides highlighting individual research activities at their sites during the year, and these are provided separate to this report and archived on the NNCI website (https://nnci.net/nnci-annual-report). Beginning in NNCI Year 4, each slide was tagged with a national research priority, typically one of the NSF 10 Big Ideas, National Academy of Engineering Grand Challenge, or another federal agency (DOE, DOD, White House) research initiative. These annual highlight slides (typically 130-140 each year) provide a glimpse at what research topics are trending at NNCI sites, and the distribution can be seen in Figure 33 below. Between Years 4 and 7 there is relative consistency with approximately 60% of highlights tagged with the NSF Big Ideas of *Quantum Leap*, *Understanding the Rules of Life*, and *Growing Convergence Research*. A further 10% of slides address other NSF Big Ideas and 14% are associated with NAE Grand Challenges. The remainder are either associated with other priorities are not indicated, including 10 slides in Year 7 related to the DoD Critical Technology Area in Microelectronics.

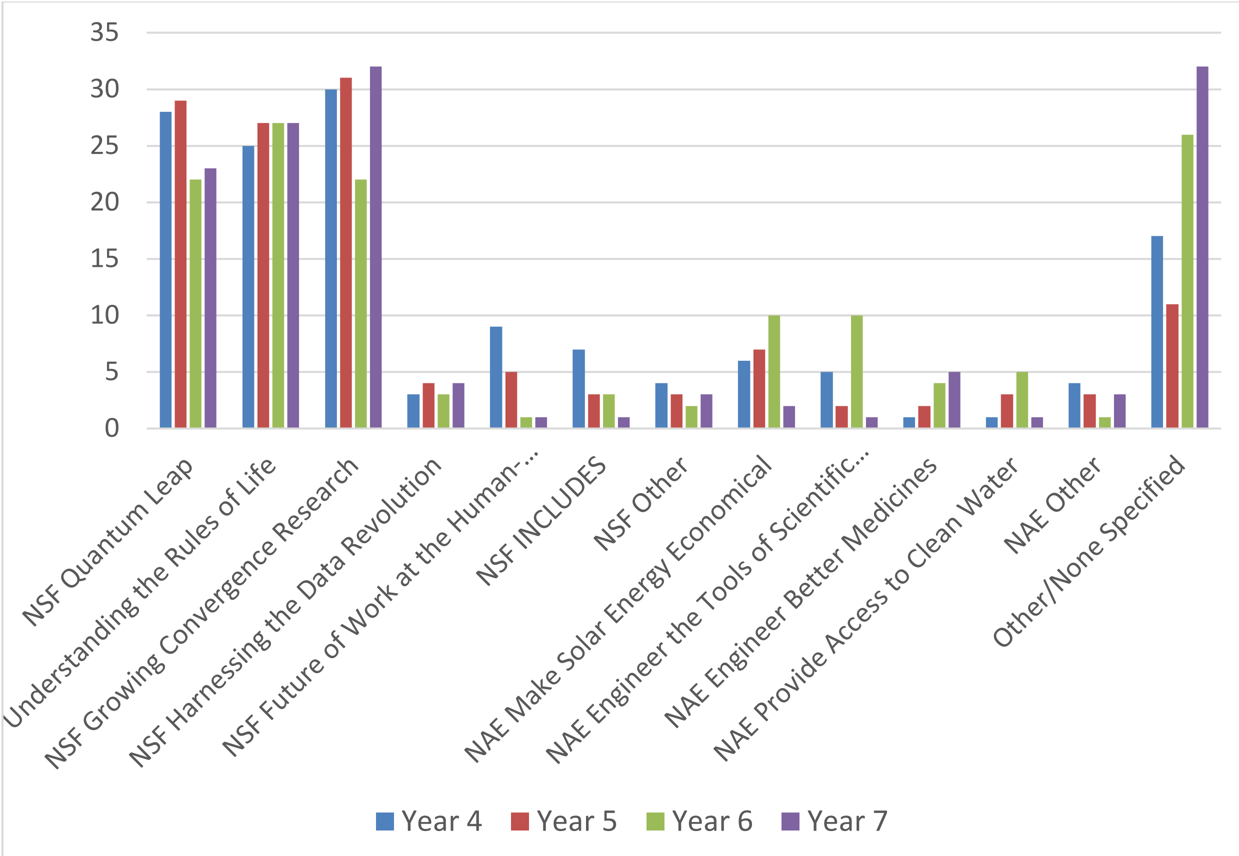


Figure 33: NNCI Highlight Slides Research Priorities (Years 4-7)

As indicated above, 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), one *Minority-Serving Institution* (MSI), UNC-Greensboro (SENIC), one *Hispanic-Serving Institution* (HSI), Northern Arizona Univ. (NCI-SW), 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 7, external academic users came from 26 *Hispanic Serving Institutions* (HSI, 25+% Hispanic undergraduate students), 33 EHSI, 5 HBCU, 2 PBI, 7 *Asian-American and Native American Pacific Islander* institutions (AANAPI), 1 *Tribal Colleges and Universities* (TCU), and 1 *Native Hawaiian-Serving Institution* (ANNH). Thus, 75 of the 233 (32%) US academic institutions using NNCI facilities serve under-represented populations. This is a significant increase from the 21% observed during Year 6. Note that some institutions carry two or more designations, but they are counted only once in the specifics provided above.

- Examples of these institutions are: Alabama A&M University, Bunker Hill Community College, Georgia State University, Navajo Technical University, Norfolk State University, San Jose State University, University of California-Davis, University of Hawaii-Manoa, and University of Puerto Rico-Mayaguez.

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

11.3. Publications

The publications data shown below (Table 18) was collected by sites for the calendar year 2021. 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. The 4,288 publications collected for CY 2021 are nearly unchanged compared to Year 6 (2020 publications), with most of the decline since 2019 coming from fewer conference presentations (approximately 50% of peak value in 2020 and 2021, compared to 2019). We continue to ascribe this to ongoing reluctance of researchers to present their work in virtual/hybrid conference formats which were predominant in 2020 and 2021. Publications reported by each site range from 89 to 608. Patents/applications/invention disclosures remain at a high level for 2020, although at a slight decline from 2019 and 2020. These trends can be observed in Figure 34.

Table 18: NNCI 2021 Publications

Publication Type (CY 2021)	
Internal User (Site) Papers	2,700
External User Papers	394
Internal User Conference Presentations	545
External User Conference Presentations	48
Books/Book Chapters	33
Patents/Applications/Invention Disclosures	568
Total	**4,288**

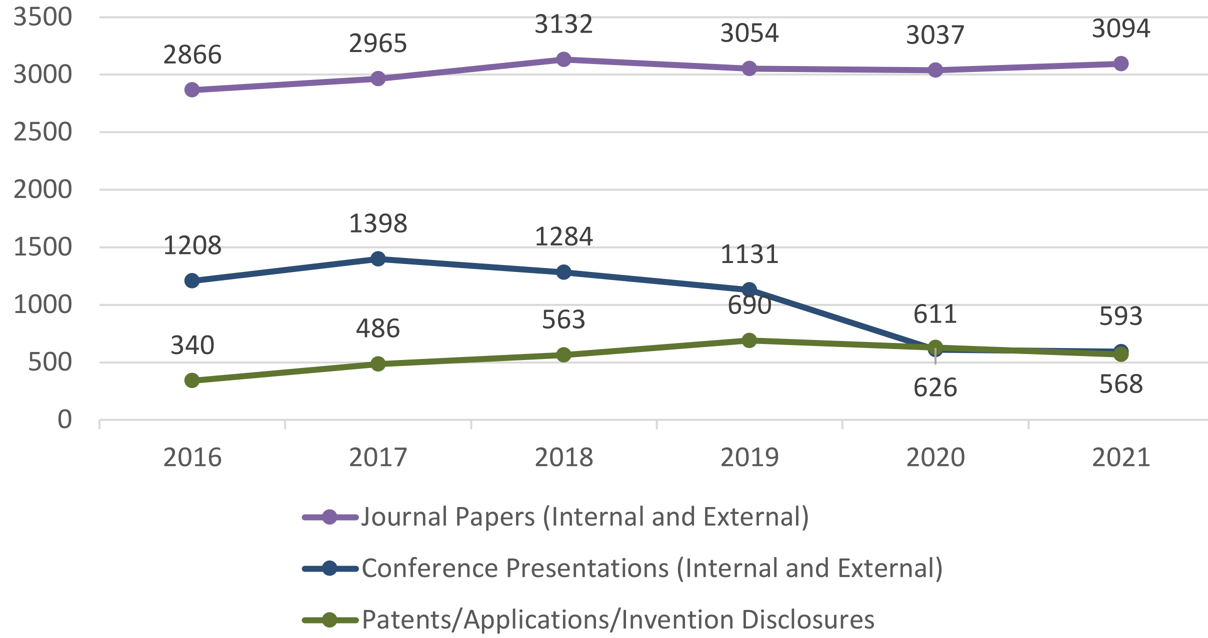


Figure 34 Number of NNCI-enabled Publications by CY.

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 35 below shows continued improvement in this metric. Finally, a further detailed search reveals that the work carried out in the NNCI facilities heavily supports industries of tomorrow, as is highlighted by a keyword search among the more than 9,200 journal articles publications published between 2018-2022 that acknowledge the NNCI 2015 or 2020 award numbers (Figure 36). "Semiconductor" is found in 26-32% of publications over that time frame while "quantum" is mentioned by 30-34% of these publications. An earlier version of this analysis, with additional search terms, was featured in the *2021 National Nanotechnology Initiative Strategic Plan*.

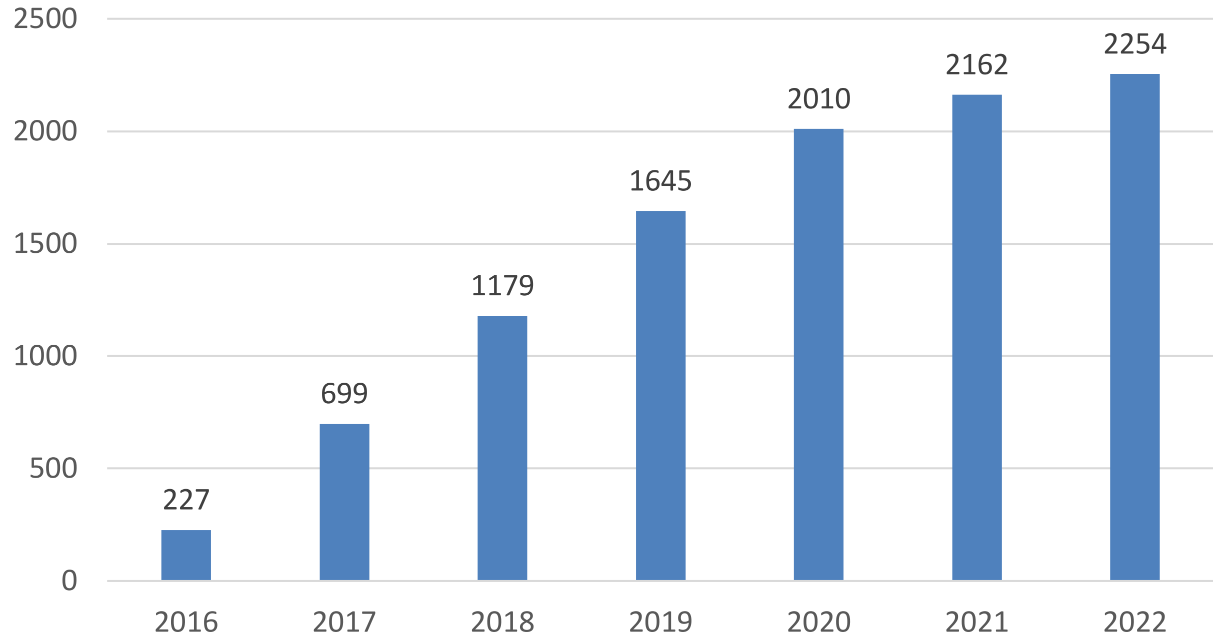


Figure 35: Number of Publications with NSF NNCI Award Numbers based on Google Scholar (NNCI-Award # or ECCS-Award #). Both 2015 and 2020 award #s were used. Search conducted 1/19/2023.

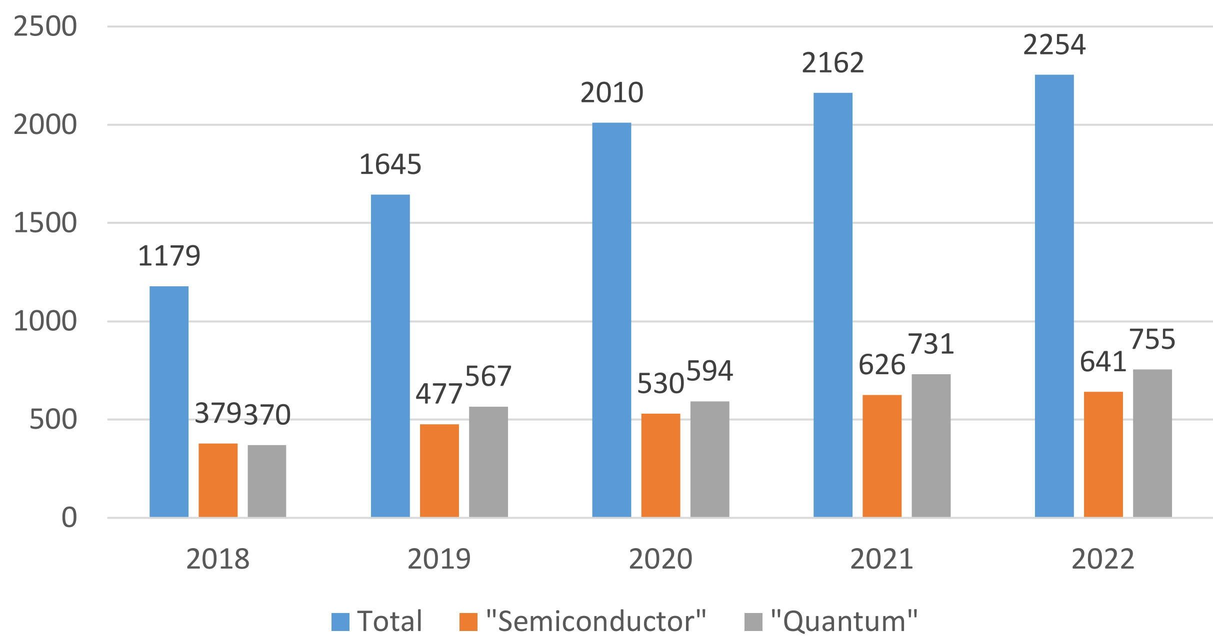


Figure 36: Number of NNCI publications (which cite the NSF award #s) on Google Scholar that also contain search terms "Semiconductor" or "Quantum" (2018-2022). Search conducted 1/19/2023.

11.4. Supported Research Centers

During 2020, the Coordinating Office asked NNCI sites to provide a list of large, multi-PI and/or multi-institution research centers supported by their facilities as a way of demonstrating some of the academic (and even economic) impact of the NNCI program. The list provided in the Year 5 Annual Report included 41 such centers and this was supplemented in Year 6 with 18 additional centers, including 3 of the 6 new NSF Science and Technology Centers awarded in 2021. Table 19below provides a Year 7 update, indicating 11 *new* centers supported by NNCI sites during the previous year. The host and supporting site are provided, but in many cases other sites are also participants in these centers.

Table 19: NNCI Supported Research Centers (New in Year 7)

Research Center	Supporting Site	Funding Source
Center for Electrochemical Dynamics and Reactions on Surfaces (CEDARS)	SENIC (JSNN)	DOE Energy Frontier Research Center (EFRC)
Center for Programmable Energy Catalysis (CPEC)	MINIC	DOE Energy Frontier Research Center (EFRC)
Center of Innovation Excellence in Semiconductors	NNI	Business Oregon
Convergence at the Interfaces of Policy, Data Science, and Environmental Science and Engineering to Combat Antimicrobial Resistance (CIP-CAR)	NanoEarth	NSF NRT
Engineering Research Center for Precision Microbiome Engineering (PreMiEr)	RTNN (led by Duke, incl. UNC, NCSU, and others)	NSF ERC
GlycoMIP	NanoEarth	NSF Materials Innovation Platform (MIP)
Hydrogen in Energy and Information Sciences (HEISs)	SHyNE	DOE Energy Frontier Research Center (EFRC)
Innovation Collaborative Laboratory for Nanotechnologies to Empower the Future Soldier (ICONS)	SENIC (JSNN)	U.S. Army Combat Capabilities Development Command (DEVCOM) Soldier Center
Multidisciplinary InvesTIGation to Ease inFLUenza (MITAGATE FLU)	NanoEarth	Flu Lab
MURI: Next Generation Molecular Dopants for Organic Electronics: From Fundamentals to New Device Concepts	NNI (led by UNC, incl. UW, NCSU, and others)	ONR

Quantum Materials for Energy Efficient Neuromorphic Computing	SDNI	DOE EFRC (renewal)

11.5. Research Funding Sources

In 2019, at the request of NSF, the NNCI Metrics Subcommittee discussed the collection of data detailing the sources of funding used to support NNCI users and research. The first set of data (grants and users) was collected in 2019 from all 16 NNCI sites for usage during NNCI Year 3 (Oct. 2017 – Sept. 2018). Due to COVID-19, this data set was not collected in 2020. In 2021, a revised set of the data (grants information only) was collected for the time period of NNCI Year 5 (Oct. 2019 – Sept. 2020) and reported in the Year 6 Annual Report (Feb. 2022). This data will next be collected in 2023 for the time period of NNCI Year 7 and will be reported in the Year 8 Annual Report.

11.6. Courses Supported

The primary mission of the NNCI is to provide training, support, and physical infrastructure for nanotechnology research. At the same time, most NNCI universities also use their core facilities in support of academic courses by providing laboratory experiences and/or expert instructors. While the students in these courses are not included in the user statistics reported above, it was the recommendation of the Metrics and Assessment subcommittee (Section 5.2) that information on these courses and students be collected to demonstrate the impact NNCI has on traditional education and workforce development. The information below was provided by fifteen of the NNCI sites for the academic year Fall 2021-Summer 2022 (corresponding to NNCI Year 7).

More than 110 individual courses were supported from 27 different academic departments listed below. Similar department names were combined for simplicity. Each individual NNCI site supported a range of 1-16 individual courses during this time frame with total course enrollment of 3,428 students (site range: 20-1,428). A word cloud of the course titles is shown in Figure 37.

Applied Physics and Archeology
Arts & Sciences (Fine Arts)
Bioengineering
Biology
Biomedical Engineering
Biotechnology Program
Chemical and Biomolecular Engineering
Chemical Engineering
Chemistry
Earth System Science
Electrical and Computer Engineering
Electrical and Systems Engineering
Electrical Engineering
Electronics
Engineering and Applied Sciences
Engineering Summer Academy at Penn
Evolutionary Anthropology
Geosciences
Industrial Engineering
Materials Science
Materials Science and Engineering
Mechanical Engineering
Molecular Engineering
Nanoengineering
Nanoscience
Otolaryngology
Physics

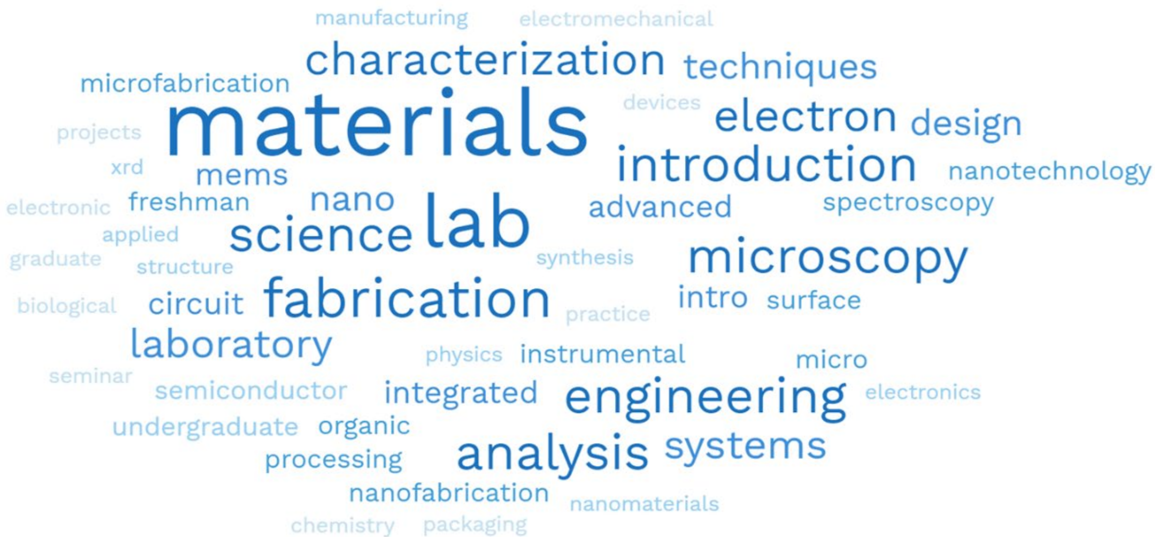


Figure 37: Word Cloud for Course Titles Supported by NNCI Facilities

11.7. Degrees Granted to NNCI Users

One of the biggest impacts that an NNCI site can have is through its training of students, since in most cases the majority of facility users are graduate and undergraduate students. Beginning with NNCI Year 6, the Coordinating Office asked sites to provide information on the number of degrees, and their academic disciplines, granted to (internal) users of the facilities. Fourteen of the NNCI sites were able to obtain that data, and some only in a limited fashion, so this reporting should be considered a lower bound only for degrees granted. The degrees awarded for Fall 2021, Spring 2022, and Summer 2022 (corresponding to NNCI Year 7) are shown in Table 20.

Table 20: Degrees Awarded to NNCI Users (Fall 2021-Summer 2022)

Academic Department	BS Degrees	MS Degrees	PhD Degrees	Other Degrees	Total
Aerospace Engineering	3	5	2	0	**10**
Biomedical Engineering	17	32	47	0	**96**
Chemical Engineering	18	40	67	3	**128**
Civil and Environmental Engineering	1	15	28	0	**44**
Electrical and Computer Engineering	55	123	97	0	**275**
Industrial Engineering	3	1	0	0	**4**
Materials Science and Engineering	60	100	123	0	**283**
Mechanical Engineering	25	60	62	1	**148**
Nanoengineering	9	27	26	0	**62**

Nuclear Engineering	0	1	1	0	**2**
Biology	10	5	10	0	**25**
Chemistry and Biochemistry	31	36	103	2	**172**
Earth and Atmospheric Sciences	1	2	8	0	**11**
Physics	28	20	57	0	**105**
Nanoscience	11	3	10	0	**24**
Computer Science	7	17	2	0	**26**
Medical School	0	1	3	6	**10**
Other	17	30	33	11	**91**
Total	**296**	**518**	**679**	**23**	**1,516**

Note that departments vary across universities and degree data was adjusted to the closest fit department when necessary. Those which did not fit the departments listed above are included in the "Other" category.

Overall, a total of 1,516 degrees were awarded by the 14 sites (mean=108, range=23-333). NNCI users were awarded 679 doctorates, 518 masters, 296 bachelors, and 23 other degrees (including MD or other graduate certificates) during this NNCI Year 7. By comparison, the NSF "Survey of Earned Doctorates (2021)" indicates that US institutions awarded 10,240 doctorates in Engineering and 4,693 doctorates in Physical Sciences. For NNCI users, 69% of all degrees (67% for PhD degrees) were awarded by engineering departments, with Materials Science and Engineering as the top PhD granting department, followed by Chemistry/Biochemistry, Electrical and Computer Engineering, Chemical Engineering, Mechanical Engineering, and Physics. Electrical and Computer Engineering is the top discipline for Masters degrees, while Materials Science and Engineering is the top grantor of Bachelor degrees. Disciplines in the "Other" category include Business Administration, Mining Engineering, Entomology, Forestry and Forest Products, Neuroscience, Mathematics, Food Science and Technology, Structural Engineering, and Science Education among many others.

11.8. Industry Success Stories

NNCI typically supports the research efforts of 700-900 companies each year, some for a single process step or measurement at an NNCI site, and others with multi-year ongoing relationships. Identifying and collecting quantifiable metrics that demonstrate the importance of access to NNCI facilities and experts on these companies, their success, and the impact they have had on their local and regional economies is difficult. Below we illustrate this success with selected anecdotes from NNCI-affiliated companies during the past year.

CNF has supported 129 different companies (34 Large and 95 Small) for research/prototyping under NNCI, including 17 new start-up companies. **NIL Technology** from Denmark set up its North American operation in Ithaca, NY to take advantage of CNF's JEOL 9500 and ASML stepper.

CNS supports start-up companies through several incubators and accelerators: Greentown Labs, Harvard Innovation Lab, The Engine, and BOLT. Example companies include **Metalenz** and **Hyperlight**.

Avisi Technologies, Inc., founded in March 2017, is an early-stage, medical device company developing VisiPlate, a nanoscale ocular implant for treating glaucoma. VisiPlate leverages a shape-recovering, mechanically robust nanotechnology invented by the University of Pennsylvania. Avisi has developed VisiPlate prototypes at MANTH for all early feasibility work. This development has led to $1.7M in Phase 1 and Phase 2 SBIR grants from the National Science Foundation and $1.6M in additional seed investment.

MiNIC staff has worked with start-up company, **Superior Nano LLC**, to win NSF funding to support the development and commercialization of lipid nanoparticles for dermal drug delivery. A SBIR Phase 2 grant was awarded to Superior Nano based on previous work at MiNIC's Nanomaterials Lab.

MONT served the needs of 25 industrial partners (20 small businesses), and 17 are based in or have satellite locations in Southwest MT. These businesses employ over 500 people with revenues over $200M in the local economy. Notable successes include 5 new SBIR/STTR Awards granted in 2021. Industrial users at MONT include **Nature's Fynd**, a food company growing sustainable protein from a microbe with origins in the geothermal springs of Yellowstone National Park, which has raised $350 million in a Series C funding, and **Universal Technical Research Services, Inc**. (UTRS) which was awarded a $39M task order to support the Sustaining Base Network Assurance Branch (SBNAB) of the U.S. Army Combat Capabilities.

In support of **Hoover Color**, NanoEarth demonstrated that pigments extracted from acid mine drainage consist of nanosized iron hydroxide or oxide particles which may explain their enhanced transparency, dispersibility, and tinting strength These properties meet those of conventional pigments, and they have the added benefit of being the result of an environmental restoration effort.

SDNI plays a crucial role in startup formation and fund raising, with more than 30 startups currently using the facilities and receiving staff support. Significant fund raising has occurred for **Roswell Biotechnologies** ($32M), **NanoCellect Biomedical** ($35M), **Fabric8** ($19M), and **Obsedian Sensors** ($14M).

Raxium (using the nano@stanford site), an innovator in single panel MicroLED display technologies, was acquired by Google for $1B in May 2022.

SENIC user company **Carbice Corp.**, which manufactures thermal interface materials based on carbon nanotubes, opened their first manufacturing facility (May 2022) in Atlanta. New SBIR grants were awarded to **Minerva Lithium**, **Kampanics**, **Kepley BioSystems**, startups out of SENIC partner JSNN.

12. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 7 report. Specific information requested included:

1. A brief narrative corresponding to the NNCI Year 7 (Oct. 1, 2021 - Sept. 30, 2022).
    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)
    g. Innovation and entrepreneurship activities (if applicable)
2. A listing of all external user institutions for NNCI Year 7, separated as follows: Academic, Small company (<500 employees), Large company, Government, International, Other. See Appendix 14.2 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. 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 10 above.
4. For this Year 7 report, all sites were asked to provide information that contribute to understanding the impact of NNCI.:
    a. The number of publications in each category for calendar year 2021. The list of publications may have been part of each site's Year 7 report to NSF, but the data presented here (Section 11.3) are only aggregate numbers of publications for the NNCI network.
    b. New centers awarded and supported by the NNCI site during Year 7 (Section 11.4)
    c. Student degrees granted – Number of degrees awarded to facility users during Year 7 (Fall 2021-Summer 2022) per academic department (Section 11.7)
    d. Academic courses supported (New metric for the 2023 Annual Report) – Number of academic courses taught enabled by NNCI facilities (lab courses or lab portions of courses) as well as the total number of students enrolled in those courses during the Year 7 period (Fall 2021-Summer 2022). This data does not include courses which are merely taught by site faculty/staff, but only those where students perform lab work in the facility. Note that some of these students may also be research users (Section 11.6).
5. User survey data, if the site did not participate in the common NNCI user survey for 2022. This data was added to the survey results presented in Section 8.3.

In addition, the user statistics for NNCI Year 7 (Oct. 2021-Sept. 2022) were collected from the sites and used by the Coordinating Office to generate both the aggregate network user activity described in Sections 11.1 and 11.2 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.

12.1. Center for Nanoscale Systems (CNS)

This has been a very challenging year for the Center for Nanoscale Systems as we attempt to define a *new normal mode of operation*. While we have been getting used to our new conditions, Covid-19 still is impacting all research operations during this period from October 2021 – May 2022. Our labs are not back to full *"pre-covid"* capacity but indications are that failing some unforeseen event we will be close to our "pre-covid" usage levels by the end of the academic year. We do note that there has been a change in the usage model to some extent. More teams are consolidating work and working in a "shift" mode. 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 transformative Nano and Quantum science. Our staff have adapted to protocol changes that allowed us to safely re-open our labs. All covid specific policies have ended. For example, all users were regularly tested by mandate. All the testing has ended heading into the Spring term. As noted in our end year report last year, we were allowed to use user experience as our trigger for access. This allowed us to remain open for both ***internal and external*** users. Testing was the key enabler for this. We stressed to the University that admission of external users was of paramount importance. We believed that it was really important to strongly support our start-up userbase, many of these small companies depend on our resources for their survival, and for many survival was in question. During the last year we have widened the door for more inexperienced users but our operations in Cambridge have been recovering slowly. Currently we are experiencing new user training levels that are near "pre-pandemic" levels. This suggests normalcy is coming.

Landing page for CNS virtual tour. The image sequence at the bottom of the page is a full extensive "walk-through" of the CNS spaces.

We used some our research bandwidth over the past year plus to complete a full VR model of CNS which allows for virtual tours of the lab (*now directly accessible from our website*). The markers embedded are links to information for specific tools and instruments, and access and training information. They direct the visitor to the relevant pages on the CNS website. The VR tool allows for a quite detailed look at CNS tools. In addition, we opened satellite facilities, (with staff support), on the new Harvard Engineering Campus. The detail of that expansion follows below.

Facility, Tools, and Staff Updates

This year we established new facilities on the new Engineering campus in Allston, MA. CNS manages three spaces at the SEC listed in the figure at right.

CNS Allston Spaces:
- ❖Soft Lithography
- ❖Imaging and Analysis (*SEM/TEM*)
- ❖Materials Characterization & Analysis (*Spectroscopy*)

New Harvard Science and Engineering Center (SEC)

While the early research focus at the SEC has been soft materials, the actual workflow and research directions are still in flux. Early indications suggest that many of our Harvard

Medical School users, as well as others in the Harvard hospital system have moved their work to our Allston labs. (The SEC is an easier trip from the medical school campus.)

The labs are fully open, staffed and as of this spring more the 200 Users had been trained on the new instrumentation. We hired a new staff member, Nick Colella, to support efforts on the new campus, moved our biological imaging staff to the SEC, and have two other staff that spend parts of their week on the new campus.

We note essentially, like all other sites, we have experienced a many months vendor shutdown/slowdown during the SEC facilities "spin-up" which is just getting loosened now. Importantly, during the pandemic we have expanded the capabilities available to remote train the userbase, both in the nanofab and the other instrumentation focused areas of the lab. Our team has developed training materials using "StoryLine" a course development software platform. Remote training and support are becoming a larger fraction of our operations.

Instrumentation/Tool Additions:

- A Heidelberg MLA150 maskless lithography tool
- JA Woollam RC2 Spectroscopic Ellipsometer
- Filmetrics F50-UVX thin film mapping system

These tools were added to enhance our ability to support device development in two key Quantum materials efforts.

Advanced Electron Microscopy:

We have also finalized the on-boarding of the "Harvard Quantum Imager", a Hitachi 300keV aberration corrected electron microscope, which has an ultra-high-resolution energy filter and the capability of imaging magnetic materials with atomic-resolution. (*This was quite an accomplishment given delays driven by Covid-19 restrictions.)* We have also added an NSF MRI funded Low Energy Electron Microscope (LEEM) system (see figure), which became operational and opened this past spring. These new tools and instrumentation expand our analysis and processing capabilities. In particular, our ability to design, measure, and study advanced Quantum Materials.

New MRI-funded LEEM System

2D Assembly Platform Effort:

We are continuing to build up two platforms enabling 2D heterostructure Van der Waals materials assembly (one in a glovebox). We plan to have the second system up running and available by early summer. The ambient system is already open for business.

<u>User Base</u>

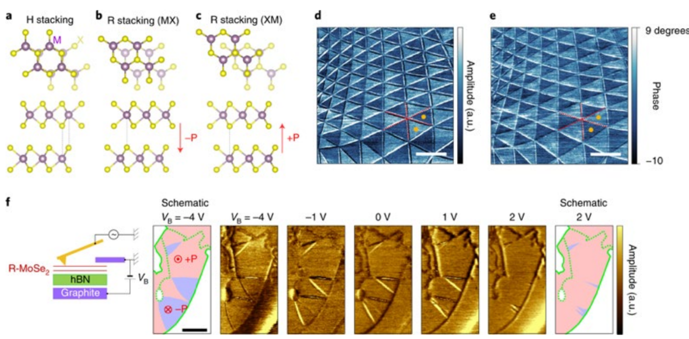
This year our accumulated userbase reached 960 active users (as of 9/30/2022). (Note: active users are users that have accessed CNS resources during the reported grant period.). Importantly ~47%

of our user base is non-Harvard, 28% being external academic users and ~19% industrial users, (~67% of which are from small companies). Overall, consistently of order 12-13% of our userbase over the last 2 years are small businesses.

<u>Research Highlights and Impact</u>

This past program year there were 112 publications. Some highlights of the work include advances in photonics, quantum science and technology, and quantum networking. Examples of some of this work is detailed below.

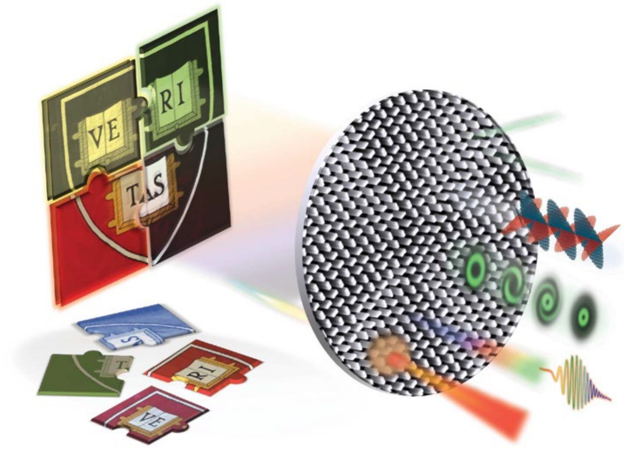
Quantum Materials: **Interfacial ferroelectricity in rhombohedral-stacked bilayer transition metal dichalcogenides***: Xirui Wang, Kenji Yasuda, Song Liu, Kenji Watanabe, Takashi Taniguchi, James Hone, Liang Fu, and Pablo Jarillo-Herro*, ***Department of Physics, MIT, Department of Mechanical Engineering, Columbia University, and National Institute for Materials Science, Tsukba, Japan*****:** 2D van der Waals materials have greatly expanded our design space of heterostructures by allowing individual layers to be stacked at non-equilibrium configurations, for example via control of the twist angle. Such heterostructures not only combine characteristics of the individual building blocks but can also exhibit physical properties absent in the parent compounds through interlayer interactions. This year the Jarillo-Herro group reported on a new family of nanometre-thick, two-dimensional (2D) ferroelectric semiconductors, where the individual constituents are well-studied non-ferroelectric monolayer transition metal dichalcogenides (TMDs), namely WSe_2, $MoSe_2$, WS_2 and MoS_2. But, by stacking two identical monolayer TMDs in parallel, they obtain electrically switchable rhombohedral-stacking configurations, with out-of plane polarization that is flipped by in-plane sliding motion. Fabricating nearly parallel-stacked bilayers enables the visualization of moiré ferroelectric domains as well as electric field-induced domain wall motion with piezoelectric force microscopy. Furthermore, by using a nearby graphene electronic sensor in a ferroelectric field transistor geometry, they quantify the ferroelectric built-in interlayer potential, in good agreement with first-principles calculations. The new semiconducting ferroelectric properties of these four new TMDs opens up the possibility of studying the interplay between ferroelectricity and their rich electric and optical properties. *Nature Nanotechnology* vol. 17, pages 367–371 (2022).



Rhombohedral Stacked ferroelectric TMDs

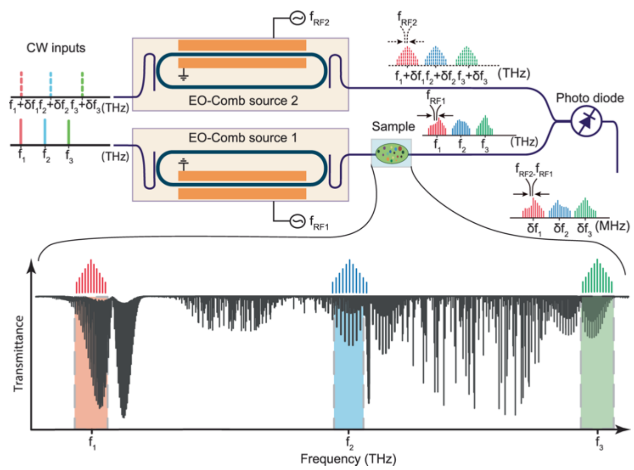
<u>*NanoOptics*</u>*:* **Tunable structured Light with Flat Optics,** *Ahmed H. Dorrah and Federico Capasso*; ***Harvard School of Engineering and Applied Science***; Flat optics has emerged as a key player in the area of structured light and its applications, owing to its subwavelength resolution, ease of integration, and compact footprint. Although its first generation has revolutionized

conventional lenses and enabled anomalous refraction, new classes of meta-optics can now shape light and dark features of an optical field with an unprecedented level of complexity and multifunctionality. This year the Capasso group reviewed these efforts with a focus on metasurfaces that use different properties of input light—angle of incidence and direction, polarization, phase distribution, wavelength, and nonlinear behavior—as optical knobs for tuning the output response. They have pioneered ongoing advances in this area. These recent developments indicate that optically tunable flat optics is poised to advance adaptive camera systems, microscopes, holograms, and portable and wearable devices and may suggest new possibilities in optical communications and sensing. *Science* vol. 376, eabi6860 (2022)

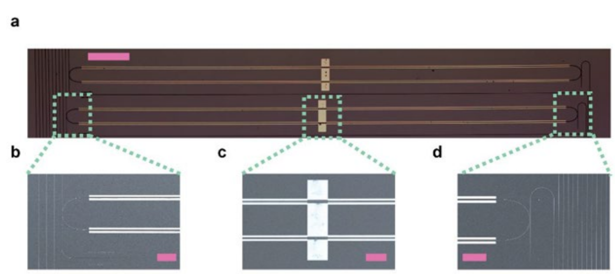


Nanoscale Metasurface Optics.

Integrated NanoPhotonics: **Thin-film lithium-niobate electro-optic platform for spectrally tailored dual-comb spectroscopy**, *Amirhassan Shams-Ansari, Mengjie Yu, Zaijun Chen, Christian Reimer, Mian Zhang, Nathalie Picqué and Marko Lončar*; **SEAS**, ***Harvard University***; Laser frequency comb generators on photonic chips open up the exciting prospect of integrated dual-comb microspectrometers. Amongst all nanophotonic platforms, the technology of low-loss thin-film lithium-niobate-on-insulator shows distinguishing features, such as the possibility to combine various optoelectronic and nonlinear optical functionalities that harness second- and third-order nonlinearities, and thus promises the fabrication of a fully on-chip instrument. Here, a critical step towards such achievement is demonstrated with an electro-optic microring-based dual-comb interferometer.



Integrated photonics frequency comb.



Integrated LNB microresonator frequency comb.

A microscope image of two fabricated lithium niobate microresonators is seen in the figure (a) at right (scale bar = 500 mm). (b) Scanning electro-micrograph (SEM) of the coupling region, (c) SEM of the microwave-probe metallic pad, (d) SEM of the drop-port (scale bar = 100 mm).

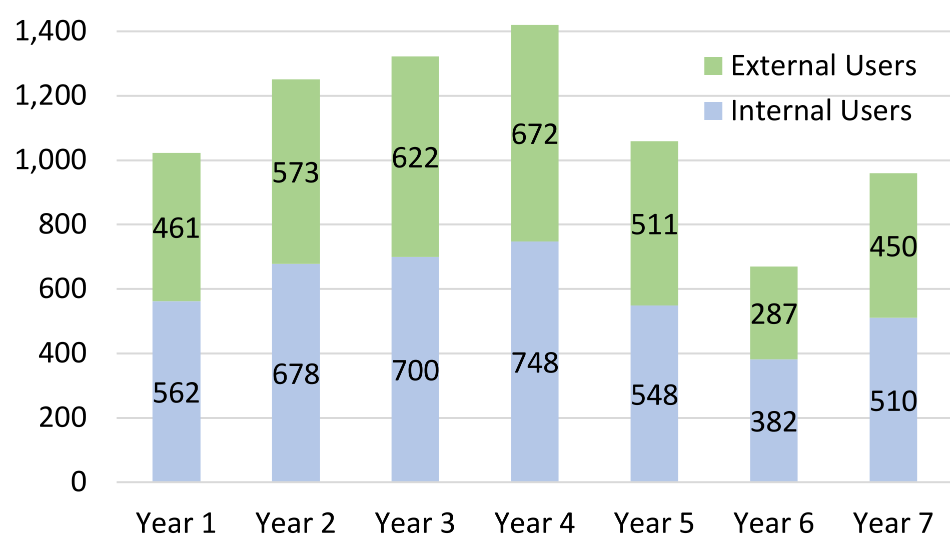
The frequency agility of the system enables spectrally-tailored multiplexed sensing, which allows for interrogation of non-adjacent spectral regions, here separated by 6.6 THz (220 cm^{-1}), without compromising the signal-to-noise ratio. Our studies show that electro-optic-based nanophotonic technology holds much promise for new strategies of molecular sensing over broad spectral bandwidths. *Commun Phys* vol. 5, 88 (2022).

Education and Outreach Activities

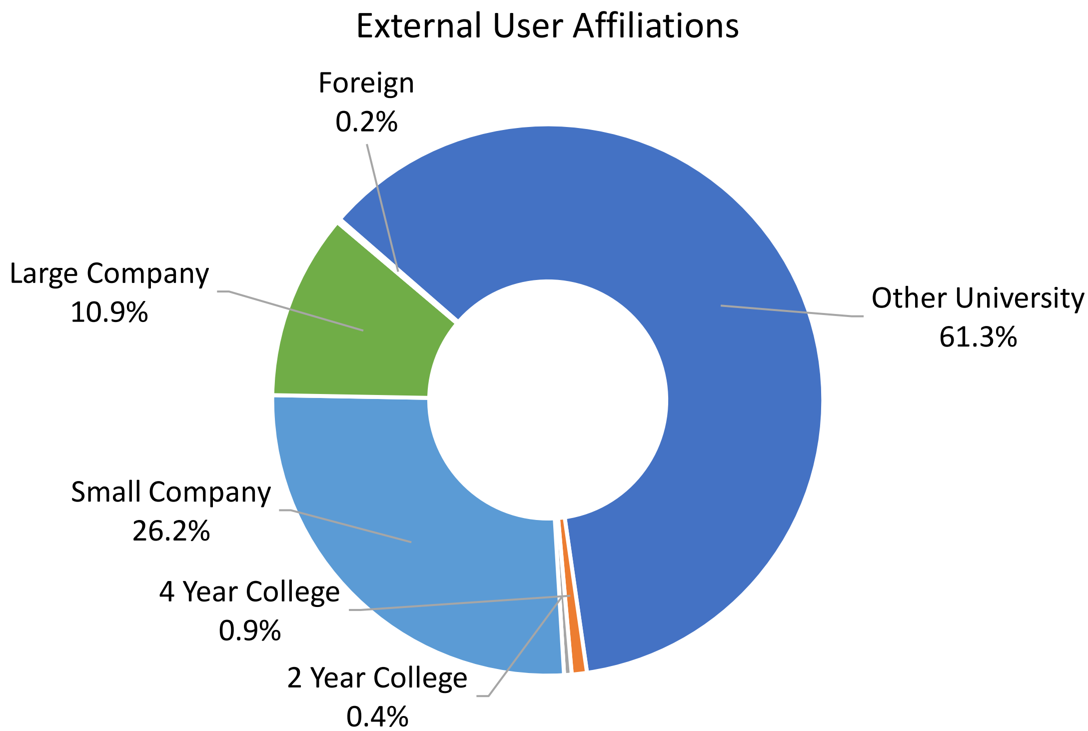
CNS this year has begun to allow classes to be taught in the labs with staff support. This is the first time we have formally had class offerings taught in CNS spaces (done informally in the past). Outreach activities focused on re-establishing our REU and REV programs this summer. Our students participated the network convocation. We also supported a Middle School teacher in the Stanford program and continued to augment our remote Master Class series. We also are continuing to "re-connect" with our CNS scholars. Several have re-engaged and begun to work at CNS again. We are also leading an effort to establish a Quantum/Nano Meeting directed toward researchers of Color (+). A proposal to NSF DMR:CMP has been submitted to support Quantum Noir.

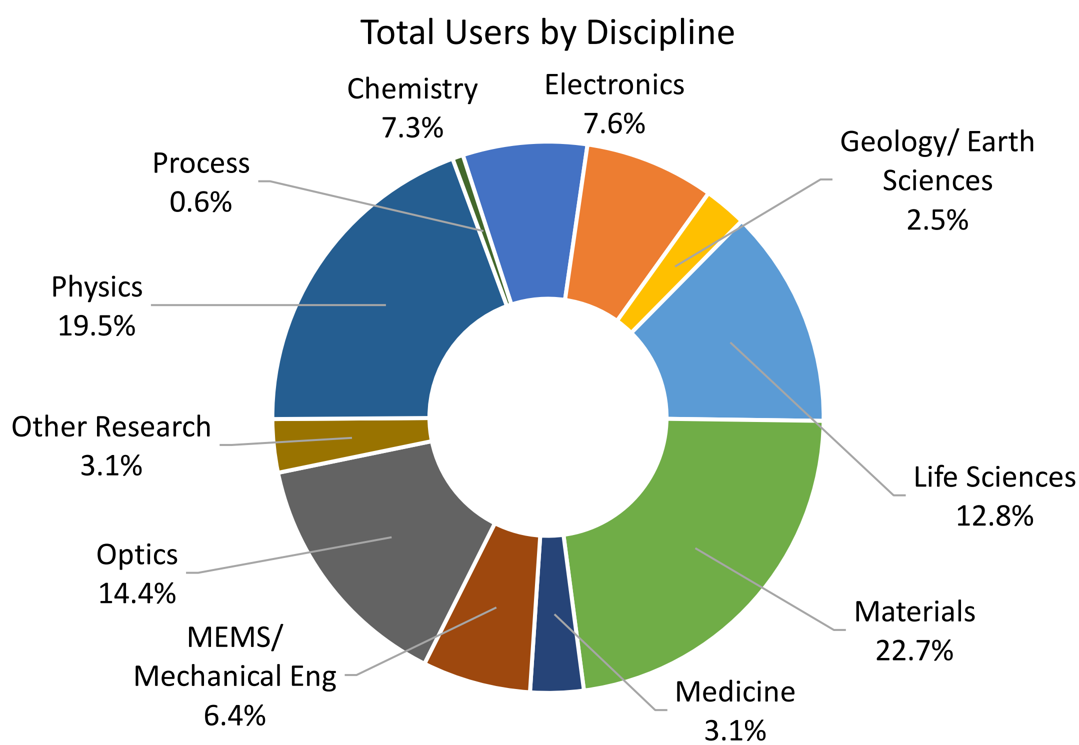
CNS Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	1,023	1,251	1,322	1,420	1,059	669	960
Internal Cumulative Users	562	678	700	748	548	382	510
External Cumulative Users	461 (45%)	573 (46%)	622 (47%)	672 (47%)	511 (48%)	287 (43%)	450 (47%)
Total Hours	174,710	181,826	185,288	204,221	114,523	116,357	142,332
Internal Hours	124,256	133,020	126,662	117,615	69,904	66,051	75,954
External Hours	50,454 (29%)	48,806 (27%)	58,626 (32%)	86,607 (42%)	45,519 (40%)	50,307 (43%)	66,378 (47%)
Average Monthly Users	511	514	538	565	317	260	379
Average External Monthly Users	201 (39%)	196 (38%)	218 (40%)	250 (44%)	137 (43%)	102 (39%)	160 (42%)
New Users Trained	415	404	452	483	191	116	366
New External Users Trained	196 (47%)	200 (50%)	233 (52%)	240 (50%)	89 (47%)	43 (37%)	183 (50%)
Hours/User (Internal)	221	196	181	157	126	173	149
Hours/User (External)	109	85	94	129	89	175	148



CNS Year 7 User Distribution





12.2. Cornell Nanoscale Science and Technology Facility (CNF)

Facility, Tools, and Staff Updates

The Cornell Nanoscale Science and Technology Facility (CNF) prides itself on its long history of proven experience as a national and international user facility. For 45 years, CNF has demonstrated dedication to the advancement of nanoscale science and technology while supporting numerous academic, industrial, and government research communities. In addition, the CNF serves as an open resource for scientists and engineers extending across a broad range of nanotechnology areas, focusing primarily on providing complex integration capabilities supporting individual user micro-nanofabrication needs.

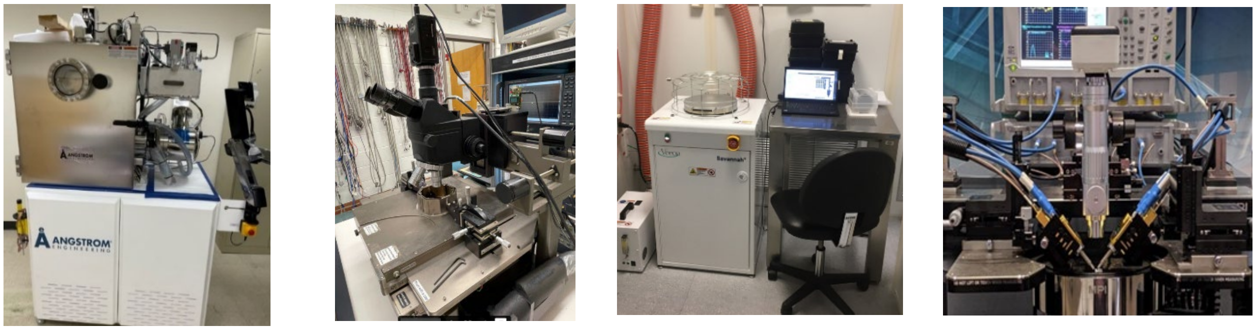
CNF prides itself on its seasoned staff who work diligently to serve and address the needs of the user community. The CNF technical staff consists of facility and equipment technicians, process, and tool engineers (B.S./M.S.), and Research Associates (Ph.D.). Their extensive expertise enables high equipment uptime, thorough training, and provision of valuable technical advice. CNF offers an affordable hands-on 24/7 facility with over 180 outstanding tools and capabilities benefiting both research and prototyping initiatives.

CNF maintains a full complement of processing and characterization equipment and has the most advanced e-beam lithography facilities in the NNCI network including, but not limited to: g-line, i-line and DUV stepper lithography; nanoimprint; contact aligners; 17 plasma etchers; 20 furnace tubes; graphene and carbon nanotube deposition; CMP; 3D printing; physical and chemical vapor deposition; plasma-enhanced CVD deposition; atomic layer deposition; molecular vapor deposition; in-house mask makers; rapid thermal processing; electron microscopy; atomic force microscopy; wafer bonding; wire bonding; packaging; electrical testing; and an extensive suite of and modeling software. Its diverse toolset enables processing of the widest spectrum of materials in NNCI. The CNF is proud of its role as a broad-based, interdisciplinary facility with initiatives spanning the physical sciences, engineering, and life sciences. CNF strives to remain at the forefront of technology while exhibiting responsiveness to new user requests and research trends.

New and more advanced capabilities are frequently added in a concerted effort to continually enhance the user experience. Despite supply chain issues and workforce shortages throughout the semiconductor industry that delayed the installation, CNF remained committed to the acquisition process. The attainment of new tools and capabilities is based on recommendations garnered from discussions with the advisory boards and new Cornell faculty. The following tools/capabilities have been acquired or installed/qualified during the past year (Table and Figure).

Tools/capabilities that have been acquired or installed/qualified over the past year at the CNF

New CNF Tools and Capabilities	
Angstrom Engineering UHV Load Locked Evaporator	Direct laser write capabilities on the DWL66FS
Veeco Savannah Atomic Layer Deposition System	Energy Dispersive Spectroscopy on Hitachi TM3000
200 mm wafer processing CHA Mark 50	DC Probe Station and Electronics
mm-wave Vector Network Analyzer and Probe Station	Microwave Small Signal Probe Station and Electronics
3D GPU Conversion Computer and 3D software	Microwave Large Signal Test System-Load Pull System



UHV Load Locked Evaporator, Microwave small signal test system, Veeco ALD system, mm-wave vector analyzer and probe station

CNF and the Cornell Institute of Biotechnology (Biotech) work together to provide NNCI users with access to 18 discrete 3-D characterization and imaging tools including, a variety of confocal microscopes, super-resolution microscopes, fluorescence microscopes, ultrasound imaging system and micro/nano-X-ray-CT scanning. CNF provides fifty percent of the financial support for one staff member from Biotech to help foster and enhance the convergence of research fields. This Biotech staff member actively contributes to discussions during technical sessions, coordinating the inclusion of analytical techniques into up-and-coming projects.

CNF and the Mechanical Engineering Department's Rapid Prototyping Lab (RPL) collaborate in order to integrate capabilities that provide user access to a dozen modern 3-D printers and laser cutters. CNF uses its tool management system to oversee billing, materials, and usage tracking for RPL. This collaboration continues to be an increasingly important union committed to the advancement and promotion of nano/micro-scale technology and microfluidics packaging in the life sciences. CNF and NNCI users now have access to a dozen modern 3-D printers and laser cutters.

The Materials Science and Engineering (MSE) Department decided to make the instruments in their High Frequency Test Lab (HFTL) available for shared use as part of CNF facilities. These instruments include: DC probe station and electronics, microwave small signal probe station and electronics, microwave large signal test system - load-pull system and a mm-wave vector network analyzer and probe station. Planning for equipment and lab procedure training for users is in the final stages.

CNF employs a team of technical management (2 FTE + faculty directors), administrative staff (2.75 FTE), and a laboratory technical staff of 21 (19.5 FTE) responsible for equipment maintenance, user instruction, and process and user support. The primary function of the CNF is supporting the user program. The expertise and experience of these team members is critical to CNF's operation. This year the CNF welcomed two Advanced Lithography Research Associates to the team, Dr. Roberto Panepucci and Dr. Giovanni Sartorello. Both Dr. Panepucci and Dr. Sartorello bring a wealth of experience in advanced lithography.

<u>User Base</u>

During year seven of the NNCI CNF hosted 1290 individual users, with 215 (16%) representing an external user base. Recent inclusion of data from new partnerships with Biotech and the RPL have revealed a new distribution baseline indicating heavier usage for life science projects and a lower % of external users. Cornell users accounted for 46,696 hours of usage (combined equipment time+tool time) while outside users accounted for 16,726 hours of usage (combined equipment time+tool time). External user fees accounted for $1.97 M of the total $3.5 M (56%) in available funds.

Overall cleanroom hours surpassed 63,000 and the monthly, average number of users was 396 (up 20% over last year). Additional user stats have been collected by the NNCI coordinating site and are presented elsewhere in this report.

Research Highlights and Impact

CNF collects technical research reports yearly for projects utilizing CNF resources. These reports are compiled and published in a document entitled, **CNF Research Accomplishments.** They are available in print and electronic form on the CNF web site.

The impact of CNF research is accentuated by the number of publications in "high impact" journals, (e.g. *Science*, *Nature*). Research highlights from recent user projects are provided in PowerPoint form as an appendix to this report.

Research conducted at CNF yields extensive publications, presentations, and patents. CNF collects publications, presentations, and patents from its users on a calendar year basis. Consistent efforts are made to encourage all publications to properly credit the CNF and the NSF award number. Users are also encouraged to report their publications to CNF. However, there is room for reporting improvements. These numbers should be considered as the minimum of CNF research documented. The user research collected during the 2021 calendar year resulted in at least: 233 Publications, 66 Presentations and 64 Patents and Patent Applications

Economic Impact

CNF remains an effective resource for the commercialization of nanotechnology. One hundred forty three different companies (107 small/startup and 36 large) have utilized CNF for major research and development/prototyping under NNCI. In addition, CNF continues to serve as an engine for small business economic development. Since the inception of the NNCI CNF has averaged 2.5 new startup company launches per year based on CNF developed technology (Table).

Startup companies that used the CNF to develop technology.

White Light Power	Kanvas Biosciences	Odyssey Semiconductor	OWIC Technologies	Esper Biosciences	Halo Labs
Inso Bio	CyteQuest	Logrus,	Jan BioTech	Heat Inverse	FloraPulse
Xallent	Ultramend	JR2J	GeeGah	Soctera	

CNF impacts large companies like Applied Materials, ASML, Corning, GE, Google, BAE Systems, MACOM, Facebook/Oculus, Panasonic, Qualcomm, Samsung, and others by providing access to advanced materials and instruments in an environment that allows flexibility of materials and design rules that creates an ideal environment for rapid technology development.

Education and Outreach Activities

The CNF supports an expansive array of education and outreach activities at multiple levels spanning from K-12, post-secondary, professional and public access. This year, CNF hosted or participated in 33 events with a total of 2562 participants.

The CNF is pleased to have assumed a leadership role in the establishment of the NNN. The overall mission of the NNN is to help build regional relationships, solve common problems, and grow awareness of the state's nanotechnology capabilities while providing more synergistic opportunities for workforce development within the state. In May, CNF hosted the first New York State Nanotechnology Network (NNN) symposium. The event highlighted student talent and united New York colleges, universities, and industries for the purpose of networking and promoting technology research activities. Eighty-eight total participants attended (65 from 10 academic institutions, 21 representing 10 industries, 2 government officials). Thirty-seven posters and 26 student presentations were also featured.

In August the CNF hosted the 2022 NNCI Nanoscale Internet-of-Things (Nano-IoT) Research Community Workshop. The hybrid meeting allowed attendees to participate in-person or virtually via Zoom. The workshop assisted the NNCI network in planning for the future of nanotechnology while simultaneously identifying and exploring goals for the Nano-IoT.

The CNF 45th Anniversary Celebration and Annual Meeting was held at Cornell University. Our plenary speaker was Dr. Mathieu Foquet, Principal Scientist at Pacific Bioscience who discussed the evolution of the SMRT Sequencing. Invited speakers from, Cornell University, Duke University, GE Global Research and Brookhaven National Laboratory focused on quantum information devices, life sciences, heterointegration, 2D materials and 3D Fabrication. The proceedings and released presentation videos of the meeting can be found online.

Following the 2022 Annual Meeting key experts in nanotechnology gathered for a strategic planning workshop that helped define the CNF's future strategic direction.

National Nanotechnology Coordinated Infrastructure (NNCI) Annual Conference was hosted by CNF at Cornell University. The Annual conferences provide an opportunity for NNCI site directors, staff, external advisory board, NSF program officers, and invited guests to share updates and exchange ideas.

NNCI annual conference attendees

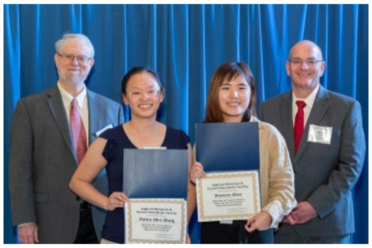
CNF REU summer interns

During the summer of 2022, the Cornell NanoScale Science & Technology Facility hosted a Research Experience for Undergraduates (CNF REU) Program. The CNF REU program is sponsored in coordination with programs at other participating NNCI sites. The six undergraduates included: Sean C. Anderson, Jr., Morgan State University, Rodolfo Cantu, University of Texas at Austin, Zeinab Ismail, St. John's University, Eryka Kairo, Seton Hall University, Rachel Qian, Villanova University, and Elisa Simoni, Rose-Hulman Institute of Technology.

CNF and the National Institute of Material Science (NIMS), Tsukuba, Ibaraki, Japan hosted the Global Quantum Leap International Research Training Experience (GQL IRTE) Program and the International Research Experiences for Undergraduates (CNF iREU) Program. Five former NNCI REU students participated in this year's IREU program.

A major part of the Global Quantum Leap program is its IRTE program which is largely managed out of CNF for GQL. IRTE is modeled after the IREU program, however with a narrower technical focus (quantum IT) and a broader recruitment (not limited to NNCI REU). In 2022, GQL/NNCI sent three students to NIMS in Japan for quantum related projects. All final reports and a list of participants are online.

Annually the CNF presents the Whetten Memorial Award in recognition of young women scientists whose work and professional lives exemplify a commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and exuberance for life. The 2022 award was presented to Hanyu Alice Zhang and Wenwen Zhao of the Applied and Engineering Physics, Cornell University.



2022 Whetten Award winners

2022 marked the return to in-person learning for CNF's short course, "Technology and Characterization at the Nanoscale (TCN)" as well as education and community outreach events. The TCN course is offered virtually each January and in- person each June. The course includes lectures and key demonstrations of the concepts involved in micro and nanoscale device fabrication.

The largest event was the Tompkins County Expanding Your Horizons Conference that welcomed around 250 budding, young scientists to the facility to explore nanoscience and watch a live, virtual tour of the cleanroom.

Nanooze is the CNF's kid friendly publication (http://www.nanooze.org). The magazine is intended to excite kids about nanoscience and nanotechnology. CNF distributes Nanooze to NNCI sites, schools, and museums for use in classrooms, libraries, and extracurricular camps. Over 106,000 copies have been distributed this year. The CNF continues to maintain a partnership with the 4-H Club, through participation in their multi-day Career Explorations event each June. Additional outreach events include alumni reunions, Nanodays, Junior FIRST Lego Expo, and hosting several school fieldtrips.

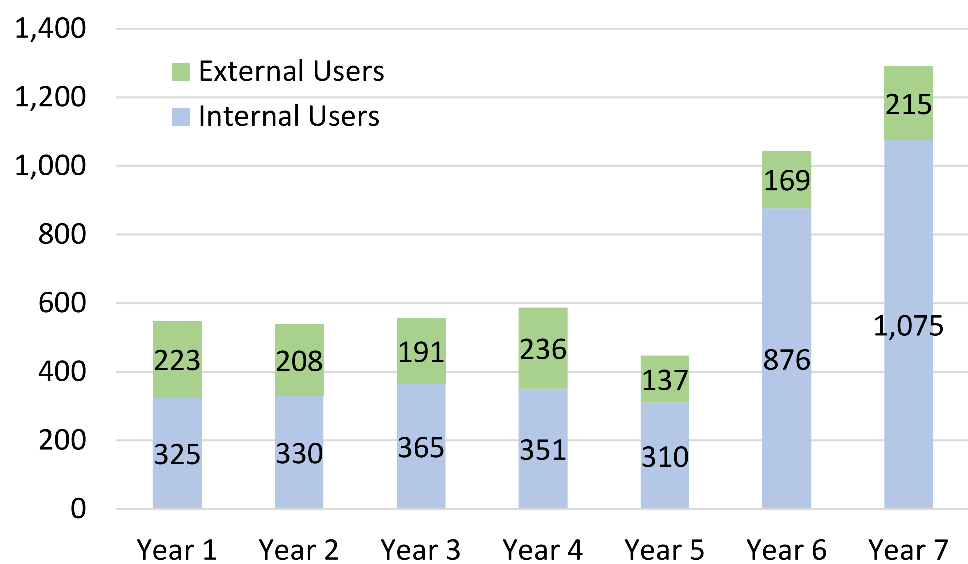
In recognition of its 45th anniversary celebration the CNF joined with Ithaca ScienCenter to bring the Nano Mini-Exhibition to the area. Over 56K visitors have visited the Nano exhibit since it was installed in late March.

The CNF and local industry have been working with Tompkins Cortland Community College (TC3) to develop a micro-credential program that will prepare people for employment in micro - nanotechnology field. The credential will provide students with the fundamental knowledge required to work safely and effectively in the semiconductor cleanroom environment as well as other high tech scientific facilities. The curriculum is expected to gain final approval in the coming months. In the fall of 2022 CNF launched the ATLAS (Advanced Training for Labor Acceleration in Semiconductors) program for high school seniors enrolled in the Tompkins County New Visions Engineering Program. Student participants are offered multiple hands-on, learning experiences in a cleanroom under staff guidance and in the classroom.

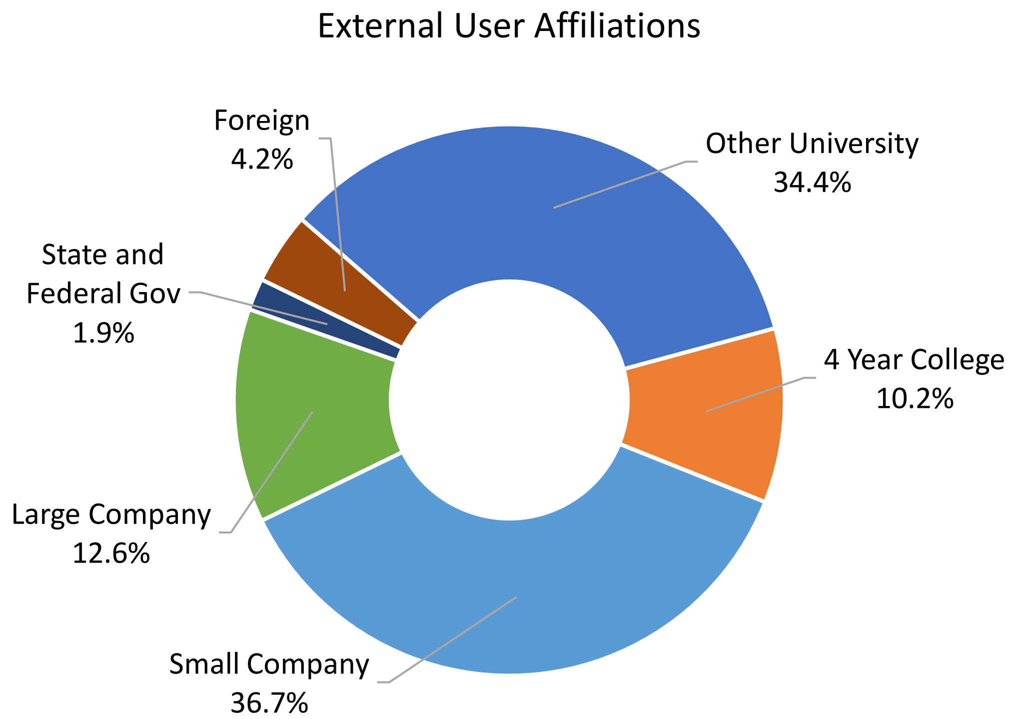
The CNF remains committed to serving the community and advancing initiatives in support of nanoscience and technology. We are grateful for the opportunity to play a continuing role in an expanding and collaborative field.

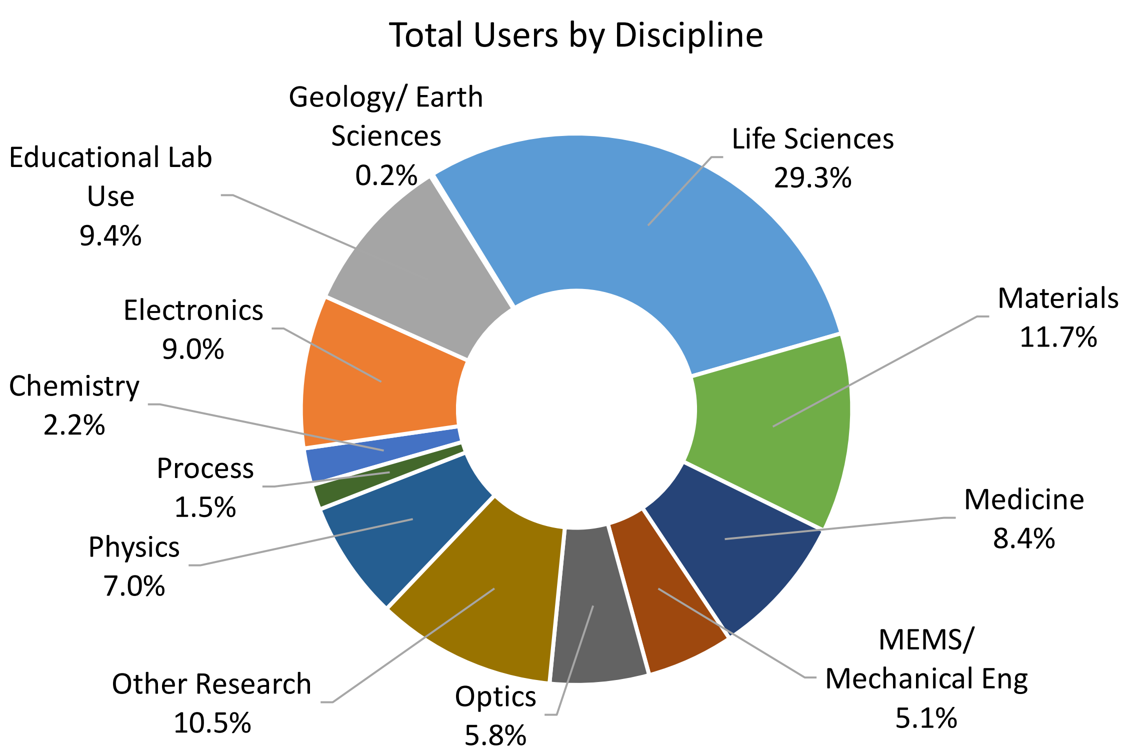
CNF Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	548	538	556	587	447	1,045	1,290
Internal Cumulative Users	325	330	365	351	310	876	1,075
External Cumulative Users	223 (41%)	208 (39%)	191 (34%)	236 (40%)	137 (31%)	169 (16%)	215 (17%)
Total Hours	40,544	45,340	53,680	56,668	31,415	53,688	63,421
Internal Hours	22,965	25,201	31,143	34,627	20,446	38,571	46,695
External Hours	17,579 (43%)	20,139 (44%)	22,537 (42%)	22,041 (39%)	10,968 (35%)	15,117 (28%)	16,726 (26%)
Average Monthly Users	210	204	225	235	149	332	396
Average External Monthly Users	67 (32%)	66 (32%)	68 (30%)	71 (30%)	39 (26%)	59 (18%)	65 (16%)
New Users Trained	131	161	174	208	77	355	361
New External Users Trained	46 (35%)	51 (32%)	42 (24%)	91 (44%)	12 (16%)	42 (12%)	77 (21%)
Hours/User (Internal)	71	76	85	99	66	44	43
Hours/User (External)	79	97	118	93	80	89	78



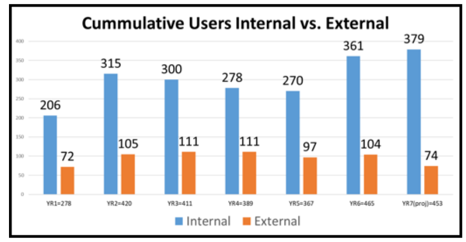
CNF Year 7 User Distribution

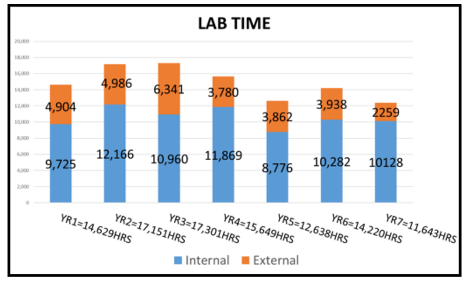


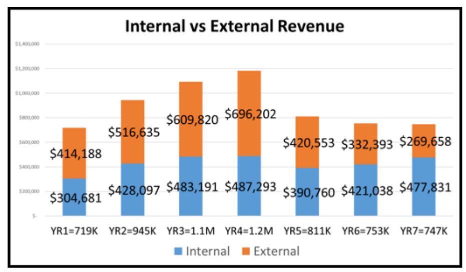


12.3. Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY Multiscale)

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







Facilities – During Year 7, our NNCI site continued to recover from the adverse effects of the deadly COVID-19 pandemic. As illustrated in the Figures to the right, our Cumulative Number of Users have recovered and even exceeded our pre-pandemic numbers, which is highly encouraging. However, our Lab Time Hours have yet to recover to match our pre-pandemic numbers. This is also reflected in our Revenue Numbers, which are also lower than pre-pandemic revenue. These data imply that our site is being used by a lot of people, which is positive, but the number of hours used per person is less than before the pandemic, which in turn depresses our revenue income collected. While this is a concern of our university administrators, we are overall positive about our site's rebound from the two-year pandemic and very optimistic about its future.

Tools and Equipment - Our NNCI site made several important equipment acquisitions during this reporting period. The UofL Micro/Nano Technology Center (MNTC) installed a new **APREO Low Vac SEM,** purchased a new **Theta Lite Optical Tensiometer** (for measuring surface static contact angle, dynamic contact angle, and free energy), installed a new $1M **Deep Reactive Ion Etch (DRIE) System** (funded jointly through the Engineering School, EVPRI Office, the MNTC and our grant), and refurbished an **Ultra High-Precision Micromilling/drilling System** (for mechanically machining a wide variety of materials), The UofL Additive Manufacturing Institute of Science and Technology (AMIST) entered an exciting partnership with the Wurth Additive Group which brought in 2 tools – the **Kurtz Ersa Alpha-140** and the **Rapid Shape I30+** metal 3D printers. The UK Center for Nanoscale Science and Engineering (CeNSE) acquired a **Seamark XM-R720A Automated Rework Station**. And finally, the UK Electron Microscopy Center (EMC) added a new stage for its **micro x-ray tomography system (MicroCT)** that allows integrated tensile and compression testing while performing 3D imaging of nano- and micro-structured materials.

Staff Updates - In this reporting period, we had some significant personnel changes within our AMIST additive manufacturing core facility. **Prof Tom Starr** stepped down as the Faculty Director, **Tim Gornet** retired as Manager, and **Gary Graf** retired as a support technician. The Engineering Dean appointed **Profs Tom Berfield (ME)** and **Li Yang (IE)** as Faculty Co-Directors of AMIST. **Ed Tackett** was hired as the new manager and **Justin Gillham** was hired as the coordinator for technical services.

Faculty Updates - Regarding new faculty hires in the micro/nano area, **Prof Sung Jin Kim** was recruited from the University of Miami (Florida) to serve as the new Faculty Director of the UofL MNTC, replacing founding director Prof Kevin Walsh. Prof Kim will be in the Electrical and Computer Engineering Department and his research expertise is in the areas of nanomaterials, energy harvesting, quantum, and biomedical sensing. The University of Kentucky hired **Dr Sarah Wilson** as an assistant professor in the Chemical Engineering Department. Prof Wilson's research interests are the engineering of systems involving microbial species (including those which have integrated nanoscale components) and nano-engineering education.

<u>User Base</u>

Annual Summit - The highlight of Year 7 was the return of our annual ***NSF NNCI Nano+Additive Manufacturing Summit***, which was suspended during the COVID-19 pandemic. Our 2022 event was by far our largest and most successful event to date, with over 260 participants and attendees. The event brought together a diverse group of micro/nano/additive researchers across the region from academia, industry, and government. This year's event was hosted jointly with the annual ***NSF NNCI REU Convocation***, which added 60 top undergraduates from leading universities all over the country. Headlining the Summit were keynote presentations from 5 nationally-renown speakers - ***Prof John Rogers (Northwestern University), Dr Gil Vandentop (VP of INTEL), Dr Ola Harryson (NCSU CAMAL), Dr Kershed Cooper (NSF), and Dr Kurt Petersen (Silicon Valley Band of Angels)***. The Summit also contained 38 Technical Presentations, 113 Research Posters, 20 Vendors and Sponsors, and an engaging Career Panel session.

Photos from our Successful 2022 NSF NNCI Nano+Additive Manufacturing Summit

Marketing - We increased the readership of our **KY Multiscale Newsletter** to over <u>16,000 recipients</u> in Year 7. The newsletter contains information about upcoming events (both local and network-wide), new core equipment and capabilities, new research highlights, site update, and any new site programs (such as seed/education/research/workforce development). We also expanded our **Social Media** presence which was helpful in attracting new non-traditional users.

Seed Program - In Year 7, we expanded our **Seed Program** and funded 8 new micro/nano/additive users, 6 of which were either under-represented populations or non-traditional users. This included new users from MiraCosta College (California), California Polytechnic State University (San Luis Obispo, CA), Pharmacology and Toxicology, Ophthalmology, Medicine, and Fine Arts.

Research Highlights and Impact

One very impactful project that we wish to highlight is the fascinating research conducted by Prof Thomas Roussel of the UofL Bio-engineering Dept and Prof George Pantalos of the UofL Dept of Cardiovascular and Thoracic Surgery. The 2 faculty were awarded a $650k grant from NASA for the development of a "Miniature Human Tended Surgical Fluid Management System for Suborbital Flight Evaluation". This custom designed system provides wound containment for astronauts needing surgical treatment on extended space missions. Their system was built using 2 of the core facilities at KY Multiscale - AMIST and MNTC. This year their novel system was successfully tested in weightlessness as a payload aboard a suborbital space flight by Virgin Galactic (see Figure 2). Their interdisciplinary research was also highlighted at the ***National Museum of American History*** in Washington DC as part of the ***2022 ACCelerate Creativity + Innovation Festival***. This open-to-the-public free event was held on April 8-10 and was a national celebration of arts, science, and innovation across the Atlantic Coast Conference (ACC) universities and the Smithsonian Institution. The title of their display was "Surgery in Space", and it focused on the NASA-sponsored device dubbed the "Aqueous Immersion Surgical System (AISS)". Students involved in the research project included Dalton Aubrey, Kessalyn Kelly and Sienna Shacklette. Over 35,000 people attended the 3-day event.

"Surgery in Space" at the ACCelerate Festival in DC at the National Museum of American History

Education and Research Activities

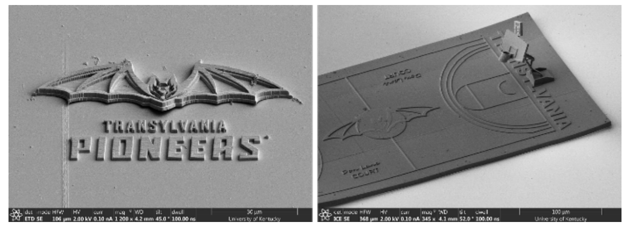
With COVID-19 restrictions lessening in Year 7, we began to re-initiate our in-person E&O signature programs. We briefly highlight some examples below.

REU Programs – The UofL MNTC and AMIST core facilities hosted 9 outside undergraduate STEM students for an exciting REU program entitled – IMPACT (Interdisciplinary Micro/nano/additive Program Addressing Challenges Today). The students received hands-on micro/nano/additive manufacturing training, professional development, and a personalized research experience. UK's CeNSE, EMC and CAM core facilities hosted 2 complementary REU programs in the areas of Engineered Bioactive Interfaces Devices and Material Symmetries. The participating students presented their research results at 2 different conferences.

RET Programs – The UofL Conn Energy Center core facility hosted 10 teachers to learn about and develop educational modules related to energy storage/transfer/conversion/efficiency/renewables. This program was led by Prof Brian Robinson of the Department of Engineering Fundamentals. In addition, Profs Faisal Aqlan and Li Yang of the UofL Industrial Engineering Department ran a second RET program that focused on Manufacturing Automation and Simulation, which leveraged the UofL AMIST core facility.

New Graduate Degree - As part of our initiative to expand educational programs related to the theme of our NNCI site, the UofL Engineering School launched in 2021 a new in-person and on-line Master of Science degree in Materials and Energy Science & Engineering (MESE).

Educational Program with Transylvania University – The University of Kentucky restarted its in-person nano-science program with Prof Stephen Johnson of Transylvania University. In this program, an interdisciplinary nanoscience course is offered, and students travel to UK to use their two-photon lithography and electron microscopy capabilities to fabricate 3D nanostructures and image them. An example of their research is shown in the Figure.



3D micro/nano-structures produced by Transylvania University undergraduates in collaboration with the UK CeNSE and EMC

Summer Camps - With COVID restrictions loosening up, we were able to restart some of our summer camps for younger students to encourage them to study STEM in college. One example is our "Nuts, Bolts, and Thingamajigs" summer camp which targeted middle school and high school students (55 participated in summer 2022). They also held a one-day workshop with the same theme for adults (5 participated).

Partnership with the Kentucky Science Center (KSC) - In October, after a 3-year hiatus, the KY Multiscale MicroNano Technology staff, along with all the Kentucky Science Center (KSC) leadership team in attendance, welcomed an energetic crowd of approximately 200 patrons for the triumphant return of their annual Adult Event celebration. The event was hosted at the KSC and open to the general public. The MNTC showcased devices made at the center, and explained various processes used in micro/nano fabrication, answered questions, and handled out marketing materials.

MNTC Showcase at the KSC

Other Activities – The UK CeNSE core supported a high-school researcher, Sam Quintero, from Sayre School in Lexington Kentucky. Mr. Quintero pursued nanoscale 3D printing for optics applications and has decided to pursue engineering as his college major starting this fall. The UK EMC core supported the Materials Science Senior Capstone program with MicroCT of carbon-fiber materials and training on various other tools. Two additional REU students associated with an NSF Mid-scale research infrastructure grant in heritage science were also supported by EMC.

<u>Computation Activities</u>

The following software packages are available to educational users at our KY Multiscale site: **ConventorWare 2018.0, Silvaco TCAD 2015.0, Tanner Tools V16.2, Xilinx Vivado with SDK Win 2014.2, Autodesk Netfabb, Materialise with Magics, Structures, SG+, Mimics and 3Matic, HP Build Setup & Farsoon Buildstar, Simplify 3D, Ultimake Cura, Chitubox, Leche, 3D Slicr, Amber, ANSYS, FieldView, Fluent, Gaussian, Matlab, MolPro, NAMD, and VASP**. Details about each software package can be found in our site Annual Report.

Innovation and Entrepreneurship Activities

The University of Louisville, in collaboration with IEEE, hosted an ***Entrepreneurship and Innovation Symposium*** that energized and empowered the next generation of innovators and entrepreneurs. The event was held Tuesday, Feb. 8, 4-6:30 pm in the Chao Auditorium at the Ekstrom Library and was opened to students, faculty, staff, and community members. Attendees networked, enjoyed refreshments, and attended a panel discussion featuring innovation experts from our campus and the local community.

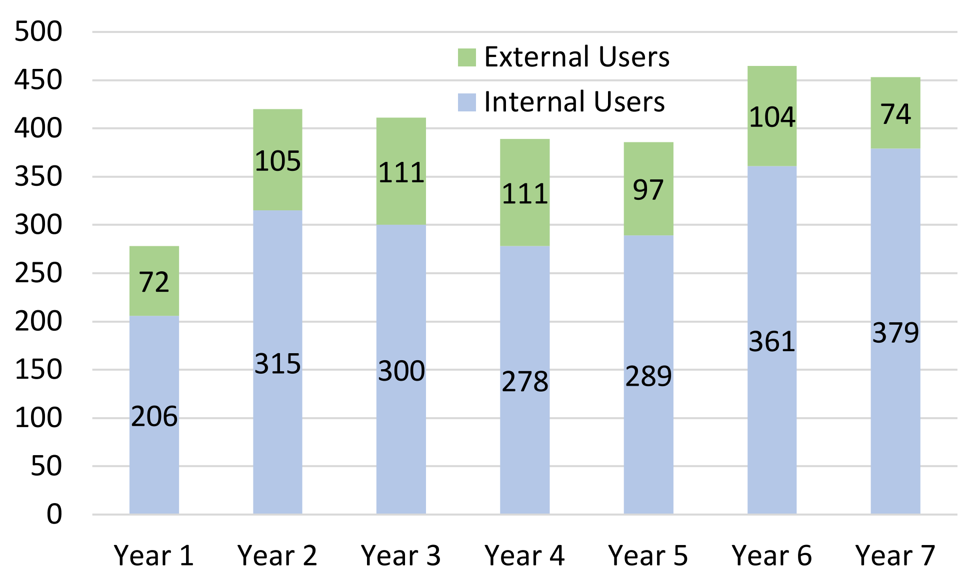
On November 22, 2022, the UofL Office of Research and Innovation presented the ***Louisville Entrepreneurship Summit***. The event brought together more than 300 innovators, entrepreneurs, investors and supporters from throughout the region for a fireside chat with America On Line (AOL) founder Steve Case, startup expo, networking and signing of Case's new book, "The Rise of the Rest: How Entrepreneurs in Surprising Places are Building the New American Dream." In addition to Case, speakers included Elliott Parker, CEO of Indianapolis venture firm, High Alpha Innovation; Jonathan Webb, founder of Kentucky-born agtech startup, AppHarvest; and Monique Quarterman, executive director of KY Innovation.

And finally, on October 17, 2022, the U.S. Department of Commerce's National Institute of Standards and Technology (NIST) announced cooperative agreement awards totaling nearly $19.8 million to four organizations to operate ***Manufacturing Extension Partnership (MEP) Centers*** in Kentucky, Nebraska, Rhode Island and South Dakota. The MEP Centers will be operated by the four awardees, the University of Louisville Research Foundation, the University of Nebraska-Lincoln, the University of Rhode Island Research Foundation, and South Dakota's Lake Area Technical College, and will provide services to small and medium-sized manufacturers in their states. This was a big win for UofL and should help with the marketing of our KY Multiscale core facilities to small and medium sized companies in the commonwealth.

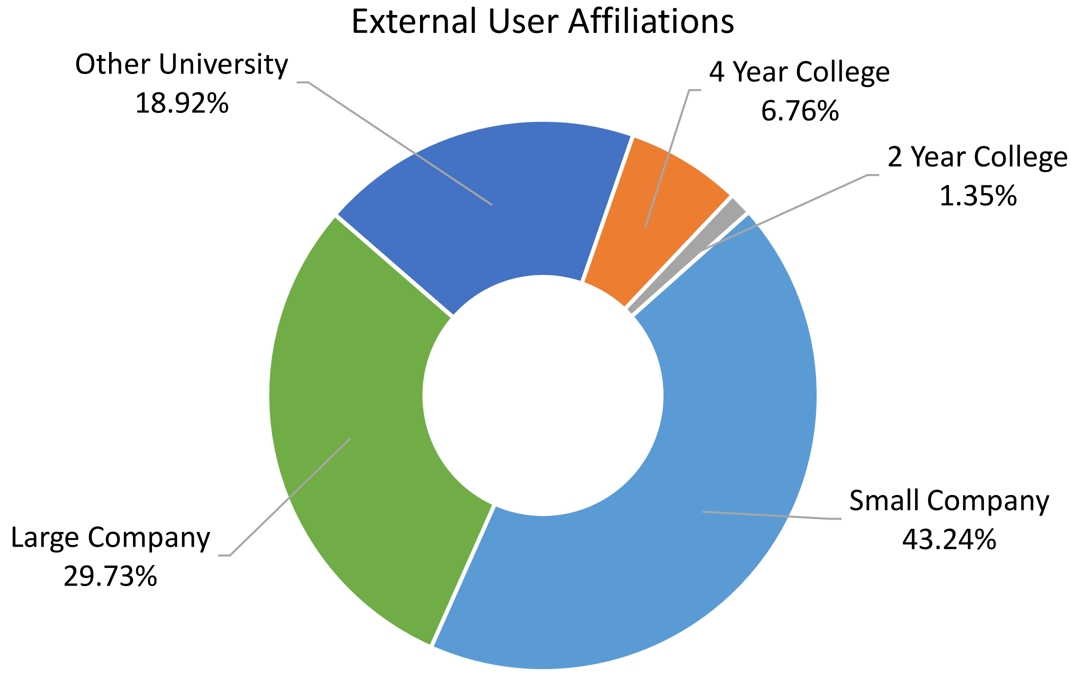
REU Coordinators at KY Multiscale, SENIC, CNF and NanoEarth participated in a virtual panel geared towards the **Research Experience and Entrepreneurship for Undergraduates (REEU)** program lead by Mathew Hull, VATech which is designed to expose NSF REU students to nano-enabled entrepreneurship opportunities linked to research.

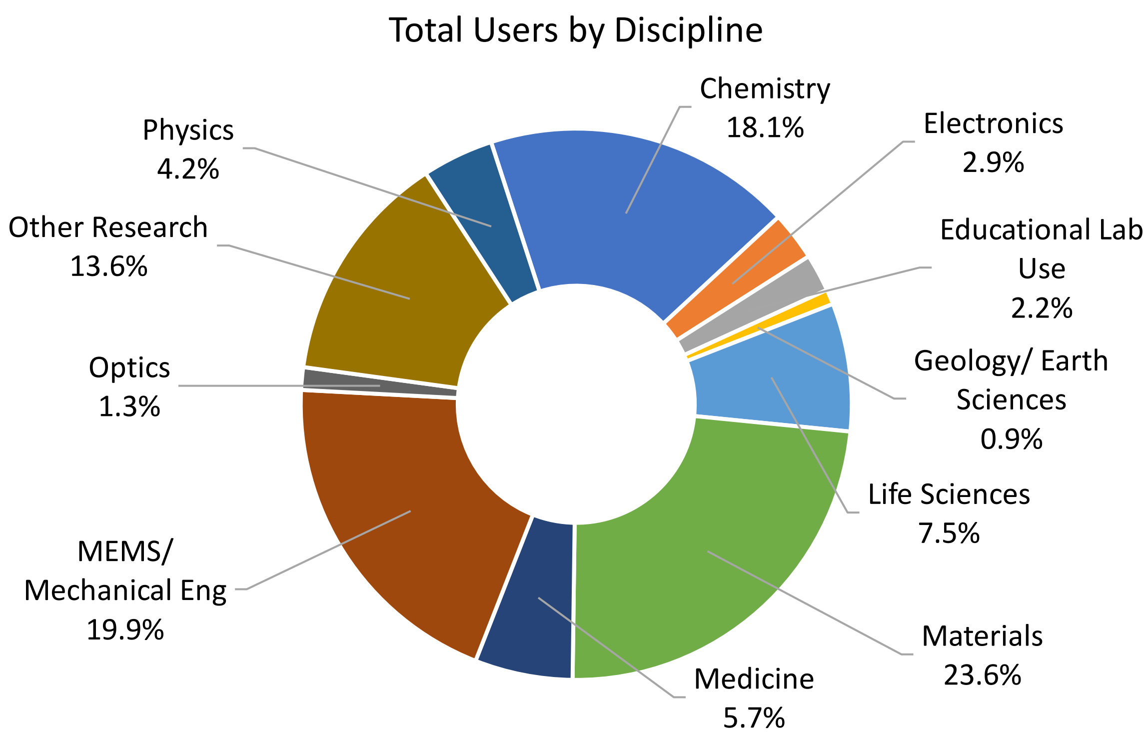
KY Multiscale Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	278	420	411	389	386	465	453
Internal Cumulative Users	206	315	300	278	289	361	379
External Cumulative Users	72 (26%)	105 (25%)	111 (27%)	111 (29%)	97 (25%)	104 (22%)	74 (16%)
Total Hours	14,629	17,151	17,301	15,651	12,895	14,220	12,387
Internal Hours	9,726	12,166	10,960	11,869	9,032	10,282	10,128
External Hours	4,903 (34%)	4,986 (29%)	6,341 (37%)	3,782 (24%)	3,862 (30%)	3,938 (28%)	2,259 (18%)
Average Monthly Users	104	141	120	140	97	127	121
Average External Monthly Users	22 (21%)	25 (18%)	25 (21%)	25 (18%)	20 (20%)	25 (20%)	17 (14%)
New Users Trained	111	251	164	223	118	165	151
New External Users Trained	26 (23%)	43 (17%)	28 (17%)	22 (10%)	18 (15%)	19 (12%)	17 (11%)
Hours/User (Internal)	47	39	37	43	31	28	27
Hours/User (External)	68	47	57	34	40	38	31



KY Multiscale Year 7 User Distribution





12.4. Mid-Atlantic Nanotechnology Hub (MANTH)

The Mid-Atlantic Nanotechnology Hub (MANTH) is a partnership between the **University of Pennsylvania** (Penn) and the **Community College of Philadelphia** (CCP). Nanotechnology facilities are housed at the Singh Center for Nanotechnology at Penn. The Singh Center includes: an 11,000 ft^2 class 100/1000 Nanofabrication Facility supporting a spectrum of diverse materials from silicon to soft materials (the QNF); and a 10,000 ft^2 Nanoscale Characterization and Scanning Probe Facility.

MANTH provides open access to leading-edge R&D facilities and expertise for academic, government, and industry researchers who work within all disciplines of nanoscale science, engineering, and technology. Fourteen professionals staff the center.

The collaboration between Penn and CCP on workforce development and curricula provides opportunities for community college students to learn more about nanotechnology, including nano-related courses and a new paid summer technician internship program at the Singh Center.

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

New Staff: *Mohsen Azadi* is a Principal Scientist at MANTH, and received his PhD at Penn. He is responsible for research support and process development for the internal and external users at the QNF. He is a scientific and technical committee & editorial review board member at World Academy of Science, Engineering and Technology.

Jason Röhr is also a Principal Scientist at MANTH. He is responsible for the physical vapor deposition and electrical characterization tools within the QNF. Prior to joining Penn, Jason obtained his BSc and MSc in Nanotechnology from the University of Copenhagen. He subsequently obtained an MRes and PhD in physics from Imperial College London and held postdoc positions at NYU and Yale University.

Travis Venables is the Lead Cleanroom Equipment Engineer at MANTH. Before joining Penn, Travis worked at Princeton University as a Laboratory Coordinator/ Cleanroom Manager. He has a BS in Biology and a minor in Environmental studies from Ursinus College in Collegeville, PA.

Anton McFadden is a cleanroom technician at MANTH. He recently obtained his A.S in biology at the Community College of Philadelphia. Anton started working at MANTH after completing the CCP internship in the summer. Prior to this, he worked in the research labs at the Wistar Institute for Cancer Research.

Expansion and New Equipment: Several improvements were made to the MANTH Scanning Probe Facility equipment including installing improved Confocal Raman optics for the Horiba scanning probe. A Gatan ultralow temperature electrical biasing sample holder was purchased for the transmission electron microscopes in the Nanoscale Characterization Facility.

The QNF is currently planning for a major expansion and several new tool acquisitions in the coming months. We are building out an entirely new process bay, bringing the total number of bays to 6. The soft lithography facility will be moved to this new bay, making way for a new back-end processing facility that will house our new HBT advanced wire bonder. The new bay marks the first major expansion of the cleanroom since MANTH opened its doors. Project completion is expected in the summer of 2023. The cleanroom is also being modified to accept our new Raith EPBG 100 keV electron beam lithography system, scheduled to be installed in spring 2023.

User Base

Total Use: A user data analysis of the period of NNCI Year 7 (October 2021-September 2022) indicates a robust return of 525 researchers to MANTH as we continue to emerge from the pandemic. In comparison, during the period of NNCI Year 5 (October 2019-September 2020 and unaffected by COVID except at the very end), MANTH served 488 users. During the corresponding period of NNCI Year 6 (a period when MANTH was operating under COVID restrictions), MANTH served 434 users.

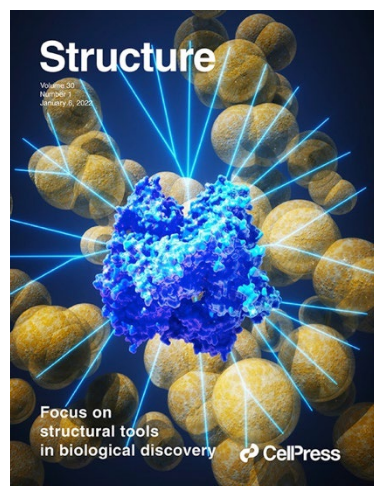
Equipment use hours continues to be robust. The total hours of lab use in Year 7 are higher than even pre-pandemic years, over 56,000 hours. Additionally, 215 new users (internal and external) were trained in Year 7, in contrast to Year 6 with total of 185.

Internal/External Use Breakdown: In NNCI Years 6 and 7, the number of external users rose from 111 to 137 (they make up 26% of all users). External use in total remains lower than the pre-CoVID era but shows signs of recovering; besides the increase in users from Years 6 to 7, the number of tool-use hours by external researchers increased from 5800 Hr. to 6200 Hr. Small companies continue to lead the way, logging in 50% of the equipment hours for external research. Although small companies used our equipment more, external academics made up most of the external user count (68%).

Disciplinary Breakdown: MANTH users conducted research in a wide range of fields; approximately 19% of the users were involved in life science or medicine, like previous years. Those who associate their field with materials research comprised 25% of MANTH users, and 44% identified as working in the physical sciences or engineering. Those who self-identify as electronics researchers have increased to 16%.

Research Highlights and Impact

Publications: Over the calendar year January 1 - December 31, 2021, MANTH enabled 271 nano-related scientific publications and 52 conference proceedings authored by our users. Among the highlights is a protein configuration study that was conducted with our Cryo-TEM and featured on the cover of the journal *Structure*. Many research programs fall under the NSF 10 Big Ideas, particularly in the *Rules of Life* and *Quantum Leap*. Other research in nano-robotics, energy storage, and electronic materials showcase work related to the Nanoscale Internet-of-Things (Nano-IoT), an area of special interest at MANTH.



Penn Professor Moiseenkova-Bell's Transient Receptor Potential on the cover of Structure.

Nano-IoT Research Community: MANTH, with NNCI partners at CNF, SENIC, NNF, and KY-NNIN have created a network Research Community, created to disseminate breakthroughs in the nanotech-enabled internet of things. It is our conjecture that many devices and applications for IoT will be enabled by nanotechnology:

- The IoT ‘things’ may in many cases comprise small-scale structures, sensors, and actuators (MEMS)
- The IoT ‘things’ may need to process and collect data, requiring on-board electronics

- The IoT 'things' will need to communicate with the Internet, requiring communication protocols in multiple bands exploiting a diversity of modalities

This Research Community held its first symposium (online) in September 2021, hosted by MANTH. The meeting was organized by participants from each member site through a series of online meetings held in the summer. The one-day symposium consisted of 4 presentations given by academic and business leaders, followed by research overviews given by the directors of each of the 5 member sites.

The invited speakers included Penn Prof. Cherie Kagan, PI of the new NSF Engineering Research Center *IoT4Ag*, Kaydon Stanzione of *Logistiwerx*, Michael Santiago of *Florapulse*, and Richard O'Brien of *Sempercon*. Figure 2 below shows the agenda.

A total of about 160 unique registrants signed up for the symposium and 65 signed in throughout the day.

The second Nano-IoT research community meeting was held in-person on the Cornell campus in August 2022, hosted by site member CNF.

MANTH-sponsored Nano-IoT Research Community Symposium Schedule

<u>Education and Outreach Activities</u>

Nanotechnology Training Collaboration with the Community College of Philadelphia (CCP): CCP and Penn have continued to partner to identify and provide educational opportunities for community college students in the field of nanotechnology. This partnership resulted in a new program for CCP students – an internship that allows them to experience day-to-day operations in a research cleanroom. The first cohort of 3 CCP students was selected and began a 20-hour/week, paid internship in the MANTH nanofabrication facility in the summer of 2022.

Over the 14 weeks of the program, the interns moved through basic safety and nanofabrication training (lithography, etching, deposition, and soft-lithography) and then on to projects that included fabricating 2D graphene transistors, solar cells, and microfluidic devices. Their internship also required them to attend lectures, observe lab demos, and present their work in periodic meetings with staff and other students. In addition to continuing to work at other jobs that they held throughout the summer internship, the interns continue their academic trajectories; 2 are completing their associate degrees and another has transferred to a 4-year engineering program.

2021 Singh REU student from the 2021 cohort, Nyvia Lyles, in her host lab (PI: Daeyeon Lee) preparing samples.

REU Program: For 2021, Penn Engineering ran undergraduate summer research programs onsite in faculty host labs and the Singh Center facilities. Students followed all Penn COVID-19 safety protocols. Programming that has historically complemented the research, such as faculty research talks, workshops, final presentations, was provided remotely. Singh REU students participated in a weekly meeting throughout the 10-week program with six summer students from an NSF-funded Partnerships in International Research and Education (PIRE) project run from Penn's Materials Science and Engineering Department called, "Research and Education in Active Coating Technologies." Singh REU students also had access to some (remote) programming organized by other Penn Engineering REU programs. Field trips and social events were not held in 2021.

The 2022 cohort of six students began on May 31, 2022. The three women and three men came from Indiana University, North Carolina A&T State University, Mount Holyoke College, University of Scranton, Cornell University and University of Notre Dame. Two identify as White/Caucasian, two as Asian, and two as Black or African American. Their undergraduate majors are Chemistry, Chemical Engineering (N=2), Electrical Engineering, Bioengineering, and Intelligent Systems Engineering.

The Singh Center has hosted 34 REU students over the six summers since 2016 (program canceled in 2020). Of these 34 alums, 15 are pursuing PhDs or an MD/PhD, 1 is a postdoctoral fellow, 9 are in STEM positions, and 7 continue their undergraduate programs. Nine alumni joined the 2021 REU cohort for a Zoom session on July 21, 2021 to discuss their current positions and academic/professional paths; two alums (now at Penn in PhD programs), met with the 2022 REU cohort to talk about their graduate school decisions.

Local Colleges and Universities: As pandemic restrictions further relaxed in year 7, MANTH was again able to provide cleanroom processing experiences to local college students. In October 2021, 14 undergraduates from Jefferson University visited the MANTH QNF cleanroom for a hands-on introduction to device fabrication. In addition, CCP students who took the NNCI-initiated course, *Intro to Nano*, conducted some of their laboratory sessions in the MANTH QNF cleanroom in March 2022.

Some of the Jefferson University students who participated in the hands-on process experience at MANTH in October 2021.

Nanoday@Penn: Each year, MANTH staff members organize NanoDay@Penn for pre-college students. In November 2021, Nanoday@Penn featured both remote demonstrations and in-person meetings with students. This year we recruited partners from nearby Temple and Drexel Universities to participate and provide content. Historically, NanoDay@Penn has served STEM classes in local high schools, but this year expanded to include four classrooms at Commodore John Barry Elementary School (K-8; 100% of students from economically disadvantaged families). A total of 11 presentations were delivered on 8 different topics to a total of 100 students across the various K-12 schools. Some students joined from in-person classrooms with their teachers while others visited MANTH and its partner sites (Figure 5).

Nanoday in-person demonstration led by students of Prof. Bargatin's lab; a student demonstrates the strength of corrugated structures.

Other High School Outreach: The American Association for the Advancement of Science (AAAS) held its annual meeting in Philadelphia in February 2022. Penn collaborated with the National Association of Academies of Science (NAAS) to host a program for high school students. MANTH staff developed an online nanotechnology overview for dozens of these high school students. Presentations included an overview of MANTH and its role in nanotechnology research, an introduction to what nanotechnology is, and live demonstrations of 3D nanoscale lithography and electron microscope characterization.

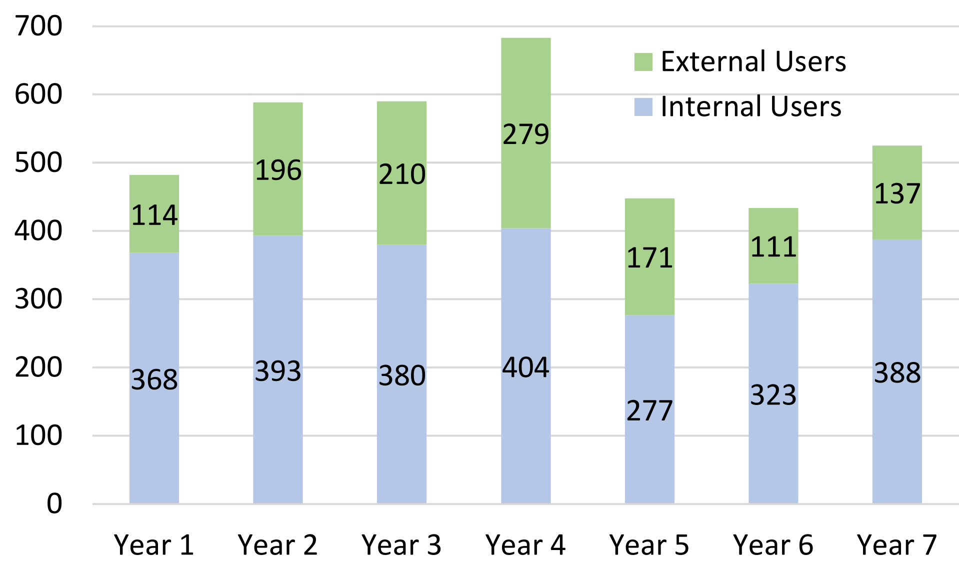
<u>Innovation and Entrepreneurship Activities</u>

Since 2016, the MANTH Innovation Seed Grant (ISG) Competition has attracted the brightest minds in nanotechnology within the Mid-Atlantic region. For 2021-2022, the call for applications was opened to academic research communities in addition to the startup community. The ISG Competition committee granted funds for MANTH equipment use to 11 entries from academia and from one local startup. The academic applicants range from undergraduate students to faculty from the University of Delaware, Rowan University, Temple University, Saint Joseph's University, Drexel University, and the New Jersey Institute of Technology.

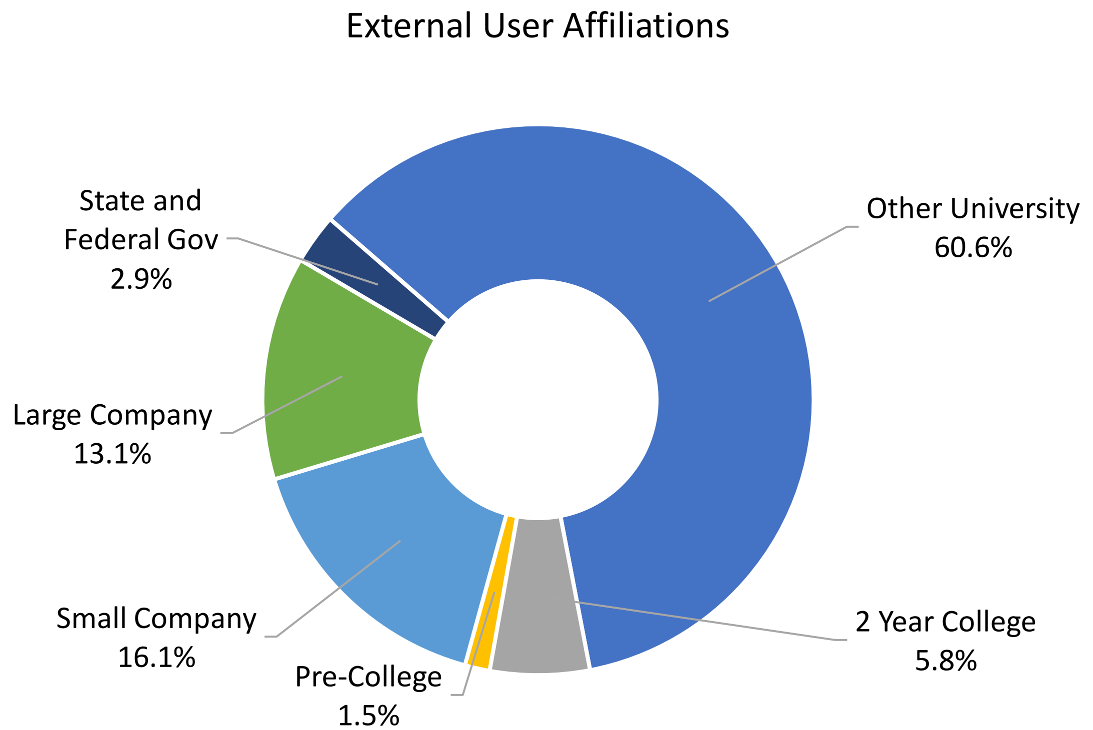
Since the inception of MANTH, over 70 small companies (defined as 50 or fewer full-time employees) have utilized our resources either on site or remotely. Pronounced growth in external use occurred prior to the pandemic (FY 2021) - a large majority focusing on Life Science and Medicine - and activity continues to grow. To date, over a third of our small companies have received external support, leveraging their engagement with MANTH to yield **$58M** of funding, approximately half from SBIR/STTR grants. The year 2021 was exceptional with 10 small companies receiving over $11M in SBIR grants, and one company raising over $20M in a series B financing.

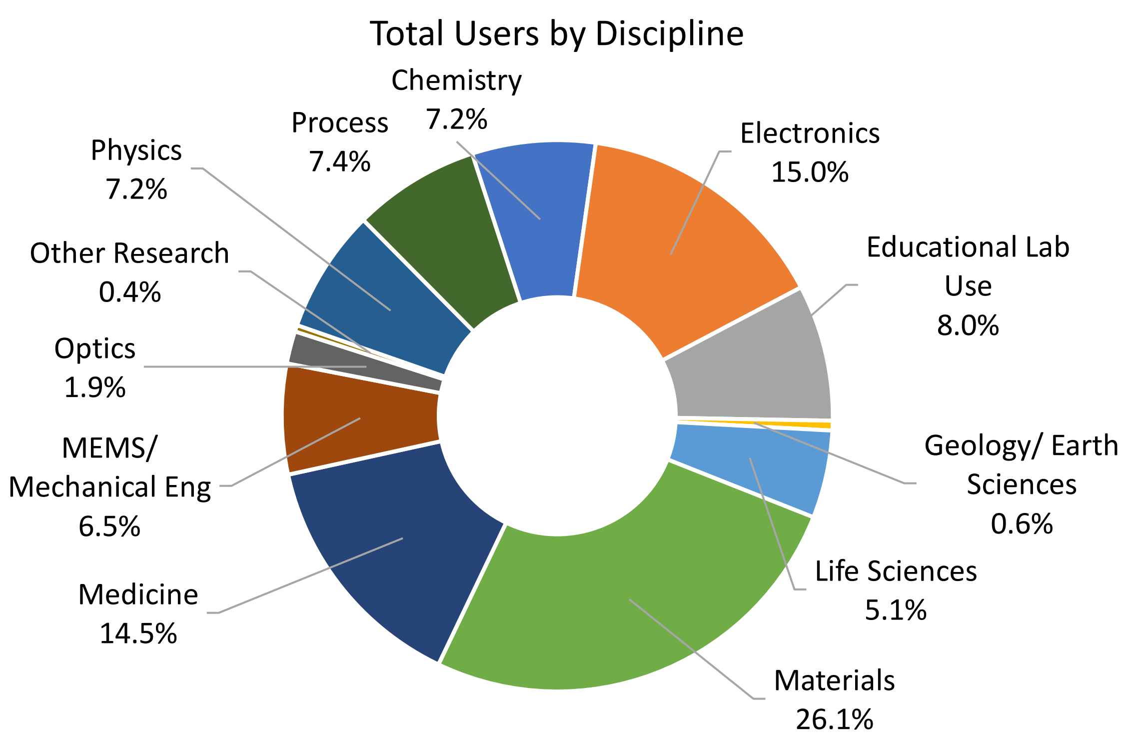
MANTH Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	482	589	590	683	448	434	525
Internal Cumulative Users	368	393	380	404	277	323	388
External Cumulative Users	114 (24%)	196 (33%)	210 (36%)	279 (41%)	171 (38%)	111 (26%)	137 (26%)
Total Hours	36,970	37,933	34,796	56,849	45,551	63,945	56,729
Internal Hours	34,545	31,542	27,436	43,673	39,379	58,094	50,921
External Hours	2,425 (7%)	6,409 (17%)	7,360 (21%)	13,176 (23%)	6,172 (14%)	5,851 (9%)	5,807 (10%)
Average Monthly Users	171	194	186	210	142	180	216
Average External Monthly Users	29 (17%)	44 (23%)	45 (24%)	61 (29%)	31 (21%)	25 (14%)	37 (17%)
New Users Trained	270	339	270	418	180	186	215
New External Users Trained	73 (27%)	138 (41%)	104 (39%)	203 (49%)	95 (53%)	52 (28%)	72 (33%)
Hours/User (Internal)	94	80	72	108	142	180	131
Hours/User (External)	21	33	35	47	36	53	42



MANTH Year 7 User Distribution





12.5. Midwest Nanotechnology Infrastructure Corridor (MiNIC)

Facility, Tools, and Staff Updates

The Midwest Nano Infrastructure Corridor (MiNIC), based at the University of Minnesota-Twin Cities, includes two core facilities: the Minnesota Nano Center (MNC), which supports nanofabrication and nanomaterials research in two cleanrooms and specialized labs, and the Characterization Facility (CharFac) which provides nanoscale materials characterization capabilities including advanced microscopy and surface analysis.

MNC new equipment and capabilities

The AJA ATC series 1800-HY UHV multi-technique deposition system, delivered in 2021, was released for use in May, 2022. This system has 6 sputter guns, a 6-pocket electron beam evaporation source, an ion source for substrate preclean, SIMS end-point analysis capability, a load lock for *in-situ* oxidation, and substrate tilt and rotation control. The system is producing high-quality superconducting films for use in Josephson junction and topological qubit devices.

The MNC received funding in 2021 through an internal award to purchase a glove-box-based 2D material assembly system. The system is now operational and is being used by several researchers. It supports the Quantum Leap focus area by enabling novel quantum structures, such as twisted graphene bi-layers and 2D Josephson junctions, to be fabricated precisely and under ultra-pure environmental conditions.

A mass-spectroscopy-based endpoint detection system was added to the MNC's Intlvac Nanoquest ion beam etcher. This system will be particularly beneficial for projects involving the etching of magnetic devices such as magnetic tunnel junctions, where Ar ion-beam etching is the preferred method and terminating the etch at the appropriate point is critical.

During this period, our Beckman Optima analytical ultracentrifuge (AUC) was fully brought online. The AUC technique monitors the behavior of nanoscale materials as they sediment under the huge settling forces developed in a specialized high-speed centrifuge. The first annual AUC user group meeting was held in April, 2022, and we have trained several new users from the life science and materials engineering communities.

The MNC has replaced its aging RTP-600S rapid thermal processing (RTP) tool with a more sophisticated Solaris 150 RTP system. The Solaris 150 can process up to 150-mm substrates at a temperature up to 1250 °C. The system possesses a unique temperature measurement system that does not require re-calibration for different wafer types and backside emissivities. The system can ramp up temperatures at a rate of up to 200 °C/sec, and supports multiple ambient gases. The system has been delivered and is awaiting final installation.

CharFac new equipment and capabilities

MiNIC expanded its atomic force microscopy (AFM) capabilities by upgrading the Bruker/Anasys NanoIR3 AFM-IR system to enable the control of the IR laser polarization state and the sample environment (improvements funded by our local MRSEC). The instrument has been collocated with two other environmental AFMs to form the new Spectroscopic and Environmental AFM Lab.

A new ThermoFisher Scientific Talos F200C G2 Analytical Scanning and Transmission Electron Microscope (S-TEM) was purchased and installed during this reporting period. This new generation high-resolution S-TEM has cryo-imaging capability and two specialized specimen holders, which allow researchers to conduct atomic-scale resolution experiments. This acquisition was possible through funds from the Army Research Office, and will be important for expanding examination of biological specimens in support of our Rules of Life focus area.

Staff updates

MiNIC experienced considerable staff turnover during this period, with several prominent staff retiring or leaving for other positions.

Dr. Greg Cibuzar, who served as MNC lab manager for over 30 years, retired in April, 2022. His replacement is Dr. Brian Olmsted, a Ph.D. graduate of the University of Minnesota, who comes to us from an industry lab at Honeywell Inc. Dr. Olmsted was hired in February, 2022 and shadowed Dr. Cibuzar for three months prior to assuming his full duties in April, 2022.

Lage von Dissen, a senior maintenance staff member in MNC and Becky von Dissen, the MNC administrator, both left MNC to take new positions within the University. They were replaced by Mark Margosian and Kristina Pearson, respectively. In addition, Emma Jore, who had been a part-time process staff member, was hired to the process team full time to replace Mark Fischer who retired in the previous term.

In CharFac, TEM scientist, Dr. Robert Hafner, retired in March, 2022 after 17 years on staff. Long-time staff member Fang Zhou took over the management of the FEI Spirit high-contrast TEM, along with its life science, soft matter and cryoEM user base.

User Base

In August, 2022 the MNC took the lead in organizing a Core Lab Open House, designed to showcase the University's research support assets for external users. The event hosted over 75 visitors from 3M, Sherwin-Williams, Emerson, and other major corporations, along with representatives of smaller firms. Attendees received tours of the Nano Center, CharFac, the Polymer Characterization lab, and several other University analytical centers.

In early October, 2021, Dr. Marti developed and presented a user webinar on dynamic light scattering entitled "DLS: What's Under the Hood?" Intended for lab practitioners in industry and academia, the webinar explored the working details of DLS and how different implementations of this technique offer different levels of accuracy and sensitivity. The webinar was recorded and is available for viewing on the Minnesota Nano Center's YouTube channel.

Over the last year MiNIC staff worked to recruit new users for our new analytical ultracentrifuge (AUC). In support of that effort, MiNIC organized and held its first AUC Users group meeting in April, 2022. The event was attended by researchers from the University's Schools of Medicine and Pharmacy, and departments from within the College of Biological Sciences and the College of Science and Engineering. MiNIC expects the AUC to become a centerpiece of the site's focus on the biological applications of nanotechnology.

During this period, MiNIC also relaunched its user incentive program called *Explore Nano*. The program is directed to new users or those returning after an absence of over two years. The program offers a $2000 credit against fees for lab and tool use as well as training fees. Under *Explore Nano*, MiNIC has hosted a total of twenty researchers from industry and/or external academic institutions. The strong response has led us to continue the program through the rest of 2022 and into 2023.

Other outreach efforts during this reporting period include: (1) production of a new video that introduces the MNC and its capabilities to potential users and students, (2) establishment of a LinkedIn page for the MNC, to which we post short notices on new tools, events, and featured facility users, (3) revitalization of our periodic newsletter, sent to current and potential clients of the MNC and CharFac, (4) an exhibit at the 2022 Design of Medical Devices conference, connecting MiNIC capabilities to local and national companies working with medical devices and pharmaceuticals, and (5) resumption of live, in-person tours of the labs and cleanrooms for visitor from industry and academia.

Research Highlights and Impact

Correlated Insulating States in Twisted Graphene Multilayers

MiNIC has supported multiple advances in two-dimensional (2D) materials research in this period. In this highlight, electronic transport in twisted tri-layer graphene with two consecutive small twist angles was studied. Such systems are interesting, since 2D materials with a small twist angle give rise to periodic patterns, referred to as a moire superlattices, which have a much larger length scale than the original lattice. In this work, devices fabricated in the MNC showed correlated insulating states at an extremely low carrier density ($\sim 10^{10}$ cm^{-2}), near which a zero-resistance transport behavior is observed, indicative of a possible superconducting state. (X. Xhang, *et al*., *Phys. Rev. Lett.* 127, 166802, 2021).

Epitaxial van der Waals Spintronics Platform

MiNIC also supports work on other 2D materials beyond graphene. In this work led by Penn State University, and using the TEM capabilities in the CharFac, synthesis of van der Waals (vdW) heterostructures using molecular beam epitaxy (MBE) was performed. In particular, MBE was used to synthesize a vdW heterostructure which merged a 2D ferromagnet ($CrTe_2$) with a topological semi-metal ($ZrTe_2$). It was found that one unit-cell-thick 1T-$CrTe_2$ grown by MBE on $ZrTe_2$ displays ferromagnetic properties, while ultrathin $CrTe_2$ can show current-driven magnetization switching. These results are encouraging for realizing novel spintronics devices in a wafer-scale VdW platform. (Y. Ou, *et al*., *Nat. Commun*. 13, 2972, 2022).

WS_2 MOSFETs with Semi-Metallic Bi Contacts

MiNIC also supports device fabrication and growth of beyond-graphene 2D materials. In particular, the MNC has developed extensive growth and processing capabilities for transition metal dichalcogenides such as, MoS_2 and WS_2, which are promising candidates for future applications in sub-1-nm-node CMOS technology. A key roadblock to date, has been the formation of low-resistance contacts to these materials. In this work, semi-metallic bismuth (Bi) contacts were used to realize dual-gated, single-layer WS_2 MOSFETs with very high drive current and low contact resistance. The results are particularly promising since the WS_2 was grown using chemical vapor deposition, a technique compatible with synthesis on large-area substrates. (L. Jin, *et al*., *IEEE Elect. Dev. Lett.* 43, 639-642, 2022).

Extremely Long-Range Josephson Coupling Across a Half-Metal

This highlight provides an excellent example of how the expert CharFac staff facilitate research from international collaborators. In this work, performed by Prof. Jacobo Santamaria at Universidad Complutense Madrid, and in collaboration with Charfac staff member Dr. Javier Garcia-Barriocanal, superconducting coupling between two regions separated by a 1-mm-wide ferromagnetic material was shown to exist at high temperature (tens of Kelvins). Such a long-range macroscopic quantum interaction in junctions with ferromagnetic spacers had remained elusive until this work. The results pave the way for low-power superconducting / spintronic applications where spin-polarized currents can be protected by quantum coherence. (D. Sanchez-Manzano*, et al.*, *Nat. Mater*. 21, 188-194, 2022).

Bio-Functionalization of Block Copolymers with Biocompatible Ionic Liquids

Linear-dendritic block copolymers (LDBCs) are promising for using as encapsulants in both hydrophobic and hydrophilic dyes for bioimaging, cancer therapeutics, and small biomolecules. However, LDBCs also can exhibit high dispersities, poor shelf-life, and high cytotoxicity to non-target blood cells. This work, led by the Tanner Lab at the University of Mississippi, reports the use of ionic liquids to modify linear and linear-dendritic block copolymer nanoaggregates for use in drug delivery and improve their performance. Cryo-TEM analysis in the CharFac suggests this improvement is due to formation of a nanoparticle surface coating, which protects against red blood cell hemolysis. The results show that by controlling the nanoscale physical chemistry, biological function can be more precisely tailored. (C. M. Hamadani, et al., *Nanoscale* 14, 6021-6036, 2022).

Rapid Detection of Volatile Organic Compounds in a Graphene Electronic Nose

Electronic noses are important vehicles for rapid detection of volatile organic compounds (VOCs) for detection of a variety of disease states in human breath. In this work, a large array of graphene sensors, fabricated partially in the MNC, was used to selectively and rapidly detect multiple VOCs. Each array contains 108 sensors functionalized with 36 chemical receptors for cross-selectivity. A supervised machine learning algorithm shows excellent results of 98% accuracy between 5 analytes at four concentrations each. This is an important step toward fully utilizing graphene-based sensor arrays for rapid gas sensing for disease detection in human breath. (N. S. S. Capman, et al., *ACS Nano* 16, 19567-19583, 2022).

Explore Nano Project: AFM Imaging of Ion Liquids around Nanoparticles

In work funded through our *Explore Nano* program, which is an incentive program to attract new external users to MiNIC, researchers at the University of Mississippi used AFM in attractive-regime AC mode to image ionic-liquid domain morphology. They also used force-distance mapping to probe structuring within the ionic liquid at nanoscale distances from hard mechanical contact with submerged PLGA nanoparticles. The cross sections exemplify shape distortions due to the presence of the PLGA nanoparticles within the liquid islands.

Education and Outreach Activities

Research Experience for Teachers (RET) Program

In 2019, MiNIC was awarded a Research Experience for Teachers (RET) grant, along with three other NNCI sites. Due to the pandemic, the program's start was delayed to the summer of 2021, so this reporting period covers year 2 of the RET grant. During the summer of 2022, two science teachers from the Twin Cities metro area were recruited for the program and were paired with University of Minnesota faculty interested in mentoring an RET teacher as part of their lab. The teachers spent the summer working with the faculty research groups and gained experience in cutting edge lab science as well as communicating their work to their peers. An important part of the RET program has the teachers develop a classroom lesson/unit/activity on some aspect of nanoscience and technology for their own classes. In March of 2022, the previous year's RET program (2021) was capped with the teachers attending the 2022 annual conference of the National

Science Teachers Association in Houston. The RET program is being professionally evaluated by Dr. Mary White of ASU, and Dr. White's report is expected to be released in the coming month.

Lab Internship Program

MiNIC continued to offer its popular laboratory internship program during the current reporting period. This program offers students from two-year community and technical colleges the chance to work in a nanoscience lab, gaining experience that can be applied to their job search or support their transition to a four-year program. During the fall of 2021 and through spring of 2022, MiNIC staff supported four students studying the effects of nanoparticle exposure on living cells. The students used our NanoBio labs and tools to characterize nanoparticle dispersions and culture several types of cells, including bacteria, yeast cells, and human cell lines. Each intern's work resulted in a written report and a poster for their academic credit, and a set of written protocols that MiNIC's labs can use for future work in this area.

Facility Tours and Classes

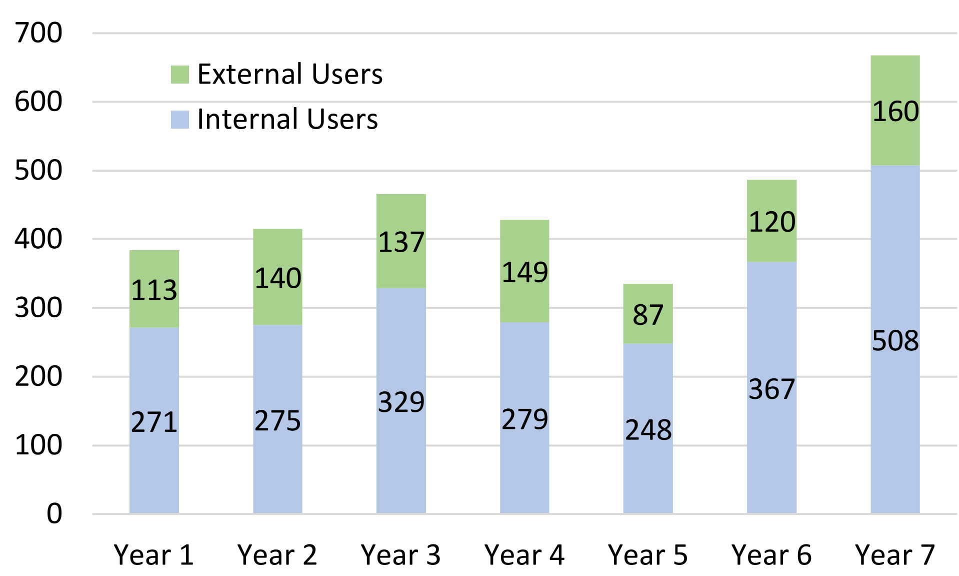
With the lifting of more COVID-related restrictions in the spring of 2022, MiNIC is slowly returning to offering cleanroom tours and classes on nanotechnology for visiting student groups. An Introduction to Photolithography and cleanroom tour was offered to a small group of high school students in April 2022, and a return to offering summer camp nanoscience classes for grades 8-12 is in the planning stage.

Innovation and Entrepreneurship Activities

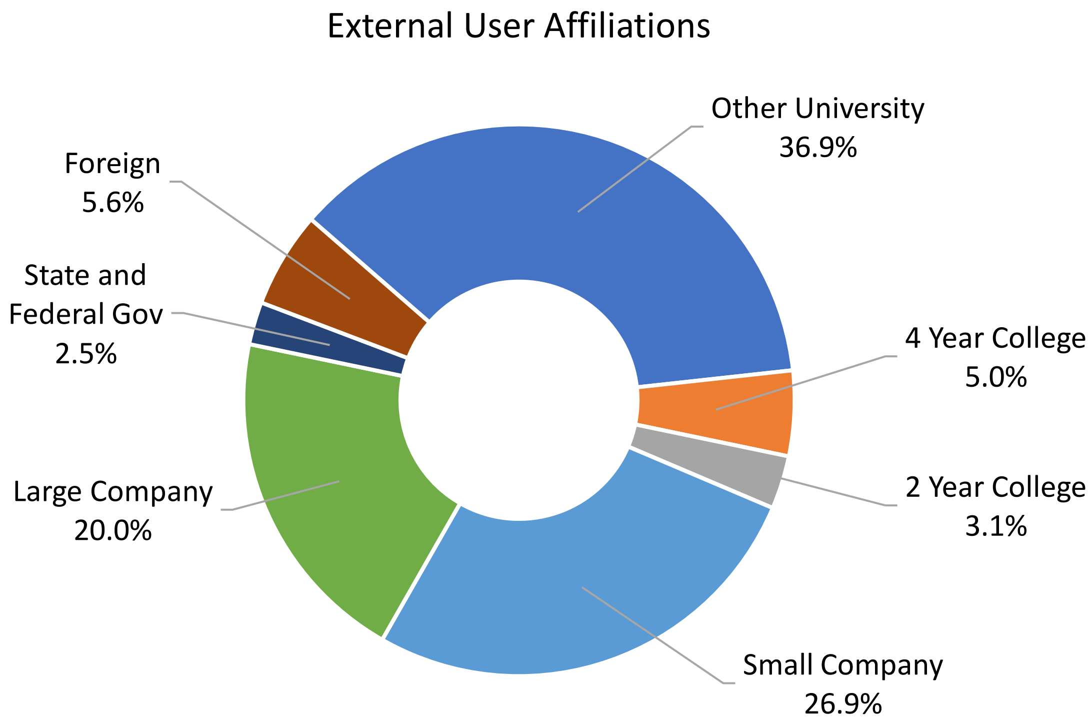
MiNIC staff member Dr. Jim Marti worked with start-up company, Superior Nano LLC, to win NSF funding to support the development and commercialization of lipid nanoparticles for dermal drug delivery. A phase 2 SBIR grant was awarded to Superior Nano based on previous work at MiNIC's Nanomaterials Lab. MiNIC has also supported fabrication and characterization work from several other nanotechnology start-up companies, including Claros Technologies, which is an advanced materials startup based in Minneapolis. Scientists at Claros use equipment available at CharFac such as SEM, XRD, and FTIR to determine the morphology, structure, and chemical nature of products made at Claros. Another startup supported by MiNIC is Grip Molecular Technologies, which is developing a multiplexed biosensing platform to create an at-home upper respiratory virus panel test. Grip is using Raman and XPS at CharFac to validate functionalization of graphene-field-effect biosensors fabricated in the MNC. Finally, a new start-up company, VOCxi Health, a spin-out from the University of Minnesota, has obtained early-stage venture funding to develop a breath diagnostic system for accurate, non-invasive, mobile disease identification. Born out of years of research using MiNIC facilities, VOCxi's patented technology is designed to measure disease from thousands of volatile organic compounds in just one minute of breath.

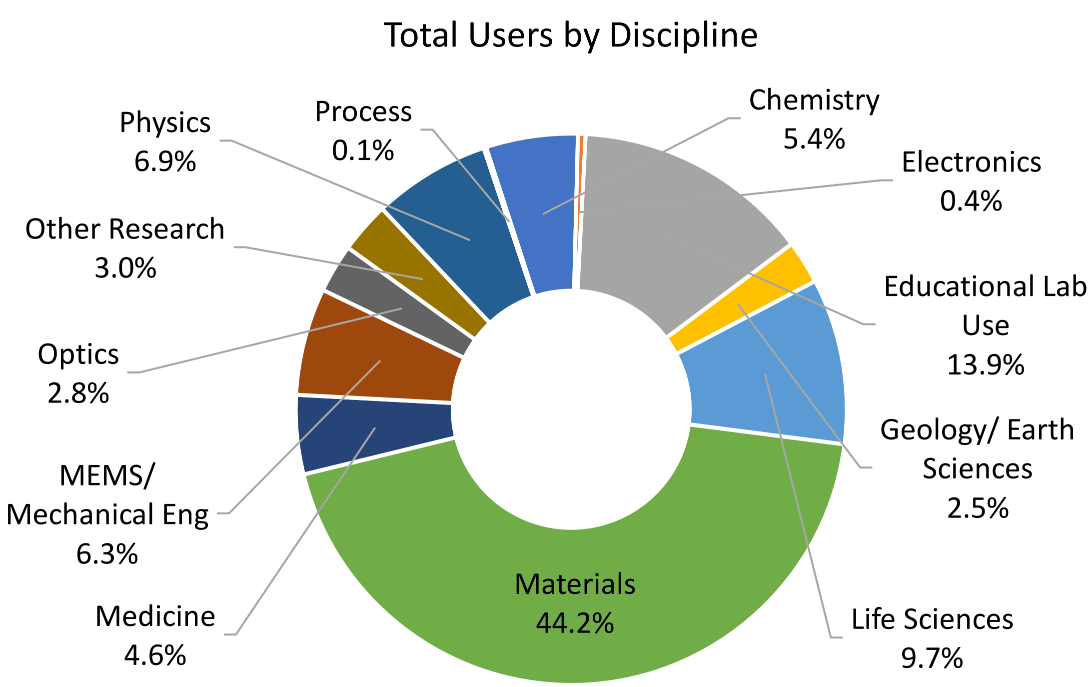
MiNIC Site Statistics

Yearly User Data Comparison	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Total Cumulative Users	384	415	466	428	335	487	688
Internal Cumulative Users	271	275	329	279	248	367	508
External Cumulative Users	113 (29%)	140 (34%)	137 (29%)	149 (35%)	87 (26%)	120 (25%)	160 (24%)
Total Hours	27,002	26,443	26,851	27,782	17,682	27,317	31,916
Internal Hours	20,495	19,733	21,324	17,780	11,491	21,303	27,384
External Hours	6,507 (24%)	6,710 (25%)	5,527 (21%)	10,002 (36%)	6,191 (35%)	6,014 (22%)	4,532 (14%)
Average Monthly Users	156	156	161	161	116	165	235
Average External Monthly Users	26 (17%)	33 (21%)	30 (18%)	37 (23%)	27 (23%)	31 (19%)	36 (15%)
New Users Trained	151	150	189	136	101	213	280
New External Users Trained	57 (38%)	59 (39%)	48 (25%)	45 (33%)	17 (17%)	39 (18%)	87 (31%)
Hours/User (Internal)	76	72	65	64	46	58	54
Hours/User (External)	58	48	40	67	71	50	28



MiNIC Year 7 User Distribution





12.6. 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 microscopy facility (TEM); Partner site with the Science Education Resource Center (SERC) at Carleton College.

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

The facilities have added roughly $2M in equipment supported outside of NNCI funds.

ICAL has installed and is running equipment funded during the last reporting period:

1. The Cameca ION TOF IV, time of flight SIMS, acquired with university funds
2. NSF EAR I/F $488k grant allowed for EDS detectors for fast elemental mapping, an EBSD detector, a CL Detector with spectrometer, and updated computer system for correlative imaging and analysis

Zeiss Supra55VP, run by Riad Rezaul, sporting two new detectors and the computer upgrade that made all of that possible.

CBE has added:

1. A new Multi-Modality Multi-Photon Digital Light Sheet Fluorescence Microscope. This custom designed microscope is optimally configured to allow real-time, high-sensitivity, high-throughput imaging. **This $1.5M instrument is** funded by NSF MRI Track 2 and MJ Murdock Charitable Trust**.**
2. A new Leica THUNDER Live Cell epi-fluorescence widefield microscope with DOD DURIP funding ($250K).

MMF has added about $140,000 in new equipment:

1. With the addition of the Bruker Dektak XTa stylus profilometer ($86K funded by the facility) users will be able to measure film and etch step heights and create 2D surface contour maps for nanostructured samples.
2. An internal university grant funded an Anric Technologies AT410 ALD system, $50K.

All MONT staffing remained stable, no changes to report.

<u>User Base</u>

We are pleased that the Y7 user count has reached an all-time high. MONT served 233 users in Y7, compared to 189 users in Y6, to 169 users in Y5, 188 users in Y4. MONT served 71 external users, up from 58 users in Y6. **This is the largest number of external users to date and right at our 30% external user target mark, which we have maintained over Y6 and Y7**. In Y6 MONT served 58 external users, who made up 30% of our user base; Y5 we had 48 external users, who made up 28% of our user base, and 27% (50 users) in Y4.

MONT awarded 6 **user grants to seed new projects** in Y7.

Three internal grants were awarded to:

Madeline Garner, graduate student, received funding for two projects to 1) explore the use of solid-state nanopore technology for biosignature detection in space and 2) to functionalize impedance sensors. This funding supports work with NASA FINESST and NASA EPSCoR.

Madelyn Mettler, graduate student, was funded to start a project on the use of antimicrobial coatings to prevent biofilm growth in ISS water systems, with an aim for NASA funding.

Dr. Diane Bimczok received funding to seek the mechanisms involved in *Helicobacter pylori* infection of the human stomach. This work is expected to generate pilot data for an NIH proposal.

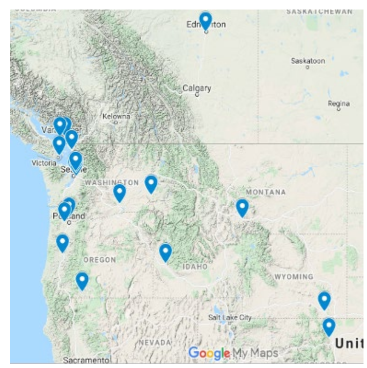
Three external grants were awarded to:

Dr. Alberto Perez-Huerta, University of Alabama, received support to study the surface chemistry of clay minerals that have been treated with amino acids, and Rare Earth Elements. These outcomes are expected to bolster several proposal submissions.

Dr. Richard Warner, Montana State University, Billings, received MONT funding to support research on metastatic melanoma. The funds will be used to develop a new sensor chip, which will allow interaction analysis of the proteins to determine the best choice of a therapeutic target for melanoma. This device will be used to generate publishable data.

Chris Arrasmith, Revibro Optics, received funding to investigate methods for improving SU8 adhesion to glass substrates and identify a wafer bonding and release process that can produce reliable microfluidics devices.

Northwest Nano Lab Alliance (NWNLA): In early November 2021, MONT and NNI hosted a virtual meeting for staff of fabrication, imaging, and analysis facilities in the northwest. **We had over ninety attendees** from universities, government institutions, small companies, and equipment manufacturers over the two days. The agenda consisted of eight invited presentations, eight breakout sessions for discussions on relevant topics, and nine vendors presenting laboratory equipment. Fourteen responded to the follow-up survey, and all strongly or somewhat agreed that the workshop was valuable. The University of Washington will host the 2023 meeting in-person, with an option of joining virtually.



Pins of participating NWNLA affiliates.

Research Communities: A second NNCI **Nanoscience for Earth and Environmental Science** Virtual Workshop was held in May 2022. MONT's education partner SERC handled the web hosting, workshop materials, registration, logistics, and marketing for the event.

MONT hosted a **Rules of Life** webinar in November 2022 (just outside of this reporting period), *The Convergence of Biology and Earth Sciences.* This virtual event explored the intersection between biology and geological sciences and explored how microbial communities interact with and shape their environment, and how we can use tools from nanoscience to better understand these interactions. About 40 people attended the event; respondents to the post workshop survey rated the event very favorably.

As a **new activity to continue to increase the number of external users served**, we embarked on an ambassador/outreach trip in spring 2022 to solicit collaborations. This is a pilot program to gauge the potential effectiveness of this type of activity to generate new facility users. At each university we showcased MONT's unique capabilities while working to understand specific local objectives at each university. We visited:

- University of Utah; we have just welcomed a new user from there
- Arizona State University
- University of Arizona

Research Highlights & Impact

Scholarly impact: During 2021, MONT researchers produced 42 journal papers, 65 other products, and 2 patents.

MONT users had several outstanding accomplishments during the reporting period. **Graduate student George Schaible's correlative microscopy image graces the cover of the 2022 volumes of The ISME Journal**, the premier journal in microbial ecology. Impact factor: 12.28 (2020). The image was generated in ICAL and used FEM, SEM, EDX, and Raman. The image reveals distinct properties of obligate multicellular magnetotactic bacterial from salt marsh sediment. Schaible is also a **MONT user grant recipient**.

MONT User Grant recipient involved in $3.5M grant to MSU funded by the Army Research Lab. Dr. Nicholas Stadie is part of an overall $10M effort involving several other universities, national labs and industrial partners that will develop and test lithium-ion batteries that use a specialized ceramic material. Stadie, Assistant Professor in the chemistry and biochemistry department and an expert in energy storage, will focus on developing graphite- and silicon-based materials for the electrodes that release and absorb energy during battery operation. **Stadie was a recipient of a MONT user grant in 2020** that helped to expand his research on energy storage capacity far exceeding that of commercial graphite-based lithium-ion batteries. Stadie's user grant contributed to this follow-on project.

MSU researcher Yaofa Li, Assistant Professor in the Department of Mechanical and Industrial Engineering, and also a **MONT User Grant recipient**, has received an **NSF CAREER Award** for his work focused on methods to cool the immense heat generated by advanced computers. Li and his students will use MONT's MMF to create devices to measure the velocity and temperature of evaporating liquids.

Education and Outreach Activities

The newly launched **MONT Empower Scholars program** awarded 4 scholarships to place underrepresented undergraduate students with MONT researchers for a research experience and tool training. Demographics include 3 Hispanic/Latinx students (one of which is female), and 1 female student. We trained 12 students from different MSU REU programs in our facilities and three participated in the **NNCI REU Convocation**.

MONT hosted 20 students in our labs during the **4-H Summer Congress**. Our newly created lessons included Become a Nano Engineer and Become a Nanoscientist in a two-part, hands-on course. Participants from rural Montana communities first made nano silver particles in workshop 1 and were then able to use the electron microscope and look at their particles to discover both physical appearance and map the elements present in the sample during workshop 2.

We have been working with the Salish Kootenai College (SKC) middle/high school programs to incorporate nanoscience/technology education on the Flathead Reservation in northwestern Montana. We are working with SKC program directors on the possibility of taking a group to Yellowstone National Park for a Nano Earth and Environmental Sciences field trip this summer with follow up in MONT labs.

During the last week of May, MONT PI Dickensheets taught a workshop to 30 college-bound students in Burundi, Africa. The multi-day course, which included several activities developed by the MONT team for high-school outreach in Montana, was received enthusiastically and prompted lively discussions related to global and societal impacts of nanotechnology and opportunities for young people to pursue careers in nano-related science and technology fields.


Students in Burundi.

MONT was involved with the nano@stanford **Nanoscience Summer Institute for Middle School Teachers**. PI Mogk presented a nano and environment talk and MONT sponsored a teacher from a rural school in eastern Montana to attend the workshop. The **Solar Cells for Teachers** course resumed this summer. MONT hosted 8 teachers from around the US in the summer of 2022. The post-course survey suggested that overall, teachers would use the lessons learned in their own classrooms. MONT also hosted one RET participant studying materials science in our ICAL facility. This was a middle/high school teacher from rural Montana.

Fifth graders enjoying NanoLand's clean room.

MONT sponsored and helped to organize MSU Science Day for 150 5^{th} graders. The main MONT PIs also have interactive displays on their particular research involving nanoscience and nanotechnology.

We have recently become involved with the Montana Science Center which provides experiential learning opportunities for all children. They have recently incorporated a hands-on STEAMlab; MONT has presented a nanoparticles lab and we are in the process of developing more lessons and labs. MONT has also sponsored the **NISE Network's Nano Exhibit** at the Center. The exhibit will be in Bozeman and surrounding areas for several months. MONT has prepared companion materials for the exhibit and handouts to direct participants to nano lessons on our outreach website page.

<u>SEI Activities</u>

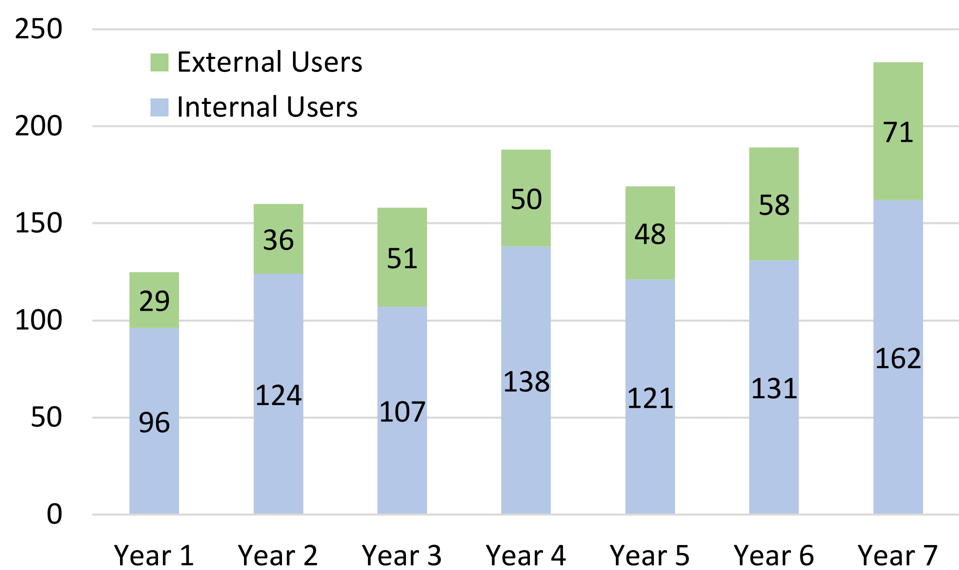
Co-PI Mogk continues to participate with the NNCI/SEI committee. Continued website development includes an expanded resource collection of journal articles and books related to ethics and nanotechnology/science, and societal issues related to nanoscience. These references can be accessed on the [SERC website](#).

Innovation and Entrepreneurship Activities

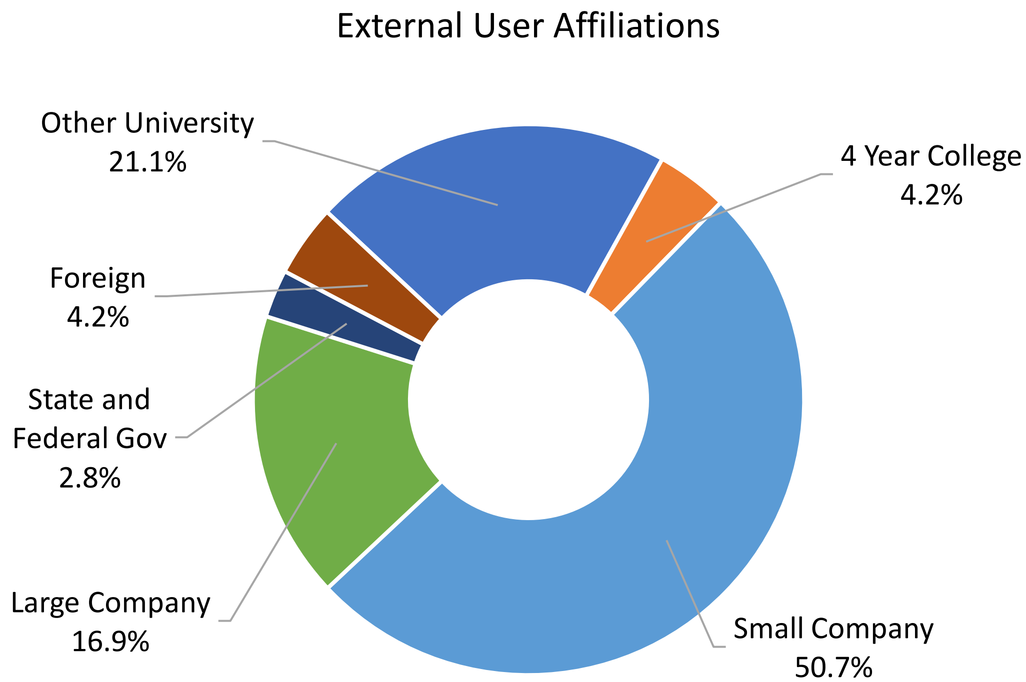
MONT actively participated in the NNCI I&E group. MONT student Matthew McGlennen participated in the **Nanotechnology Entrepreneurship Challenge**, and Dr. Andrew Lingley served as a panelist for the final student showcase. MONT organized and hosted the best-ever attended NNCI Webinar, given by Dr. Miguel Orteaga from Teledyne Scientific, on transitioning from a university fabrication facility to a foundry. Over fifty people attended virtually, and the recording currently has over 60 views. We are also coordinating with the Montana High Tech Business Alliance to host a speaker focused on innovation and entrepreneurship for the summer REU convocation hosted at MSU. Finally, we are working closely with the MANCEF organizers to make sure the event is attended by NNCI members.

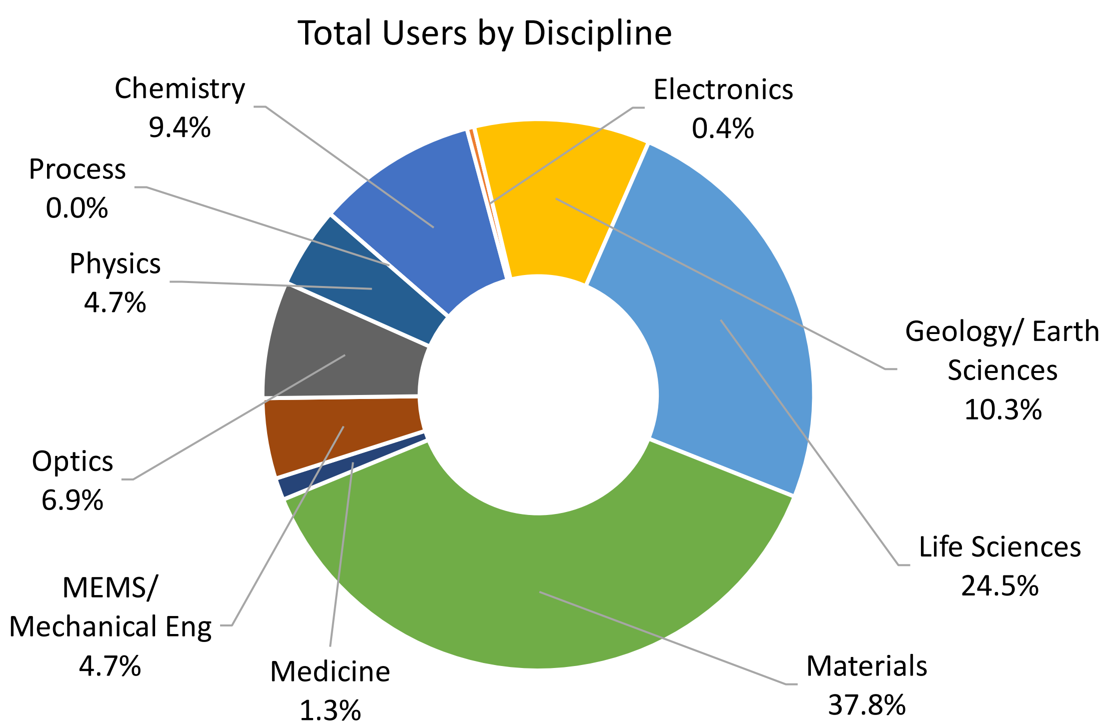
MONT Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	125	160	158	188	169	189	233
Internal Cumulative Users	96	124	107	138	121	131	162
External Cumulative Users	29 (23%)	36 (23%)	51 (32%)	50 (27%)	48 (28%)	58 (31%)	71 (30%)
Total Hours	3,599	4,713	5,420	6,398	4,858	7,735	9,142
Internal Hours	2,842	3,901	4,541	5,332	3,395	6,550	7,512
External Hours	747 (21%)	812 (17%)	879 (16%)	1,066 (17%)	1,463 (30%)	1,185 (15%)	1,630 (18%)
Average Monthly Users	46	51	43	62	48	57	75
Average External Monthly Users	8 (17%)	10 (20%)	7 (17%)	10 (16%)	9 (19%)	13 (23%)	17 (22%)
New Users Trained	36	58	58	76	70	86	86
New External Users Trained	1 (3%)	9 (16%)	8 (14%)	6 (8%)	7 (10%)	20 (23%)	17 (20%)
Hours/User (Internal)	30	31	42	39	28	50	46
Hours/User (External)	26	23	17	21	30	20	23



MONT Year 7 User Distribution





12.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

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

In Year 7 we acquired an AXIS Supra$^+$ x-ray photo-electron spectroscopy system from Kratos Analytical for the Eyring Materials Center (EMC), one of the ASU core facilities under the NCI-SW umbrella. The system provides elemental and chemical bonding information on the sample's first few atomic layers.

The Kratos x-ray photoelectron spectroscopy facility is located in the EMC core facility.

A new Heidelberg MLA150 direct write laser scanning tool has been installed in the Nanofab and is currently being commissioned. The tool produces features smaller than the current optical exposure tools without the added cost of photomasks.


The Heidelberg direct write lithography system allows great flexibility to pattern a wide range of substrate materials.

A TEM-Talos F200i TEM has been acquired for the NAU Flagstaff campus. It is a work-horse tool designed for a wide range of materials and applications. It will be managed by NCI-SW co-PI Dr. Miguel Yacaman and ¡MIRA! lab director, Dr. Gregory Uyeda. Dr. Uyeda officially joined the NCI-SW team in Year 7. He is an expert in multiple characterization techniques and capabilities that are part of NCI-SW NAU, including scanning probe and optical microscopy Dr. Uyeda will be the day-to-day operator of the newly acquired TEM.

With support from the state legislature the Arizona New Economy Initiative has allowed us to acquire additional tools that will be commissioned in the Advanced Electronics and Photonics core facility during Year 8. These investments in NCI-SW core facilities and our efforts to grow the semiconductor industrial base has attracted the attention of the Arizona congressional delegations with recent visits from Senators Mark Kelly and Kyrsten Sinema. Both senators were strong proponents of the CHIPS for America act that has led to new fab facilities being built in the metropolitan Phoenix area by Intel and TSMC.

Senator Sinema during a recent tour of the Advanced Electronics and Photonics core facility on the ASU science park.

<u>User Base</u>

The NCI-SW provides intellectual strengths and infrastructure in renewable energy, nanomaterials, health sciences, environmental nanoscience, and the societal aspects of nanotechnology. For the five-year renewal we proposed to establish a southwest regional association of university nanotechnology lab managers. While the activity was placed on hold due to the pandemic in Year 6 we have now implemented the program as the Southwest Nano-Lab Alliance (SW-NLA) and the first annual meeting was held at ASU on April 14-15, 2022. The goal of the SW-NLA is to bring together facility managers from ASU and the Universities of Arizona, New Mexico, and Utah to discuss best practice for managing cleanrooms and associated multi-user facilities, on-going challenges, and future opportunities. Outcomes from the meeting included: i) sharing of standard operating procedures; ii) establishing user access to the University of Arizona electron beam lithography tool as a backup tool for other sites; and iii) tentative agreement to charge internal rates among SW-NLA users.

In Year 7 we continued our seed funding program to recruit new users for the NanoFab and EMC core facilities. First time cademic 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. During Year 7 we are supporting Preyom Dey, a Ph.D. candidate at the University of New Mexico, working in Dr. Steven Brueck's research group. Preyom is working with our electron beam lithography engineer to pattern nanoscale calibration standards that will be used in the calibration of their technique for enhanced resolution optical microscopy.

Research Highlights and Impact

The research focus of the NCI-SW is to provide general R&D micro- and nano-fabrication support across a broad range of disciplines including the life and health sciences; environmental nanotechnology; geological nanoscience; and renewable energy. The NCI-SW also established a user facility for the Societal and Ethical Implications (SEI) of nanotechnology that develops tools for the broader social science community to explore the social aspects and implications of nanotechnology. The addition of the ¡MIRA! Center at Northern Arizona University in Year 6 provided new expertise and infrastructure related to materials science and quantum information. In 2021 our external users published 25 papers in top-tier journals including Nature Communications, Nano Letters, Journal of Applied Physics, and the Journal of the American Chemical Society, a significant increase from the 18 in 2020.

The NCI-SW impacts regional economic development by supporting the R&D needs of the small business community and by workforce development. In Year 7 our workforce development program was recognized by grants from Intel and the NSF. The Intel award is from their Mindshare program on the topic "Broadening Participation in Science and Engineering Higher Education". It has the goal of increasing the STEM pipeline for minority students wanting to pursue careers in semiconductor manufacturing. The program will last 20 months and support semester long internships for students to work in our core facilities under the mentorship of ASU engineering staff.

The NSF award is part of a national program led by Penn State University. The project will provide educational opportunities for military personnel, veterans, and their family members to gain the knowledge, skills and abilities needed to enter the nanomanufacturing workforce. In particular, the NCI-SW will continue our long-running partnership with Rio Salado College to recruit veterans and active service members though the Dept. of Defense Skillbridge program. Participants will enroll in a 12-week semiconductor manufacturing certificate program with hands-on training in our Nanofab and Advanced Electronics and Photonics core facilities. The program offers stackable certificates approved by the American Society for Testing and Materials (ASTM). The award is from the NSF Division of Undergraduate Education and will last for four years.

Designed specifically for active U.S. military personnel, veterans, and their immediate family, the Microelectronics and Nanomanufacturing Certificate Program (MNCP) helps meet the needs of a growing microelectronics and semiconductor workforce. This free program combines live-streamed lectures with intensive, hands-on-site training in a cleanroom environment—as found in a semiconductor fabrication facility.

Education and Outreach Activities

Following the retirement of Ray Tsui, we are fortunate to have recruited Jessica Hauer as the new NCI-SW E&O coordinator. Jessica has extensive experience as a grade school teacher, as an administrator in a large Phoenix public school system, and she is familiar with the NNCI having spent one summer in our RET program. As a result, she has got off to a running start organizing multiple hands-on outreach events using our Zoom connected scanning electron microscope. She works closely with Anna Tanguma-Gallegos of the Center for Broadening Participation in STEM (CBP-STEM), another NCI-SW partner. Anna has developed relationships with the nanotech community and participated in train-the-trainer workshops so she can deliver NCI-SW outreach herself to teachers, faculty and students from 2-year HSIs and Tribal colleges starting in Fall 2022.

The major public outreach activities supported by the NCI-SW are the ASU "Open Door" and "Geeks Night Out" hosted by the City of Tempe. Both are signature events of the Arizona SciTech Festival, and are normally scheduled in February and March. In 2022 that timeframe unfortunately coincided with an infection surge of the Omicron variant of the coronavirus. ASU cancelled "Open Door" and we decided to forego participation in "Geeks Night Out" as a precautionary measure. However, the NCI-SW did participate in the 9th Flagstaff Community STEM Celebration held as an in-person event at the Fort Tuthill Fairgrounds four miles south of the NAU campus. The event took place from 1-4 pm on April 30 and the NCI-SW activities included optical and scanning microscopy hands-on demonstrations.

Volunteers from the NCI-SW ¡MIRA! Center presenting at the 2022 Flagstaff Community STEM Celebrations.

The NCI-SW hosted 5 REU students for the summer of 2022. As before, this was a diverse cohort selected from 2- and 4-year schools and under-represented groups. The REU students conducted their research work at NAU since dorm housing is more available there. We were also able to resume the RET program at the ASU campus with one instructor from a local school (Gateway Community College). Our former REU student Jeremy Barrios presented his research from summer 2021 at the national Annual Biomedical Research Conference for Minoritized Scientists (ABRCMS) conference, Nov. 10-13, 2021 and received a best poster award.

In the collaboration with Rio Salado College (part of the Maricopa County Community College District), the NCI-SW hosts advanced laboratory curriculum at ASU for students enrolled in RSC's two-year, 62-credit AAS degree in Nanotechnology which contains an 18-credit Certificate of Completion. Sixteen in-person labs were conducted for RSC students in Year 7. This is a significant increase from the six labs conducted in all of Year 6 and suggests a good recovery from challenges imposed by the pandemic is starting to take place.

Societal and Ethical Implications Activities

During Year 7, Dr. Jameson Wetmore and Dr. Ira Bennett led the NCI-SW SEI User facility. The unit works one-on-one with visiting scholars and facilitates workshops, resources, course development, events, and in-depth training focusing on the social dimensions of nanotechnology and emerging technologies. The flagship activity of this SEI user facility is Science Outside the Lab (SOtL). This year's SOtL program ran May 16-27, and incorporated previous speakers from the National Science Foundation (NSF), Sloan Foundation, National Aeronautics and Space Agency (NASA), Environmental Protection Agency (EPA), and National Institutes of Health (NIH), among other policy agencies intersecting policy with science and engineering. We had 21 participants from eight different NNCI universities.

With the 2021 SOtL participants, we launched an ambassador program to support and extend the SOtL experience's learning into local communities. Through October 2021, our 21 participants engaged with their communities. They ran seminars, mentoring sessions, K-12 outreach, and even policy workshops to share the insights and skills they gained through their participation in SOtL. Many of these projects were done in conjunction with the NNCI education coordinators at the various sites. The SOtL Ambassadors program continued in Year 7 with proposals for seminars, online forums, and a website where women in STEM can share their struggles and institutional barriers to success.

During the fall 2021 semester, Martín Pérez Comisso, PhD candidate and SEI research assistant at ASU led a course entitled "Research Challenge: Latin America," which brought together students from ASU, the University of Guadalajara, Mexico, the University of Concepción, Chile, and the University de la Plata, Argentina to produce knowledge mobilization strategies for issues about emerging technologies.

Finally, we have worked to share SEI ideas beyond NNCI and ASU as well. For instance, Dr. Wetmore gave a talk to the NCI-SW REU/RET Webinar to introduce those participants to both science policy and science and values. And Dr. Wetmore was able to engage directly with policymakers from around the world through an address he gave to the 13th Meeting of OECD Working Party on Bio-, Nano- & Converging Technologies. He offered suggestions for how to build SEI into national policies on converging technologies. And finally, Mr. Perez Comisso was invited to participate as a reviewer for a capstone project at NYU about Nanotechnology and Society in late April 2022.

Computation Activities

Dr. Dragica Vasileska, Professor of ECEE at ASU, is coordinating the computational activity for the NCI-SW, including educational activities that involve the nanoHUB. Dr. Vasileska has been a long-time contributor and user of the NCN's nanoHUB (3rd largest contributor out of 2570 contributors), although she is not funded by a nanoHUB contract.

Outside of ASU, Prof. Vasileska is collaborating with: Dr. Michael Povolotskyi (employed at NRL) on energy relaxation processes in GaAs due to femtosecond laser excitations; Prof. Edmundo Gutierez (INAOE, Puebla, Mexico) on low-temperature self-heating effects in 45 nm technology node FD SOI devices from Global Foundries; Assoc. Prof. Amir Goldan Hossain from Stony Brook on modeling of Se photodetectors for medical imaging applications; Prof. Gilson Wirth from UFRGS in Porto Alegre, Brazil on the topics of fluctuations in the on-current in both n- and p-channel devices; and with Prof. Katerina Raleva (University Sts Cyril and Methodius, Skopje, Republic of North Macedonia) on the topic of self-heating effects in nano FinFETs.

Innovation and Entrepreneurship Activities

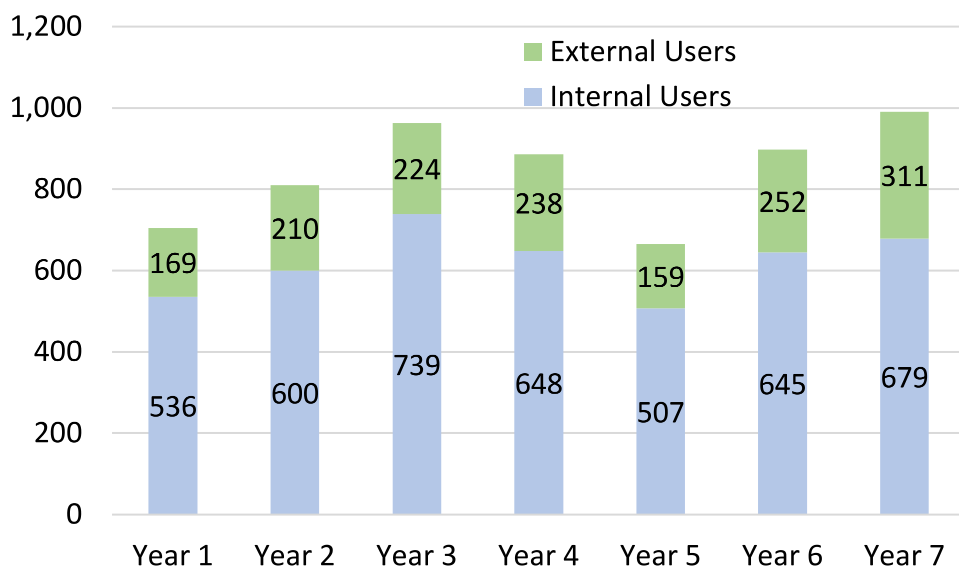
The NCI-SW supports small business users including SBIR and government funded 'spin-out' companies, most notably iNanoBio and Advent Diamond. Both companies benefit from user access to NCI-SW core facilities at the non-profit rate that is considerably lower than the standard industrial rate.

INanoBio is a startup based out of Scottsdale, AZ and Menlo Park, CA. The company's mission is to develop high-accuracy early-stage disease diagnostics using transformative nano-biotechnology platforms and machine learning. In 2019 they received $5.4 Million over four years as part of the Defense Advanced Research Projects Agency (DARPA) contract to a consortium led by the Icahn School of Medicine at Mount Sinai New York. They are also implementing a longitudinal, non-randomized study to evaluate the utility of their protein arrays in detecting unique antibodies in COVID-19 patients.

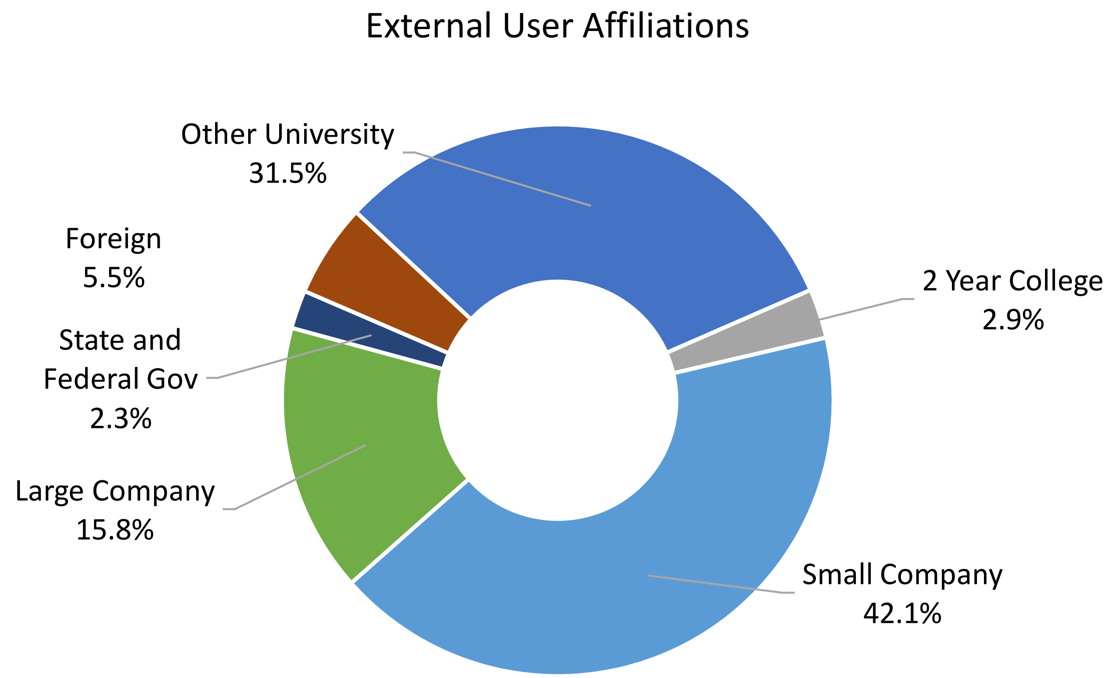
Advent Diamond has received more than $4M to develop diamond-based radiation detectors and high-power RF components, including a $750k NSF SBIR Phase II award. Dr Manpuneet Benipal, the CEO and Founder of Advent Diamond is a member of the NCI-SW External advisory Board.

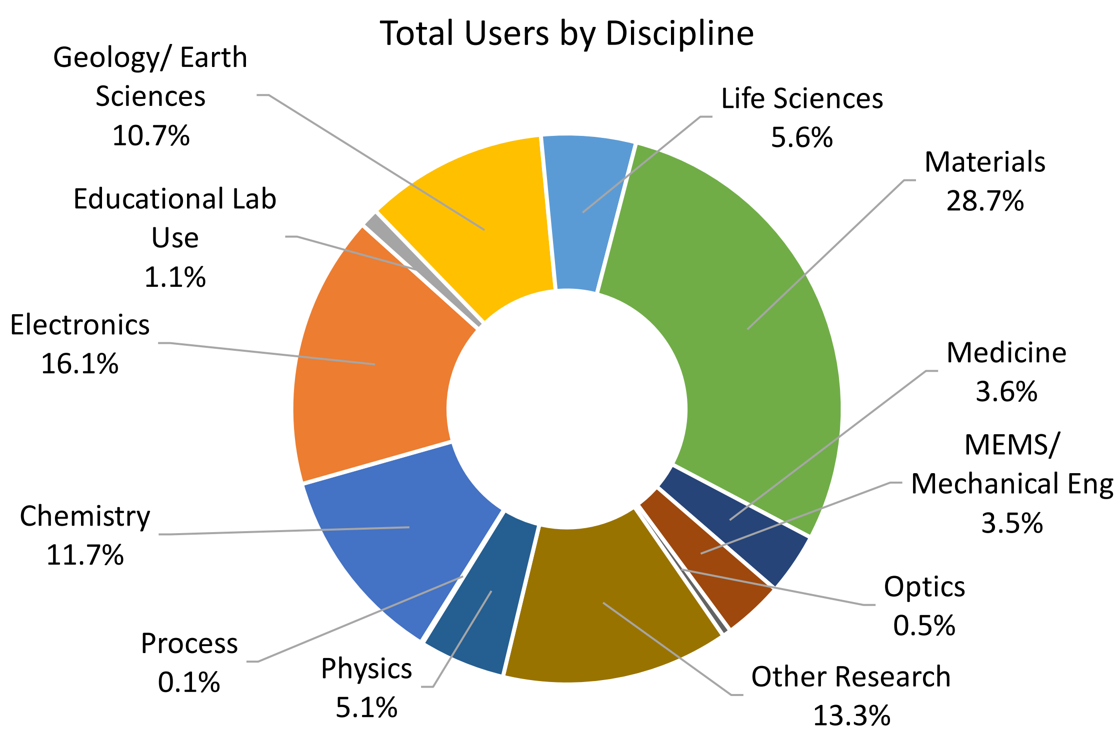
NCI-SW Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	705	810	963	886	666	897	990
Internal Cumulative Users	536	600	739	648	507	645	679
External Cumulative Users	169 (24%)	210 (26%)	224 (23%)	238 (27%)	159 (24%)	252 (28%)	311 (31%)
Total Hours	43,098	49,370	46,647	50,630	30,206	51,029	71,372
Internal Hours	32,883	38,270	37,954	37,996	23,997	43,124	60,568
External Hours	10,215 (24%)	11,100 (22%)	8,693 (19%)	12,834 (25%)	6,209 (21%)	7,904 (15%)	10,804 (15%)
Average Monthly Users	271	313	284	312	272	311	328
Average External Monthly Users	43 (16%)	49 (16%)	47 (17%)	56 (18%)	45 (17%)	68 (22%)	86 (26%)
New Users Trained	275	333	675	700	375	692	628
New External Users Trained	47 (17%)	53 (16%)	102 (15%)	143 (20%)	35 (9%)	187 (27%)	180 (29%)
Hours/User (Internal)	61	64	51	58	47	67	89
Hours/User (External)	60	53	39	54	39	31	35



NCI-SW Year 7 User Distribution





12.8. 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 US Midwest. General *goals* of NNF are to: (a) assist NNCI in strengthening the quality and quantity of research and applications of nanoscience, nanotechnology and materials in the United States, (b) engage new university and industry users in our region in fabrication and characterization of nanoscale materials and structures, (c) provide critical assistance to companies and start-ups in order to benefit commercialization of nanotechnology, and (d) stimulate more students, including under-represented groups, to enter engineering and science careers. NNF's strong education-outreach (E/O) programs helped attract students to engineering and science careers. We target underrepresented groups and create greater awareness about the importance of nanoscience and nanotechnology in modern society. Our established E/O activities make the fascinating phenomena of the quantum world accessible.

Facility, Tools, and Staff Updates

The enhancement of NNF facilities has proceeded through funds received from the University of Nebraska, U.S. Army Research Office, NSF:NNCI and NSF MRI. The Physical Properties Facility is preparing to receive an advanced Dynacool PPMS system. NNF recently received funding to add nitrogen vacancy (NV) microscopy option for NNF's Attocube SPM system through NSF MRI proposal. The Hysitron TI 950 triboindenter system also undergone upgradation with a new software and computer. An AR200 Laser measurement sensor from Acuity, with computer and software for TEM sample thickness measurements, was purchased by the ENIF Facility. Staff members supported wholly or in part by NNCI:NNF include: NNF Coordinator and User Contact: Dr. Jacob John; NNF Staff Scientists: Dr. Andrei Sokolov, Dr. Wen Qian; NNF Education-Outreach Coordinators: Steven Wignall and Dr. Hanh Phan.

User-Base

The NNF organized in-person events this year aimed at expanding external usage. Several of the NNF external user outreach programs were impacted by the pandemic earlier. The NNF Facility Coordinator/User contact was not able to personally visit universities, colleges, and industries in the region and neighboring states to recruit new users. We were able to communicate with several industries during the last six months. A few industries visited NNF facilities for tours and disussions during the last six months. Some of them are currently using our facilities.

Minicourse: Free Equipment Training for External Students and Industry Engineers: Our annual 3-day Minicourse for external users was held in October 18-20, 2021. The NNF provided free hands-on operational training on instruments of their choice for almost 30 external participants during the 3-day Minicourse. Each participant received training on 2 or 3 instruments of their choice during the Minicourse. The Minicourse attendees were graduate students and industry engineers from neighboring states such as South Dakota, Wyoming, and Kansas.

NNF Seed Grant/Free Usage Program for External Universities/Companies During Campus Visits: The NNF Facilities Seed Grant program aims to provide resources to Industries, start-up companies, and students from 4- and 2-year colleges 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. The NNF coordinator will start to visit Industries, Universities and Colleges in neighboring states when the Covid-19 related restrictions are relaxed or fully removed.

Research Highlights and Impacts

Research Focus Areas in NNF: The NSF recently awarded $20M funding for the EPSCoR proposal on "Emergent quantum materials and quantum technologies" lead by the NNF Director Prof. Christian Binek. The interdisciplinary research by a team of 20 PIs and 4 universities in the state of Nebraska will add to the pool of NNF users and transform NE into an internationally recognized hub in the field of quantum materials. The NNF facilities will play a critical role in facilitating, supporting and enabling advanced quantum materials and technology research of the new EPSCoR EQUATE Center. EQUATE includes 20 faculty members from the University of Nebraska-Lincoln, the University of Nebraska at Kearney, and Creighton University. It also will leverage existing partnership with Little Priest Tribal College and Nebraska Indian Community College. The UNL hired four faculty in QMT in the Departments of Physics, Chemistry, Electrical and Computer Engineering, and Mechanical and Materials Engineering. These new faculty, along with several present faculty, will form a strong research group in the NSF Big Idea: Quantum Leap. Because of UNL's commitment to a quantum materials cluster hire, expertise in this forward-looking field is on an upward trajectory in NE. UNL's Chancellor selected in 2021 Quantum Science and Engineering as one of seven grand challenge themes which see significant $40M funding over the next five years. In this context, Director Binek submitted a $5M grand challenge proposal which, if funded, will continue to strengthen NNF's transitioning to quantum materials science.

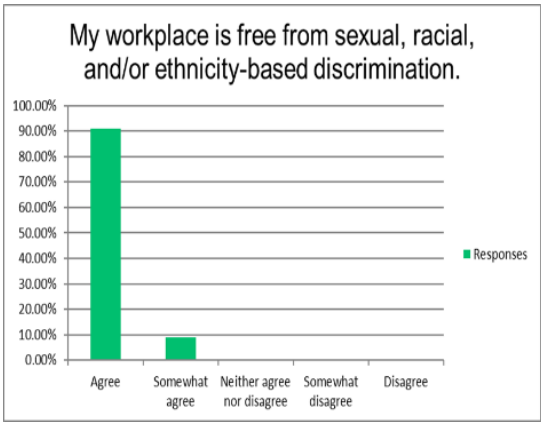
Projects of External Users:

Monolith Materials, NE: Monolith, a California-based company, has invented and developed carbon nanoparticle production by burning natural gas. A new plant, under construction in Nebraska, will replace a coal-fired power plant with a hydrogen-burning one and employ 300 people when fully developed. The company is using NNF for characterizing the NPs using high-resolution S/TEM. Recently, Monolith received approval for a $1.04 billion loan from the DoE to expand their Clean Hydrogen and carbon black production facilities in Hallam. Completion of the facility expansions will allow Monolith to operate on a global scale. Since obtaining the DoE loan, the R&D team of Monolith has been expanding their usage of NNF facilities.

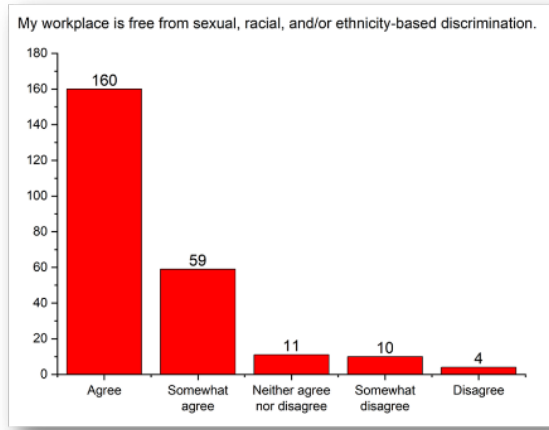
Electronic Fluorocarbons, PA: Electronic Fluorocarbons company is working with NNF to find low global warming potential alternatives to incumbent HFCs such as CHF_3 and CH_2F_2 used in semiconductor materials etching applications. The company uses the facilities and expertise at the NNF for achieving this goal.

Economic Impacts: The NNF critically supports all research in materials and nanoscience at the Univ. of Nebraska. 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 30 regional institutions in 5 states in the Midwest region during the 6th 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.

Diversity Survey: Although there is always room and need to further improve, the diversity survey conducted by the NNCI network reveals that NNF realized an outstanding diversity climate compared to its NNCI peer sites.



NNF Survey Results

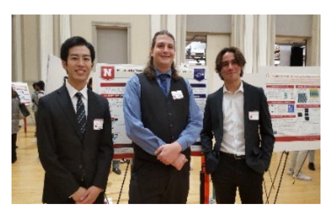


NNCI Network Survey

<u>Education and Outreach Activities</u>

The main goals of NNF's education and outreach programs and communications are to increase awareness of nanoscience to students, teachers, businesses and the general public and to increase the number of students entering nanoscience fields, especially among underrepresented groups. With COVID-19 subsiding to some extent this past year, most EO programs were returned to their format, and some new activities were created.

NNF-Sponsored Events: National Nanotechnology Day Celebrations in October included a couple of different events: 1) NNF submitted images by graduate and postdoc students to the national NNCI 2021 **Plenty of Beauty at the Bottom** image contest. One NNF entry received the Top Prize in "Most Stunning". 2) NNF recognized Nano Days in Nebraska by providing a booth at both the State Teachers of Science Conference (NATS) and at our annual Astronomy Day at UNL. This was our recognition of the nationwide festival about nanoscale science and engineering sponsored by the National Science Foundation. Teachers from around the state at all levels were exposed to this event and Nanotechnology. Total attendance at the events were approximately 300. Hosting in-person **Junior/Senior High Tours** was challenging due to Covid-19 university guidelines, but we were able to conduct several of these tours and continued to use virtual tours in some instances for junior and senior high students, parents, and teachers interested in learning more about what UNL has to offer in nanoscience research. We resumed in person tours with the Girls Inc from Omaha, with a group of 25 students. Estimated number of participants in tours this year both virtual and in person were 250-300.



Nano and Discover Engineering Days: NNF partnered with the UNL College of Engineering to introduce hundreds of rural and urban middle-school students and their teachers to the various fields in engineering and nanoscience at the University of Nebraska–Lincoln throughout the year. Events were filled with hands-on activities that applied math, science and creative thinking skills. October 2021 through September of 2022, 750 junior high students from 21 schools throughout Nebraska received nano lessons using hands-on materials provided for the lesson. **Nebraska Robotic Expo:** In conjunction with the Prairie Stem organization, and the Engineering Dept.at the University of Nebraska Omaha we did an online presentation on "Robotics in Nanotechnology. This enveloped 25 minutes of Lecture/Powerpoint with questions at the end. This was later uploaded on Youtube for permanent access for students and teachers. **Family Science Night:** A new addition this year was a collaboration with the Southeast Community College system for a Family Science Night. We set up a table with Demonstration and activities for children and their family to experience the wonders of Nano and Quantum Physics. We have already repeated this event at the Beatrice campus and will be part of the Spring calendar for Lincoln again.

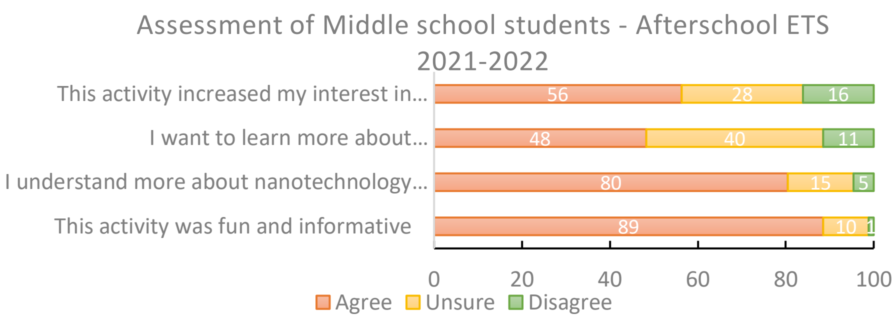
Workforce Development: Nanotech Lab Course for Student Users This one-credit-hour per semester course provided graduate students with an introductory, but yet comprehensive, view into the large variety of the instruments available at the NNF. The purpose of this course was to help student's master experimental skills in their own research area and to broaden their horizon in experimental nanotechnology methods, complementary to that area.

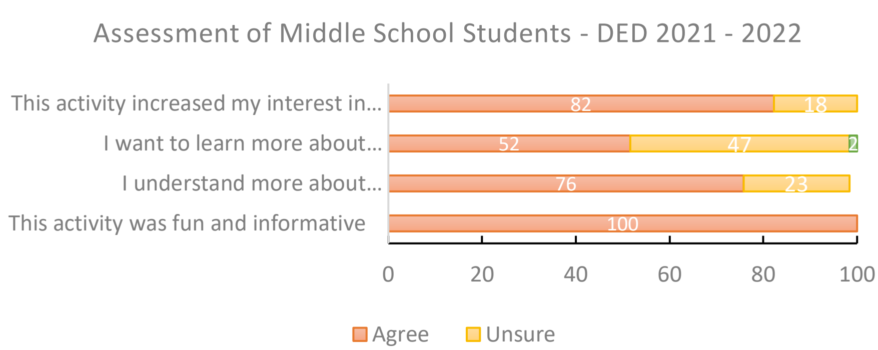
Research Experience for Undergraduates (REU): Two undergraduate students have been selected regionally to work in research labs 8-10 weeks as part of NNF's REU program during the 2021 summer. We were also honored this summer to represent the NNCI as one of the Host schools for the Japanese exchange program. Hibiki Mitsobushi selected the lab of Yongfeng Lu to study the "Pyrolysis of two-photon polymerized foam structures". NNF has committed to host the NNCI REU Convocation in August 2024. **High School Intern Program:** NNF hosted in person 17 high school interns June-August this year 2022. Faculty from Chemistry, Physics, and Engineering provided the high school students the opportunity to work in research labs for 8-10 weeks with the help of a graduate student mentor to guide and train them in research techniques. Following their summer internship, students did 2 virtual poster presentations of their research work. **Rural Workforce Development:** In an effort to support the development of our workforce, we provided undergraduate student cohorts from Central Community College (CCC), Columbus, NE, first-hand opportunities to use our NNF Facilities, which included Electron Nanoscopy Instrumentation, Nanofabrication, Surface & Materials Characterization, X-Ray Characterization, and Nano Materials and Thin Films. Students have regularly performed research in NNF labs along with CCC faculty on a regular basis. **NNCI Site Collaboration**: Two community college undergraduates using our facilities weekly were chosen for the 2021 Nanotechnology Entrepreneurship Challenge Program (NanoEarth) as part of a new collaborative entrepreneurship addition to NNCI REU's. This great connection between NNF's community college partner and another NNCI site will help the student bring her research to market. One of the students won the award for best Entrepreneurial Project in this Challenge. **Teacher Conferences/Workshops:** With things opening up more we were able this year to attend 2 in person Conferences/Workshops including the Nebraska Association of Teachers of Science (NATS) Oct 8th, and the state AAPT meeting and Astronomy Day (Oct 16th). We had a booth at both activities, and a Nano/Quantum activity was presented during the Astronomy Workshop for the attendees. Attendance was ~250 - 300 for both. **Research Experience for Teachers**: Five teachers were selected to participate in NNF's in-person 2021 Summer RET Program scheduled from June 14 - July 23. Teachers worked in nanoscale science and engineering labs to gain hands-on experiences in the techniques and tools used within NNF facilities, with follow-up support during the school semesters. Participants include three high school science teachers (grades 9-12) and two community college faculty within

commuting distance from NNF. **Nanoscience Summer Institute for Middle School Teachers in Partnership with Stanford:** Last summer nine teachers participated in the NanoSIMST four-day virtual workshop at the end of June. The goals of the workshop were to: 1) excite teachers about nanoscience, 2) equip middle school teachers with content knowledge and empower them with pedagogy to teach their students; and 3) effectively teach thousands of students about nanoscience. Teachers from across NE will learn about quantum, nanoscience and engineering through lectures, hands-on activities (materials sent in advance), facility video tours, and guest speakers. They will also develop their own lesson plans to bring back to their classrooms.

Diversity: K-12 Diversity Programs NNF's After-School programs for diverse elementary through high school populations expanded during this year. 1) NNF's partnership with Educational Talent Search (ETS) which serves eligible low-income, first-generation students in grades 6th through 12th grew to 6 middle schools bi-monthly, and 2 High schools once during the year. NNF created lessons, and gave presentations to 90-100 junior high/25 high school students bi-monthly (Oct.-May), for a total of almost 500 students. 2) Thirty diverse Upward Bound high school students were given three 2-hour nano workshops during the summer with career information and hands-on activities. 3) Twenty-five diverse Girls Inc. high school students were given a 2-hour nano workshop during the school year with tours of nano-related research in NNF Facilities, career information and hands-on activities. **Traveling Nanoscience Exhibit:** Our 400-sq.-ft. hands-on exhibit has been hosted by the W.H. Over Museum in Vermillion, South Dakota. Due to Covid-19 the Museum has been closed for an extended time, but reopened for the 2021 summer. The exhibit has been used for several Saturday Science seminars by local faculty from the college. The exhibit is currently at the Children's Museum of South Dakota. Our second Traveling Exhibit, the Sun, Earth, Universe Exhibit, was hosted by the Children's Museum of Kearney, Nebraska from October 2021 to December and is currently at Wayne State College in Nebraska, with SAC museum being it next location.

Assessment Activities: The NNF evaluated efforts to promote nanoscience among diverse, underrepresented groups, and urban and rural middle-school students by surveying participants at the completion of the After-School programs for Educational Talent Search (ETS) and Nano and Discover Engineering Days participants. ETS students responding said they understood more about nanotechnology after the activities (80%) and 56% of the ETS students had become more interested in studying science and engineering. Students in our fall 2021/spring 2022 Discover Engineering virtual





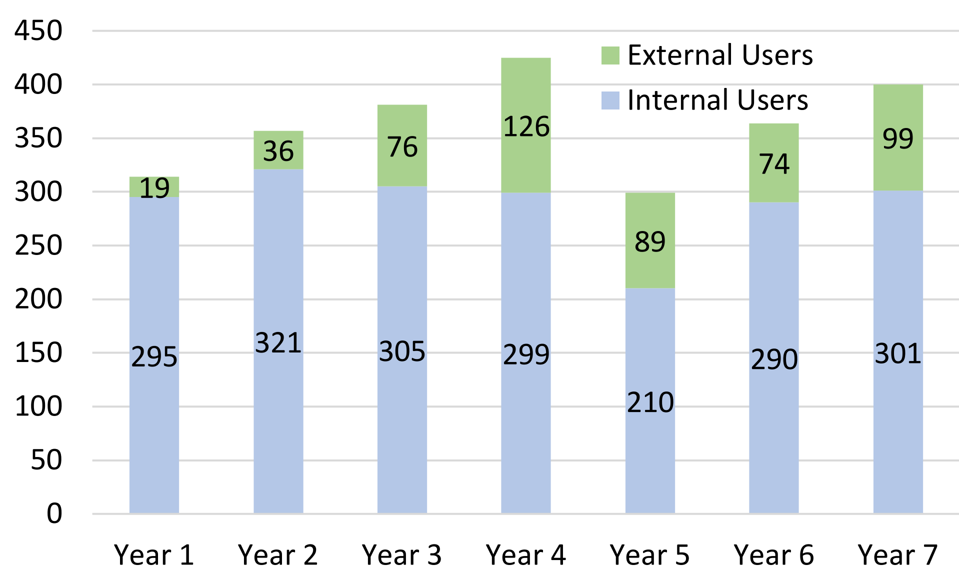
outreach events to 21 Nebraska schools were assessed and all of the 542 students agreed that the DED hands on activities were fun and informative. Among the respondents, 76% understood more about nanotechnology and 82% of them responded that the activities had increased their interest in studying science and engineering. This resulted in 52% of the students surely wanting to learn more about nanotechnology. NNF is a member of the NNCI Evaluation Working Group which continues to provide information and advice on how to 1) define and follow an evaluation plan, 2) include consideration for the population involved and measurement methodology, 3) assess and analyze data, and 4) apply the results to planned and future activities and share lessons learned with others. The NNF will continue to promote broadening participation in nanoscale science and engineering through a variety of REU and workforce development programs, strategic partnerships, and resources. Diversity and participation of underrepresented groups will be a priority with many new and innovative opportunities for future users to increase their understanding, knowledge, and actual experiences. Quality assessment practices will be an integral part of the learning processes and activities.

Innovation & Entrepreneurship Activities

Entrepreneurship success by NNF faculty user Prof. Ravi Saraf: Vajra Instruments, INC, a small startup and recipient of several federal government grants including SBIR, was founded by UNL faculty and NNF User Prof. Ravi Saraf. Vajra Instruments, Inc. is focused on an inexpensive screening tool for pancreatic cancer. Recent research indicates that less than hundred microRNA (miRNA) sequences specifically generated by tumors are sufficient for early detection of PaC and other cancers for effective intervention with excellent prognosis MiRNA can be extracted from urine and blood using standard kits. Vajra Instruments is a regular user of the NNF facilities. Access to the NNF Nanofabrication Cleanroom facility is critical for the success and operations of small startup company Vajra Instruments. The NNF Nanofabrication Cleanroom facility is providing Vajra Instruments high quality electrochemical microarray chips for screening pancreatic cancer. Chip fabrication is based on laser lithography using Heidelberg DWL66 direct laser writer and depositing Cr/Au metallic thin films using sputtering system. The firm is working to directly measure the tumor specific miRNA extracted from about ml of serum or plasma using a disruptive technology called SEED. Measurement by SEED is virtually blind to non-specific binding with consistency. The binding time of targeted miRNA to the probe will reduce from hours for conventional microarray methods to below one hour.

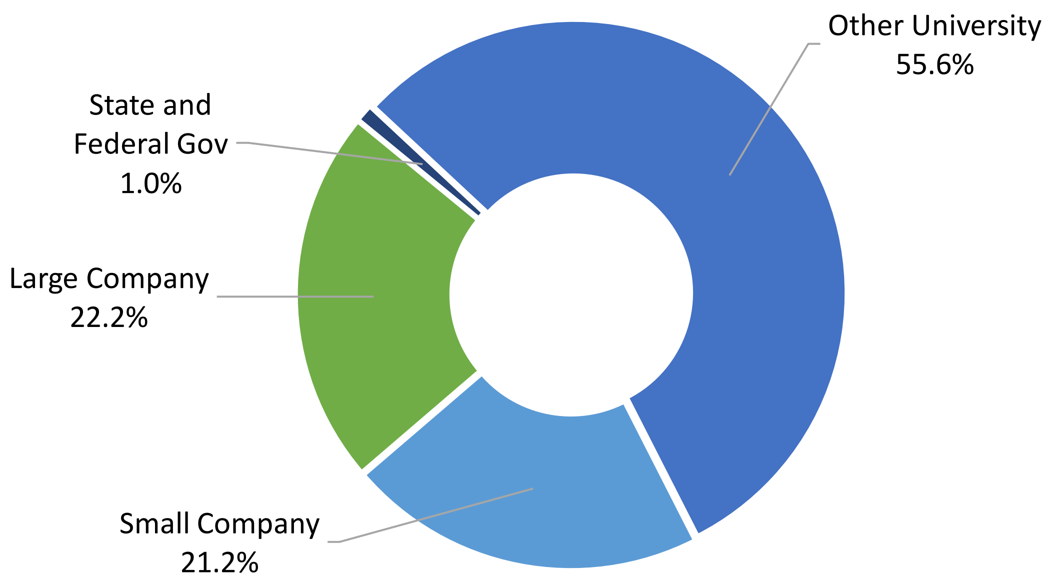
NNF Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	314	357	381	425	299	364	400
Internal Cumulative Users	295	321	305	299	210	290	301
External Cumulative Users	19 (6%)	36 (10%)	76 (20%)	126 (30%)	89 (30%)	74 (20%)	99 (25%)
Total Hours	23,445	20,102	24,008	31,037	24,002	23,422	27,262
Internal Hours	23,123	19,278	22,260	27,468	20,809	20,382	23,388
External Hours	322 (1%)	824 (4%)	1,748 (7%)	3,569 (11%)	3,192 (13%)	3,040 (13%)	3,874 (14%)
Average Monthly Users	40	120	132	137	90	120	134
Average External Monthly Users	3 (8%)	7 (6%)	19 (15%)	18 (13%)	14 (15%)	15 (12%)	17 (13%)
New Users Trained	47	54	124	98	150	215	278
New External Users Trained	0 (0%)	1 (2%)	6 (5%)	7 (7%)	5 (3%)	16 (7%)	26 (9%)
Hours/User (Internal)	78	60	73	92	99	70	78
Hours/User (External)	17	23	23	28	36	41	39

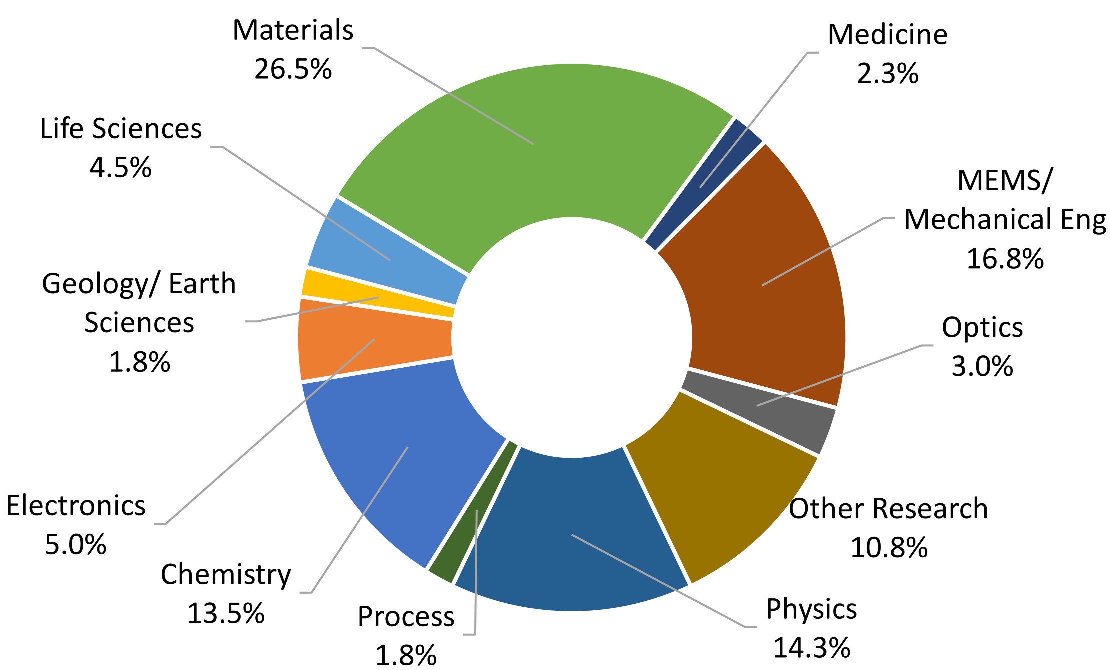


NNF Year 7 User Distribution

External User Affiliations



Total Users by Discipline



12.9. NNCI Site @ Stanford (nano@stanford)

nano@stanford

The NNCI site at Stanford University (nano@stanford) 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. The site also aims to develop and propagate a national model for educational practices that will help students and visitors become knowledgeable and proficient users of the facilities, as well as contribute to workforce development among underrepresented communities through our community college internship programs. Stanford's facilities offer a comprehensive suite of advanced nanofabrication and nanocharacterization tools, including resources not routinely available at shared nanofacilities, such as MOCVD, a JEOL electron beam lithography tool that can inscribe sub-10 nm features over 8-inch wafers, a Cameca NanoSIMS, and a scanning SQUID microscope. The facilities occupy ~30,000 sq. ft., including 16,000 sq. ft. of cleanroom space, 6,000 sq. ft. of which meet stringent specifications on the control of vibration, acoustics, light, cleanliness, and electromagnetic interference. Close to thirty expert staff members (including sixteen PhDs) maintain the instruments, teach users to operate them, and consult with users to optimize processes for their applications. nano@stanford includes the ***Stanford Nano Shared Facilities*** **(SNSF)**, the ***Stanford Nanofabrication Facility*** **(SNF)**, the ***Stanford Microchemical Analysis Facility*** **(MAF)** and the ***Stanford Isotope and Geochemical Measurement & Analysis Facility (SIGMA).***

Facility, Tools, and Staff Updates

During year 7 of the award, nano@stanford added several new capabilities:

(1) A second **ATC-1800-E AJA evaporator system** provides added capabilities and higher throughput for a popular, heavily used system. This system has six sources and accommodates up to three 4" wafers or a single 6" wafer.

(2) A **Red Devil graphite hot zone furnace** will be used for high temperature (up to 2000°C in argon atmospheres) annealing of wide band gap material devices.

(3) The **Jokoh NAGS20 Ultra-high pressure homogenizer** is a simple, desktop-sized system that enables "pulverization, emulsion, and dispersion" of solids and liquids.

(4) A **Seki Microwave Plasma CVD system** will allow researchers to deposit poly- and single crystal diamond films.

(5) The **Physical Electronics VersaProbe 4** adds new XPS capabilities, relative to the existing VersaProbe 3 XPS, including a 4-contact, heating/cooling stage for in-situ temperature and electrical cycling experiments, Reflection Electron Energy Loss Spectroscopy (REELS), and Ultraviolet Photoelectron Spectroscopy (UPS).

(6) A second **Durham Magneto Optics MLE microwriter** provides higher throughput for a heavily used system. The tool allows users to do "mask-less" lithography, its light source has a slightly shifted wavelength compared to the original tool, and it enables 15x faster write-speed for SU-8 resist.

(7) A **Filmetrics F40 reflectometer** measures the thickness and optical constants of transparent film with a spot size down to 1 micron.

(8) A new **TA Instruments thermal characterization equipment suite** which includes a Q5500 Thermogravimetric Analyzer (TGA) and Q2500 Differential Scanning Calorimeter (DSC) which are used to measure thermal properties.

In late May, the VP of the Dean of Research approved a $19M investment to renovate a campus building that previously housed an accelerator to allow for a significant expansion of SNSF. The project is in the early planning stages, but will add significant lab space, new characterization capabilities, and a dedicated educational space.

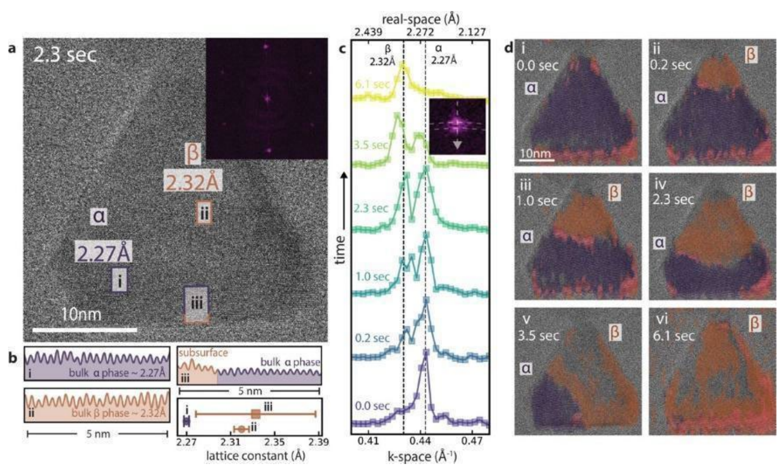
In year 7, there was some staffing turnover related to the pandemic and the high cost of living in the Bay Area. Our new staff members include Dr. Sara Ostrowski (Associate Director of nano@stanford), Lavendra Mandyam (Senior Process Etch Engineer at SNF), Alexander Denton (ALD Process Engineer at SNF), Andrew Barnum (TEM Scientist at SNSF), Dr. Christina Newcomb (SPM Manager at SNSF), Wendy Fang (Financial Analyst at SNSF), and Elise Estanislau (Administrative Assistant at SNSF).

<u>User Base</u>

In year 7, nano@stanford served a total of 1286 users including 830 internal users, 301 industrial users, 37 external academic users, and 117 state and federal government users**.** This is a 22% increase overall in the number of users compared to year 6, indicating continued recovery from the pandemic. The user revenue was $6.5M, with $3.5M from external users.

<u>Research Highlights and Impact</u>

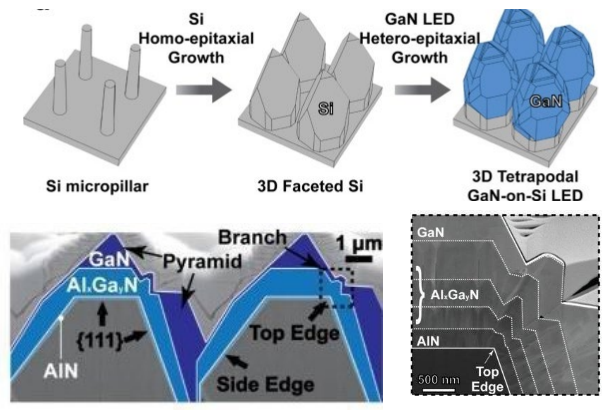
The following are three representative research highlights from an internal user, an external academic user, and an external industrial user. A comprehensive list of research publications is provided in our year 7 site Annual Report and additional research highlights are available in the supplemental file. During 2021, we captured 287 published journal articles from internal users, 41 articles from external users, 18 conference presentations, 2 patents granted, and 1 book chapter.



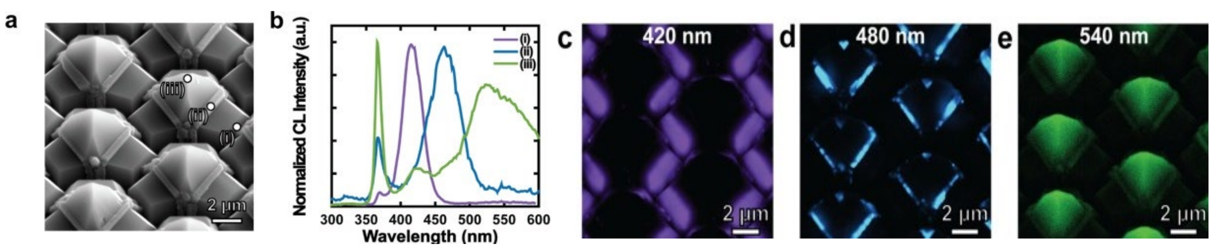
High-resolution TEM images of triangular nanoprisms revealed the presence of two phases, a and b, with different lattice spacings. Further FFT analysis was used to observe the hydrogenation-induced lattice expansion and phase progression.

Lattice-resolution, dynamic imaging of hydrogen absorption into AgPd nanoparticles: Alloying of palladium (Pd) can be used to alter a material's mechanical stability and catalytic activity, as well as absorption thermodynamics. Yet, atomistic mechanisms of hydrogen (e.g., dissociation and intercalation) only are understood via theoretical calculations since imaging dynamic metal–gas interactions at the atomic scale is challenging. **Prof. Jennifer Dionne's research group** utilized high-resolution Transmission Electron Microscopy (TEM) and Fast Fourier Transform (FFT) analysis of triangular nanoprisms to observe the hydrogenation-induced lattice expansion within AgPd (Figure above). This work supports the use of the strong reactivity and absorption affinity to H_2 of Pd and Pd alloys for hydrogen-based technologies (energy storage and production).

Enhanced GaN-on-Si LED performance using 3D structures: Compared with conventional GaN LED sapphire substrates, silicon substrates are lower cost, have higher thermal conductivity, and enable highly directional light emission. However, large lattice and thermal mismatches between GaN and silicon lead to defects that lower GaN device performance. One approach to resolve strain issues is to manage the properties of the deposited films, using buffer interlayers with gradually changing compositions. Another approach is to structure the silicon surface to grow isolated, disperse, defect-free GaN islands. In this paper, **Prof. Dong Rip Kim from Hanyang University in Korea** combined these approaches by etching arrays of vertical pillars into silicon and seeding the arrays with tetrapodal GaN crystals (Figures right and below). In contrast to previous approaches using structured silicon substrates, this approach resulted in a space-filling, continuous LED array and addressed strain-induced threading dislocations that limit emission in conventional LEDs. The Kim lab demonstrated up to 300% higher light emission efficiencies compared to planar deposition on sapphire substrates, and tunable emission in the violet-to-green spectrum. Furthermore, the multicolor emission could be tuned by varying the silicon pillar formation and film composition. This work used the MOCVD GaN deposition system at nano@stanford.



(a) Schematic showing the fabrication of 3D tetrapodal GaN-on-Si LEDs over 3D faceted Si (b) Cross-section SEM (left) and TEM (right) showing facet evolution of tetrapodal GaN-on-Si LEDs. https://doi.org/10.1016/j.apsusc.2021.150584.



(a) SEM of multi-color emission LEDs. White dots indicate cathodoluminescence (CL) excitation points. (b) CL spectra corresponding to points in SEM. (c-e) Monochromatic CL images by wavelength. https://doi.org/10.1016/j.apsusc.2021.150584.

Start-up Company Success Story: Shortly after launching their company in 2017, Raxium contacted nano@stanford to jump-start its process development while building its own fabrication facility. Operating in stealth mode, Raxium only recently revealed its product, said to be the most vibrant and smallest micro-LED commercially produced (Figure at right). Raxium's activity in our facilities peaked in 2019, with its team of 22 process engineers and technicians all trained and using the facilities. Raxium's choices in building their own fab were strongly informed by their experience with the nano@stanford processes and equipment, including their purchase of an ASML stepper. As their

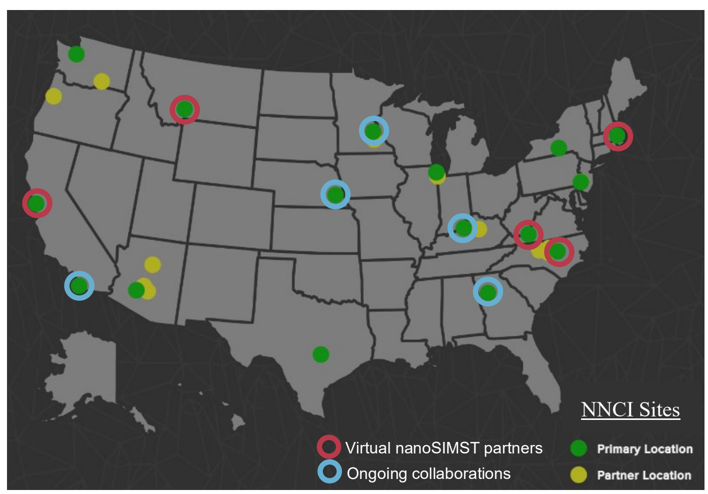
Relative sizes of the industry standard LED and Raxium's microLED. https://raxium.com own facility came online, Raxium's use of nano@stanford declined but the company does still occasionally use our facilities. In May 2022**, Raxium was acquired by Google for a reported ~$1B.**

Education and Outreach Activities

The NNCI site at Stanford has continued to develop and implement education and outreach initiatives that strive to promote STEM awareness and excitement among youth, community college students, K-12 educators, and the public. Highlights from our education and outreach efforts include edX on-line technical training modules that are publicly available and have a certificate option, a community college internship program, a professional development workshop for teachers called Nanoscience Summer Institute for Middle School Teachers (NanoSIMST), and DEI-focused outreach activities.

In year 7, we nearly doubled our **community college internship program** to hire a total of nine interns from West Valley College, Mission College, Foothill College, Chabot College, and DeAnza College. Six of the interns are women of color and eight are from underrepresented groups. Our interns learn various nanofabrication and characterization skills (e.g., deposition, etching lithography, SEM, and ICP-MS), support staff with process control and facility tours, and share their experiences with other K-16 students during outreach events and with the public through their Instagram account. As a testament to the positive impact of the program, all mentors and interns chose to extend their internship well beyond the 20-week minimum commitment. We have overlapped the new interns with our veterans to build a sense of community and to lower the initial time investment from staff.

The **NanoSIMST** workshop educates middle school science teachers about nanoscience and enables them with pedagogy for classroom implementation. To date, the program has generated 107 alumni teachers, impacting over 5272 students total, and over 1,767 students this past year. Teachers are incentivized to participate with education credits, a workshop stipend, classroom materials kits, and an additional classroom implementation stipend when they teach the materials and report the outcomes. This summer, we offered an in-person workshop for thirteen Bay Area teachers, offering additional travel stipends to reach more diverse communities. We also led a network wide initiative for a permanent virtual workshop, in collaboration with four other NNCI sites (e.g., MONT, CNS, RTNN, and NanoEarth). Twenty-one teachers from eleven states participated in the virtual workshop and 71% of those teachers were from Title 1 schools. External evaluation of the 2021 workshop found extremely positive feedback with 100% of respondents stating they would recommend the



Map of the network wide NanoSIMST expansion experience to a colleague. The evaluation also revealed a large increase in teacher confidence in understanding and teaching nanoscience, relative to before they attended the workshop.

Our **DEI-focused outreach activities** extend our reach to low-resource, underserved communities. For example, we have partnerships with the Science Learning Institute at Foothill College, which supports first generation and underrepresented students interested in STEM, and with Oakland Promise. We offer these partners facility visits and STEM-focused activities to K-12 and community college students. In year 7, we launched a mini grant opportunity for Stanford graduate students and postdocs to develop educational videos and K-12 classroom projects inspired by famous scientists from minority groups. We accepted four students for the Spring 2022 inaugural cohort, who will receive funding for a stipend ($700) and development costs (up to $300). The output will be hosted on our website and YouTube channel as a library of experiments with relevant research connections that will be publicly accessible.

Societal and Ethical Implications Activities

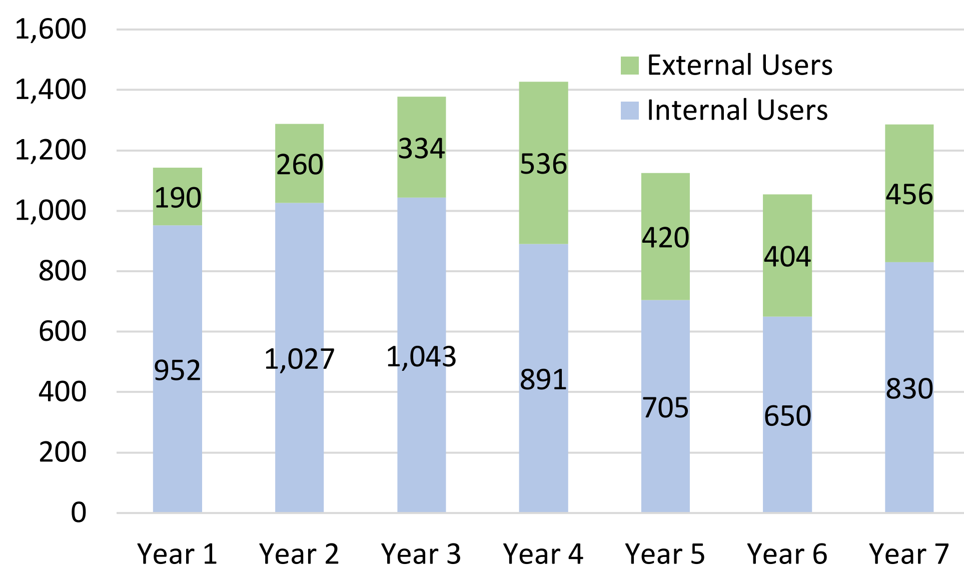
SEI activities have continued to progress in year 7, with nano@stanford actively engaging in the NNCI Science Outside of the Lab (SOtL) program that is organized by our sister site NCI-SW and ASU. Eight Stanford students have participated in the SOtL program (4 students in 2018, 2 in 2019, and 2 in 2021). These students are building on their SOtL experience by forming an SEI student working group to create an educational module that aims to familiarize our nano@stanford community with the broader concepts of ethics as applied to nanotechnology. The SEI module will integrate the educational platform, Pear Deck, to enable interactive content, facilitate transparency, and encourage ethics discussions. The module will also leverage UT Austin's nanotechnology ethics video as an additional resource for interested viewers. The content will be available on the nano@stanford website and will be recommended for new users. The SOtL ambassadors are also designing an infographic about misconduct reporting that will be displayed in our facilities.

Representative slide from the SEI educational module

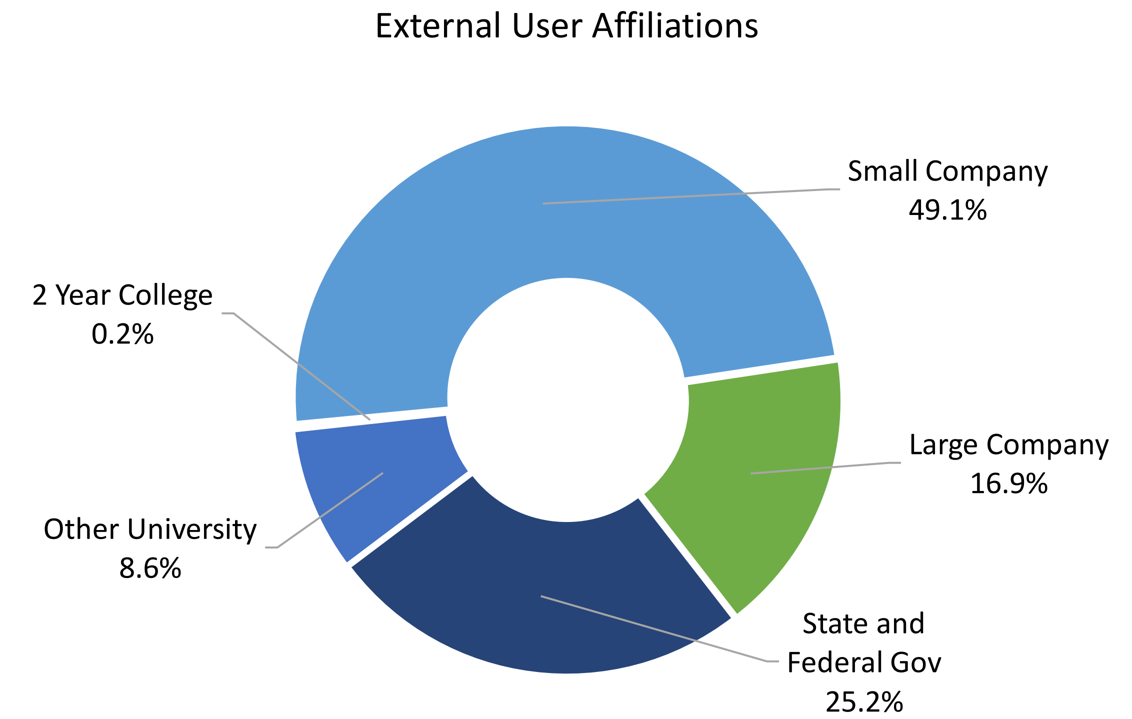
nano@stanford Site Statistics

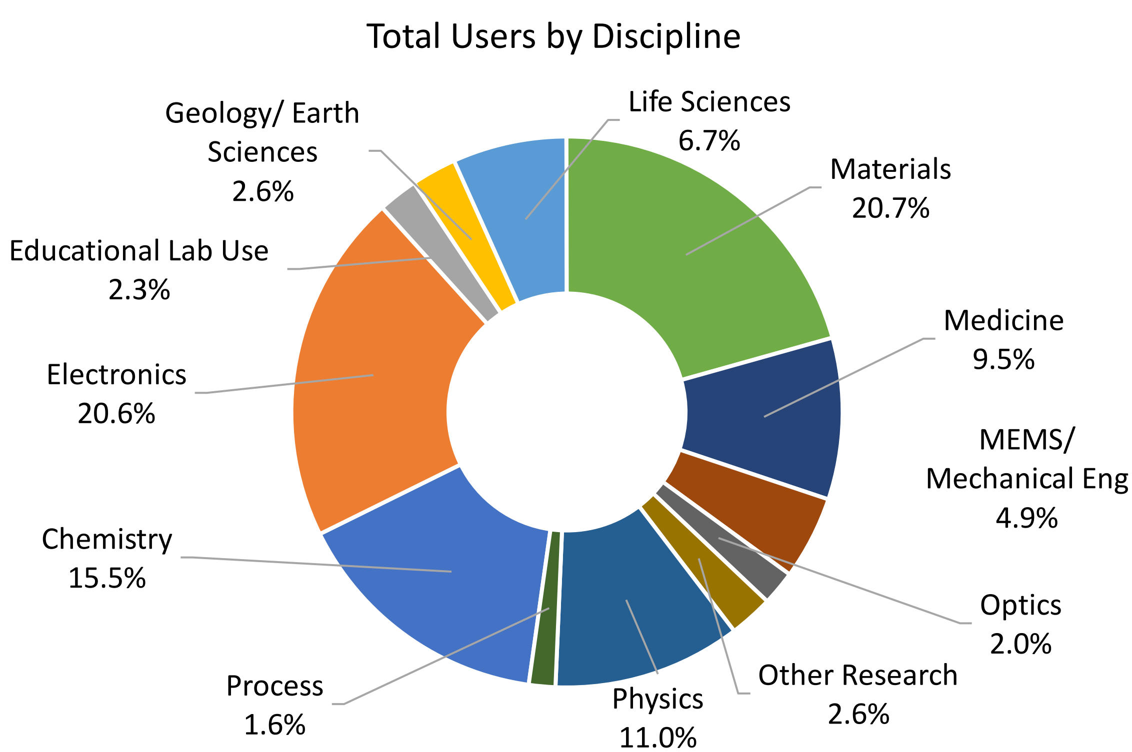
Yearly User Data Comparison	Year 1	Year 2	Year 3	Year 4*	Year 5	Year 6	Year 7
Total Cumulative Users	1,142	1,287	1,377	1,427	1,125	1,054	1,286
Internal Cumulative Users	952	1,027	1,043	891	705	650	830
External Cumulative Users	190 (17%)	260 (20%)	334 (24%)	536 (38%)	420 (37%)	404 (38%)	456 (35%)
Total Hours	113,089	113,193	135,054	119,877	78,663	104,536	108,702
Internal Hours	94,996	91,248	105,083	72,408	47,856	63,013	69,230
External Hours	18,093 (16%)	21,944 (19%)	29,971 (22%)	47,469 (40%)	30,807 (39%)	41,523 (40%)	39,472 (36%)
Average Monthly Users	520	572	601	615	405	470	548
Average External Monthly Users	74 (14%)	92 (16%)	115 (19%)	213 (35%)	136 (34%)	162 (34%)	176 (32%)
New Users Trained	550	579	584	596	359	491	581
New External Users Trained	97 (18%)	143 (25%)	194 (33%)	262 (44%)	159 (44%)	186 (38%)	197 (34%)
Hours/User (Internal)	100	89	101	81	68	97	83
Hours/User (External)	95	84	90	89	73	103	87

*Starting in Year 4 the Stanford site began to categorize users from the SLAC National Lab as federal government (external) users instead of internal users.



nano@stanford Year 7 User Distribution





12.10. 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. NNI leverages collaborations with academic, industry, and government partners, such as the Department of Energy's Pacific Northwest National Laboratory (PNNL), 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 interests and needs. The growing and distributed user base of NNI facilities includes academic and industrial users as well as nontraditional users in 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 research and innovation for nanotechnology and quantum information science and technology.

Facility, Tool, and Staff Updates

Infrastructure Investments

The Quantum Technologies Training and Testbed Lab (QT3) is a unique combined teaching and user facility, which provides state-of-the-art optical characterization tools for quantum technologies. The mission of the lab is to offer hands-on access to quantum technology hardware to accelerate both research and training in this growing field. The QT3 lab's 800 square-foot facility is located at the heart of campus in the Electrical Engineering Building. QT3 tools and laboratory set-ups can be utilized for teaching labs, capstone projects and research.

Major New Tools and Capabilities

- University of Washington:
- 300 nm high-resolution capability for Heidelberg DWL 66+ lithography tool
- KLA P17 stylus profilometer
- Woollam RC2 spectroscopic ellipsometer with xNIR capability, shipped in early 2023
- Nanotronics nSpec LS wafer defect analysis tool, shipped in December 2022

Oregon State University:

- Anton Paar SAXS
- Buchi spray drying system
- Cordouan Amerigo DLS and Zeta
- Mettler Toledo FTIR 701L
- Bruker NMR console and flow cell
- PHI 5000 VersaProbe II

Staff Updates

NNI has hired a number of staff members, including four new WNF process engineers hired from industry (Micron, Jireh, Texas Instruments, and ASML). MAF has seen one position turn over, and is currently filling a vacancy, and the director of ATAMI at OSU, Dr. Sam Angelos, retired and was replaced by Todd Miller.

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 and industry, with regional startups and small businesses representing the largest portion of external users.

The WNF saw steady increases in user activity. The facility has maintained staff rotations, while offering 24/7 operation apart from necessary shutdowns for facility needs. WNF monthly revenues have recovered to levels even higher than pre-COVID.

MAF staff have continued to put a major effort into creating training videos and developing remote methods to get people trained on MAF tools. A video version of the MAF lab tour for safety introduction is now included in the new user registration process through Coral. In addition, MAF staff are, as usual, available to acquire data for users. The MAF is now back up to full capacity after the partial shutdown during COVID and revenue levels are at pre-COVID levels. The MAF has been seeing an increase in interest from industrial users. Additionally, MAF staff are currently working on funding to update 'workhorse' tools such as the x-ray photoelectron spectrometer, as well as upgrading it with capabilities that will better serve MAF users.

NNI, supplemented by the Institute for Nano-engineered Systems, provides funding for seed grants with the goal to recruit new users with innovative applications of nanotechnology. Among a strong pool of 12 applicants, 4 seed grant winners were selected in spring 2021, including one external investigator from Western Washington University in Bellingham, WA.

During the past year, ATAMI, APSCL, and the Materials Synthesis and Characterization Facility (MASC) at OSU experienced growing user access and revenue. The three-month moving average of revenue increased by over 40% during the past year. We have added two new ATAMI tenants: Phosio (NSF SBIR Phase I recipient) and nexTC (DOE EERE SBIR Phase II recipient).

Research Highlights and Impact

Here we highlight *quantum information science and technology (QIST)* activities, which have continued to expand, driven by QuantumX, a UW campus-wide interdisciplinary initiative of faculty performing cutting-edge research in QIST, and the Northwest Quantum Nexus (NQN), a UW-led coalition of research institutes and industrial organizations in the Pacific Northwest and neighboring regions (including Microsoft and Pacific Northwest National Labs) with the goal of advancing QIST research and developing a QIST-trained workforce. QuantumX faculty such as Mo Li (NNI co-PI), Kai-Mei Fu (NNI senior personnel, QuantumX co-chair), and Arka Majumdar (QuantumX co-chair) now constitute the heaviest academic users in our site.

A cluster hire of new QIST faculty in the UW College of Engineering continued through 2022. After hiring ECE Assistant Professor Sara Mouradian, an MIT graduate and Berkeley postdoc focusing on trapped-ion quantum sensing, and ECE Assistant Professor Rahul Trivedi, a Stanford graduate and Max Planck-Harvard Research Center for Quantum Optics postdoc working on simulation and design of next-generation quantum devices, 3 new faculty have joined in 2022: Serena Eley, previously an Assistant Professor at the Colorado School of Mines, works on electronic and magnetic properties of quantum materials and devices; Juan Carlos Idrobo, previously at Oak Ridge National Laboratory, has unique expertise in TEM imaging, and Charles

Marcus, a member of the National Academy of Sciences, brings an extensive record investigating quantum coherent phenomena in mesoscopic electronics.

Co-PI David Ginger leads a new NSF Science and Technology Center for Integration of Modern Optoelectronic Materials on Demand (IMOD) and the UW component of a new ONR MURI on doping in organic semiconductors. Research in IMOD focuses on new semiconductor materials and scalable manufacturing processes for new optoelectronic devices for applications ranging from displays and sensors to a technological revolution, under development today, that is based on harnessing the principles of quantum mechanics.

At OSU, we took part in the Oregon Semiconductor Competitiveness Task Force, which highlights opportunities for semiconductor industry expansion in Oregon. Areas highlighted include increasing R&D strength around chip research and production and talent development. ATAMI has partnered with the City of Hillsboro on a Business Oregon Center of Innovation Excellence planning grant on semiconductors with a focus on public-private partnerships that concentrate their efforts on developing the funding, facilities, talent, and support services. We have hired two new faculty in the area of electronic devices and are in the early stages of expansion in these research areas to align with OSU's new Collaborative Innovation Complex, which will harness one of the nation's most powerful supercomputers, a cleanroom and advanced research and learning in artificial intelligence, robotics and materials science.

Education and Outreach Activities

NNI's E&O portfolio emphasizes workforce development, supporting underrepresented populations in college transition towards 4-year degrees that can support careers in nanotechnology (including women and communities farthest from educational justice), engagement of Regional First Nation Tribes, and the integration of evaluation and assessment to ensure continuous improvement and to determine the impact of E&O efforts. In addition to our E&O activities and workforce development, senior personnel Kai-Mei Fu leads a $3M NSF Research Traineeship for graduate students in quantum information science and technology. A Graduate Certificate in Quantum Information Science and Engineering has been fully approved by the UW Graduate School in April 2022. The program complements students' doctoral training while preparing them for careers in quantum information science and technology.

College Transition Support

NNI is in the second year of our partnership with the UW College of Engineering and the UW's Office of Admissions to support a new college transition program for a cohort of incoming University of Washington students coming from backgrounds farthest from educational justice – The Engineering Dean's Scholars Program. Each cohort is between 45 and 48 students, and we achieved a 96% retention in College after the first year of the program. The current cohort, #2, consists of 45 students as of autumn quarter 2022. Compared to the general population of admitted UW Engineering students, in the 2022 admitted pool of students who are eligible for Dean's Scholars, we saw a 5% increase in women, a 73% increase in first generation college students, a 52% increase in low-income students, and a 38% increase in URM students. We have hired our first two scholars who began working in the WNF cleanroom this academic year.

Workforce Development

Providing traditional 4-year undergraduates and community college students engaging work opportunities is one of several ways NNI facilities have supported workforce development in the region. Over the past year, 18 students worked in the WNF cleanroom as lab assistants (excluding undergraduate researchers from the labs of participating NNI faculty). This pool of student staff drew from the diverse talent across engineering and STEM majors at UW. Of the 18 students, 6 were women, 1 was Native American, and 1 was Hispanic or LatinX. In addition to WNF's Student Lab Assistant Program, the MAF also employs two paid UW undergrad research assistants, one of whom self-identifies as Native Hawaiian or Other Pacific Islander. MAF student assistants learn about lab safety, data processing, and how to use various MAF instruments. Over the past year, NNI facilities at OSU had 6 undergraduate researchers working on different nanotechnology related projects under the guidance of NNI faculty and staff. Students ranged in experience level from freshman to seniors and included participants in STEM Leaders, a mentoring and research program aimed at increasing diversity in STEM fields. Close to 90% of students participating in OSU NNI related activities identify as female or other underrepresented groups in engineering.

Since March of this year, the WNF has started specific activities to address workforce development and career opportunities for students who have experience working at or using the WNF cleanroom. These include job fairs and opportunities for companies to acquire talent and present job-specific information to students. We plan to host workshops on semiconductor processing, metrology, electrical characterization, design and DOE technique throughout the year that students can attend. Additionally, we have expanded student assistant recruitment to include the Dean's Scholars College Transition Program.

First Nations Engagement & Educators-in-residence

This past summer - Co-PI Baio was able to relaunch a program designed to bring science teachers from schools within local tribal communities to OSU to participate in a NNCI supported research project. Each participant partakes in data collection and analysis, literature discussions and weekly lab meetings with the project team, thereby exposing the instructor to state-of-the-art experimental protocols, numerical methods and advanced spectroscopic techniques. The participating educators then work with OSU faculty to design educational modules to bring back to their classroom.

Undergraduate and Graduate Courses

The University of Washington and Oregon State University offer comprehensive curricula with both conventional graduate courses and evening classes for professional master's program (PMP) students. Currently, several courses utilize the NNI facilities: EE 527 Nanofabrication Techniques, EE/ME/MSE 504 Introduction to Microelectromechanical Systems (MEMS), EE/MSE 486/528 Integrated Circuit Fabrication, ME 461/561 Mechanics of Thin Films, BioEn 492/592 ChemE 458/558 Surface Analysis, and OSU's CHE 444/544 Thin Film Processing, ECE418/518 Semiconductor Device Processing, CHE417/517 Instrumentation in Chemical, Biological and Environmental Engineering, and BioE445/545 Surface Analysis.

<u>Innovation and Entrepreneurship Activities</u>

The NNI site has renewed its efforts in innovation and entrepreneurship activities on several fronts. We actively participate in the newly created NNCI I&E working group. Together with group lead Matthew Hull from the NanoEarth site, PI Karl Böhringer organized and hosted an online NNCI Seminar on Innovation & Entrepreneurship featuring MEMS serial entrepreneur and member of the Silicon Valley Band of Angels Kurt Petersen, who spoke to the NNCI community about "What Investors are Looking for in Early Stage Start-up Companies" in October 2021. This seminar series continues approximately quarterly with leaders in I&E.

Other I&E events have included a virtual presentation and discussion on "Transforming patient care with nano-engineered systems" in April 2022 featuring two UW faculty-entrepreneurs and the College of Engineering Associate Dean for Medical Technology Innovation, and a "Distinguished Practitioners in Nano-engineered Systems" seminar by MANTH director and entrepreneur Mark Allen in May 2022.

At OSU we had five events hosted by OSU Advantage, including "SBIR/STTR Success Tips for Startups with Leon Wolf," "Avoiding Conflicts of Interest as Academic Startups," and "OSU Advantage Speaker Series: Inside the Mind of a Cleantech Investor."

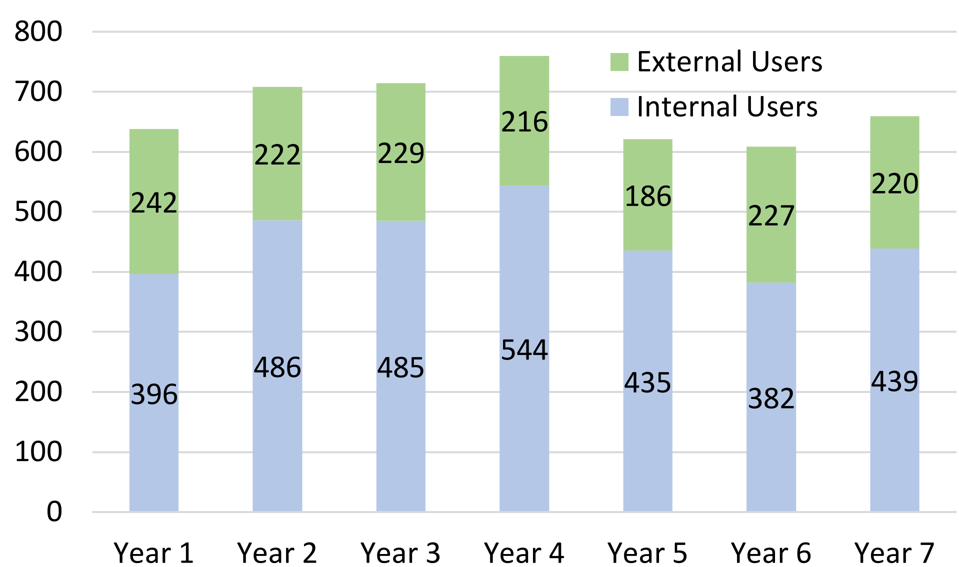
Currently we are aware of at least eight small businesses with active SBIR/STTR grants performing part or all of their R&D work at NNI facilities.

UW / OSU Spin-offs

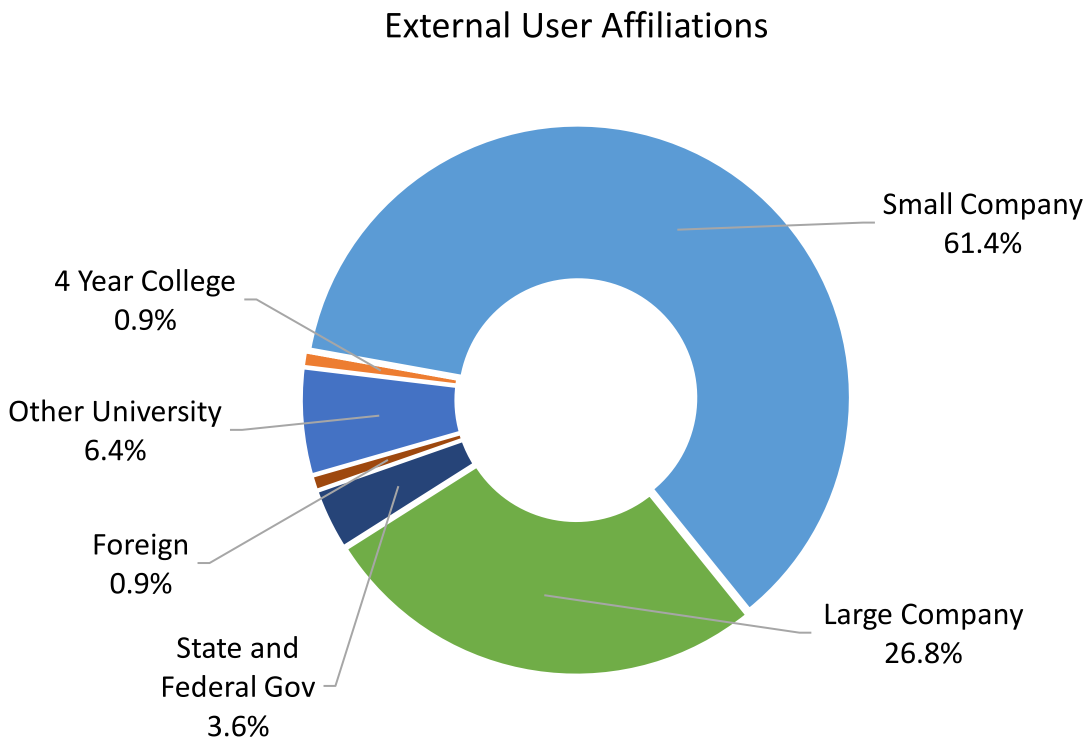
- *Inpria*, which is developing resists for extreme ultraviolet photolithography, uses ATAMI, OPIC, and APSCL facilities and has been recently acquired by JSR Corp. for $514M.
- *Anavasi Diagnostics*, a UW spin-out with labs located in NanoES, has been awarded $14.9 million from the National Institutes of Health (NIH) Rapid Acceleration of Diagnostics (RADxSM) initiative. UW spin-out *Tunoptix, LLC,* which develops tunable metasurface optics for machine vision and AR/VR applications, received additional seed funding from a commercial partner and SBIR grants from DARPA, NASA, and NSF.
- *NexTC Corporation*, an OSU spinout located in ATAMI, provides high-performance, low-cost insulator and conductive oxide coatings and has received SBIR funding from DOE and NSF.
- *Crown Electrokinetics*, located in ATAMI, developed a technology to apply a film to glass windows to darken them, change their color, adjust interior lighting or conserve energy. Crown has a new 27,000-square-foot Salem factory that will cut and assemble window inserts and apply electrokinetic films made at ATAMI.

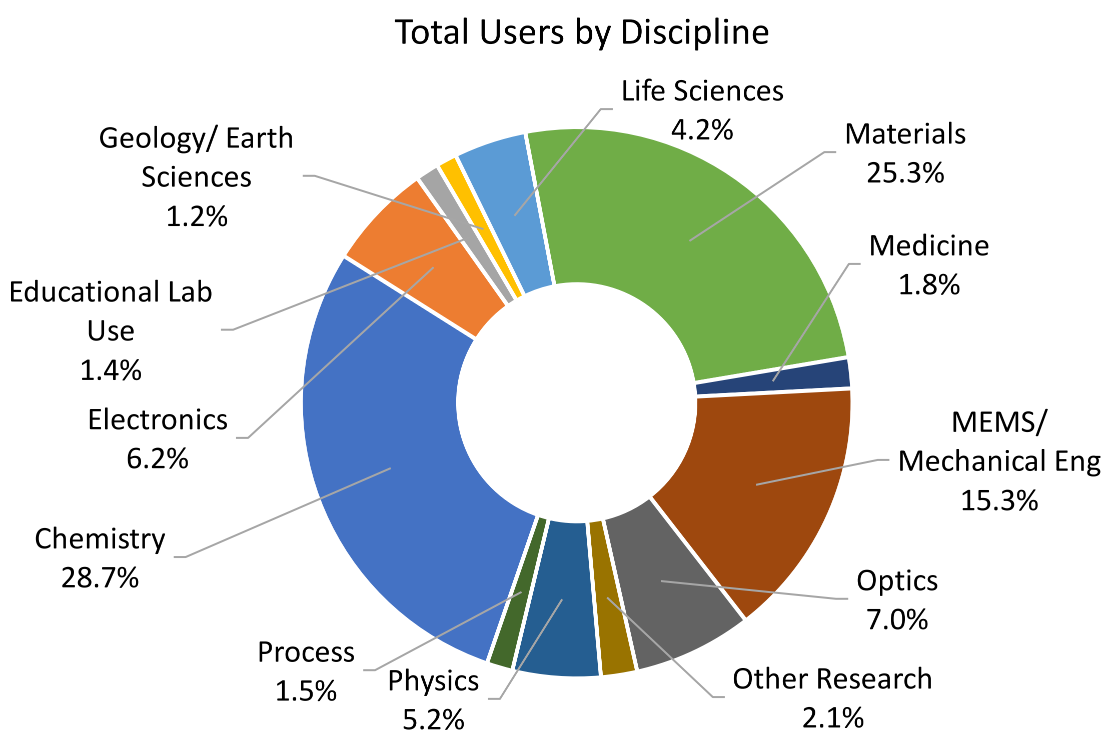
NNI Site Statistics

Yearly User Data Comparison							
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Total Cumulative Users	638	708	714	760	621	609	659
Internal Cumulative Users	396	486	485	544	435	382	439
External Cumulative Users	242 (38%)	222 (31%)	229 (32%)	216 (28%)	186 (30%)	227 (37%)	220 (33%)
Total Hours	38,350	46,562	55,925	65,032	55,939	72,122	60,027
Internal Hours	21,822	30,600	27,695	35,564	22,262	26,740	29,379
External Hours	16,528 (43%)	15,962 (34%)	28,230 (50%)	29,468 (45%)	33,677 (60%)	45,382 (63%)	30,648 (51%)
Average Monthly Users	267	277	266	304	226	252	265
Average External Monthly Users	103 (39%)	98 (35%)	93 (35%)	93 (31%)	77 (34%)	88 (35%)	85 (32%)
New Users Trained	126	159	206	134	64	115	186
New External Users Trained	41 (33%)	37 (23%)	57 (28%)	31 (23%)	18 (28%)	31 (27%)	56 (30%)
Hours/User (Internal)	55	63	57	65	51	70	67
Hours/User (External)	68	72	123	136	181	200	139



NNI Year 7 User Distribution





12.11. Research Triangle Nanotechnology Network (RTNN)

Facility, Tools, and Staff Updates

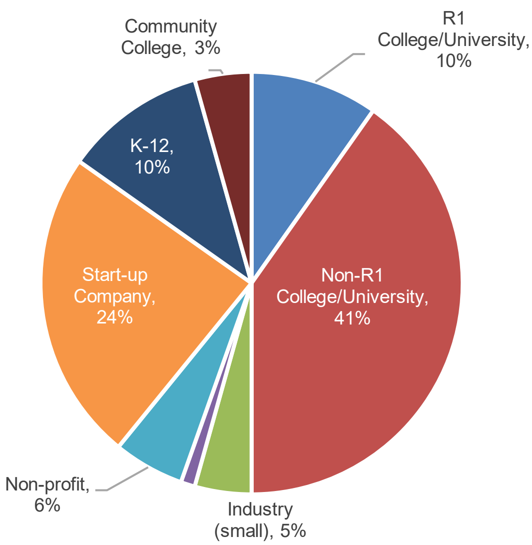
Tools: In Year 7, 7 new instruments valued at >$2.0 million were acquired, including a Kratos Analytical AXIS Supra X-ray photoelectron spectroscopy (XPS) system, a Thermo Fisher Tundra Cryo Transmission Electron Microscope, an Asylum Research Jupiter XR Atomic Force Microscope (AFM), a Rigaku HyPix 3000 Pixel Array Detector for XRD, a Plasma-Therm SLR 730 chemical vapor deposition (CVD), an Apogee Spray Developer Tool, and a Biacore T200 Surface Plasmon Resonance (SPR) System. **Techniques:** CHANL expanded their Focused Ion Beam (FIB) system to enable lift-out procedures for TEM specimen preparation. SMIF recently developed a new technique to acquire haze measurements on their Shimadzu UV-3600i UV-Vis-NIR spectrophotometer. Haze is the proportion of diffuse transmittance to total transmittance and is used to characterize material surface treatment. NNF has also added substrate thinning capabilities by acquiring an Allied MetPrep1X Precision Grinder. NNF has also developed a "quick-turn" LED process that enables a rapid (1-2 day) turnaround time to evaluate the optoelectronic properties of LED structures. The AIF now has the ability to deposit carbon on their FEI Quanta FIB, allowing a protective layer of carbon to be deposited on the area of interest instead of the normal platinum deposition capability. This is preferred in cases where EDS analysis is desired and there is a risk of Pt spreading into a region of interest and masking elements natively present in the sample. Building the User Base: 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. **Staff:** Dr. Jin Nakashima joined AIF as a Senior Research Scholar in October 2021. Dr. Nakashima earned his M.S. and Ph.D. in Wood Science and Technology from Kyoto University in Japan and has 20+ years of experience sample preparation and microscopy experience focused mostly on biological specimens. In AIF, Dr. Nakashima assists clients' research and manages the biological sample preparation and bio-EM laboratories alongside Dr. Aaron Bell. Dr. Nina Balke, an Associate Professor in the Material Science and Engineering (MSE) department at NC State, was appointed as the new Director of the AIF, succeeding Dr. Jacob Jones, who remains involved with AIF through an official role in the NC State College of Engineering as Special Advisor on Nanotechnology and Shared Instrumentation. The PCOST program welcomed Anne Njathi as the new Assistant Director of Assessment. Njathi is a doctoral student in Communication, Rhetoric and Digital Media with over 8 years of multidisciplinary work experience. PCOST also added three advanced undergraduate research assistants: Jongsue Cho, Lori Wilichowski, and Ava Freyaldenhoven. Cho and Wilichowski will work exclusively on SEI research activities associated with the RTNN. Freyaldenhoven will work with the SEI Director, Dr. Berube, on multiple research activities. All three women are undergraduate students completing their BS in Communication. Phillip Strader, who previously served as RTNN Project Scientist and Client Development Coordinator at the AIF at NC State, was appointed the new RTNN Manager effective January 2022. SMIF hired Emily

CHANL Director, Dr. Bob Geil (left), demonstrates E-Beam Evaporation as part of the 2022 CHANL Microfabrication Workshop for undergraduates.

Moreno-Hernandez as a Program Coordinator to help manage and coordinate efforts for RTNN related activities and manage business operations for SMIF.

User Base

Satisfaction: Unique surveys conducted during Year 7 were used for collecting demographic and user satisfaction data from various RTNN programs. Surveys were hosted on Qualtrics, the analysis was done on SPSS with some original SAS coding, and all surveys were IRB-approved. Overall, facility users who responded to the survey were very satisfied with their experiences in the facility they used in Year 7 (6.36 ± 1.09 on a 7-point Likert scale where 7=very satisfied, n=307). This level of satisfaction was consistent with responses from previous RTNN years (Year 6: 6.28 ± 1.22, n=213). Greater than 99% of users (n=307) indicated that they would return to the lab they utilized if further work was necessary.



Affiliations of participants in the Kickstarter program (n=90)

RTNN Kickstarter Program: This program supports use of the facilities by new, non-traditional users by providing free initial access. To date, 90 projects have been awarded (Year 7: 7 projects). The figure at left shows the affiliations of the program participants. Most participants are from non-R1 colleges/universities (41%), start-ups (24%), while K-12 students/classrooms make up about 10%. The RTNN strives to retain the participants as long-term RTNN users and to highlight their successes via social media campaigns to recruit new users and solicit proposals. Of the projects who completely used their time in the program, >40% subsequently continued to use facilities spending >$302,000 of their own funding in facility use. The program brings in new users and provides a pathway to facility sustainability. Several recipients utilized data generated with the Kickstarter program to publish as well as propose and secure additional funding such as SBIR Awards. Ongoing assessment and interviews of Kickstarter recipients reveals that respondents continue to be happy with the overall program, indicate that they will return to the facilities, and have positive interactions with RTNN staff.

Screenshot of a video filmed for "Nanotechnology, A Maker's Course" with a demonstration of Focused Ion Beam systems from Roberto Garcia

Online Coursera Course: "Nanotechnology, A Maker's Course," introduces nanotechnology tools and techniques while providing 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 261,530 (Y7: 41,173) people have visited the course website, over 32,940 (Y7: 4,810) have engaged with course components, and over 9,490 (Y7: 1,414) have completed the course.** Several participants have engaged with RTNN outside the course (e.g., Kickstarter program, workshops, newsletter subscription). *Assessment:* Students were highly satisfied (7=very satisfied) with the course materials on all five measures (6.31). Students were also highly satisfied with the course instruction on all five measures (6.33). Similarly, students were also highly satisfied with the multimedia content of the course (6.46). Over 90% of respondents noted they were “likely” or “very likely” to recommend the course to others. 70% of respondents noted they had a better knowledge of the capabilities of RTNN's facilities.

Workshops, short courses, symposia: In Year 7, RTNN held >8 virtual short courses with over >65 participants. Standard-instrument-focused short courses introduce tools and techniques to provide a foundation for subsequent training on a specific tool. To provide a library of reference materials, the virtual courses are recorded and edited. The RTNN also helps to plan and execute the Carolina Science Symposium on an annual basis with collaboration from the Joint School of Nanoscience and Nanoengineering (JSNN), which is part of SENIC. This event is student-focused, giving many early career students their first opportunity to present research in a professional setting. In 2021 (Year 7), this event continued as a two-day virtual event and attracted >60 participants. The event returned back to the in-person format for 2022 (Year 8).

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 had >700 unique visits monthly with >99% of these new visitors to the site in Year 7. We also maintain two subscription lists to share information and opportunities: one to principal faculty (>260 PIs) and one to other stakeholders (>3,700 subscribers).

RTNN is actively promoting activities, events, and opportunities on multiple social media platforms including Twitter, Facebook, and LinkedIn. 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 4% increase in Facebook followers, 14% increase in Twitter followers, and a 43% increase in LinkedIn followers since the end of Year 6.

Research Highlights and Impact

Core technical capabilities and specialized expertise and facilities in the RTNN span the following areas: low dimension and layered nanomaterials; materials for energy efficiency and sustainability; nanomaterials for biology medicine, and environmental assessment; and advanced materials/interfaces (metamaterials, nanomaterial/nanostructure interfaces).

Scholarly and Economic Impact: Work performed in the RTNN led to >210 publications in 2021 by our users (170 of which cited the NNCI award number). 50 of these publications were authored by external users (37 cited the NNCI award). Work performed in the facilities led to >56 patents filed and >31 patents awarded in 2021.

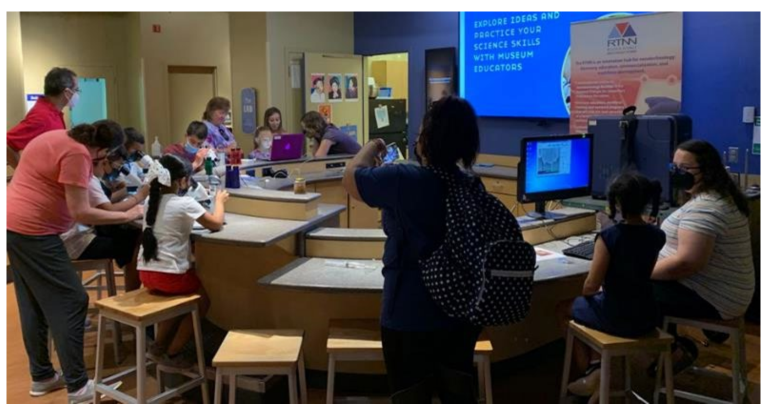
Education and Outreach Activities:

RTNN E&O Events. Evaluated programs are highlighted.

Year 7 Education & Outreach Events	
	Participants
Kickstarter Program	7
Engaged learners in Coursera course on nanotechnology	>4,800
In-Person Outreach Events	>980
Remote outreach events (e.g., SEM demonstrations in classrooms)	>970
Short courses, workshops (in-person or virtual)	>65
Virtual symposia/conferences	66
Outreach content YouTube views	>7,600
Technical content YouTube views (e.g., short courses, training)	>184,000
Synchronous Events (Total)	>2,085
Asynchronous Events (Total)	>196,400
Total	>198,480

RTNN's educational and outreach activities are a focal point of RTNN's goal to build the user base; the table gives an overview of RTNN's educational and outreach activities. In Year 7, facilities and staff accommodated a return to in-person outreach, while still offering virtual and remote outreach alternatives where they may still be preferred.

In-Person Programs: Year 7 marked a strong return to in-person events, including new/resumed outreach events and the first year of hosting a new RTNN-focused collaborative REU Site in the summer of 2022. The success of these programs is facilitated by the relaunch of the RTNN Student Ambassadors Program and participation of new staff hires in Year 7. At least 45 outreach events were in-person this year with a total of >980 participants reached, meaning RTNN outreach programs reached more people in real-time this year face-to-face than through virtual outreach.



Left: RTNN Student Ambassadors Alex Hsain and Jessica Chestnut host a booth with nano-activities (Sunprint photolithography) and information at the 2022 NC Science Olympiad; Right: Multiple RTNN Staff host a "Super Scientist Saturday" at the Durham Museum of Life and Science with a tabletop SEM and optical microscopes.

Community Engagement: "Building the user base" activities optimally have an important long-term component, which we emphasize with community and K-12 engagement, particularly for under-represented groups in STEM and rural and/or indigenous communities. Many events engage directly with diverse communities, i.e., Girl Scouts STEM Day @ Duke (>240 participants, ~95%

RTNN Student Ambassador Winston Lindqwister helps at an RTNN outreach event with a Waccamaw-Sioux tribal community.

URG), NC SciFest with Currituck County MS (Title 1 School, 98 Participants), Community STEM Day with a Waccamaw-Siouan Tribal community (95 participants), and STEM/nano activities at the Franklinton Middle School "Ram Camp" (38 participants, >50% URG) in Franklinton, NC (~1 hour outside the Research Triangle region). Virtual Outreach options remain extremely valuable in reaching larger audiences, especially with rural and indigenous communities via remote SEM sessions through RAIN, remote activities, Community Science nights, and more.

Societal and Ethical Implications Activities

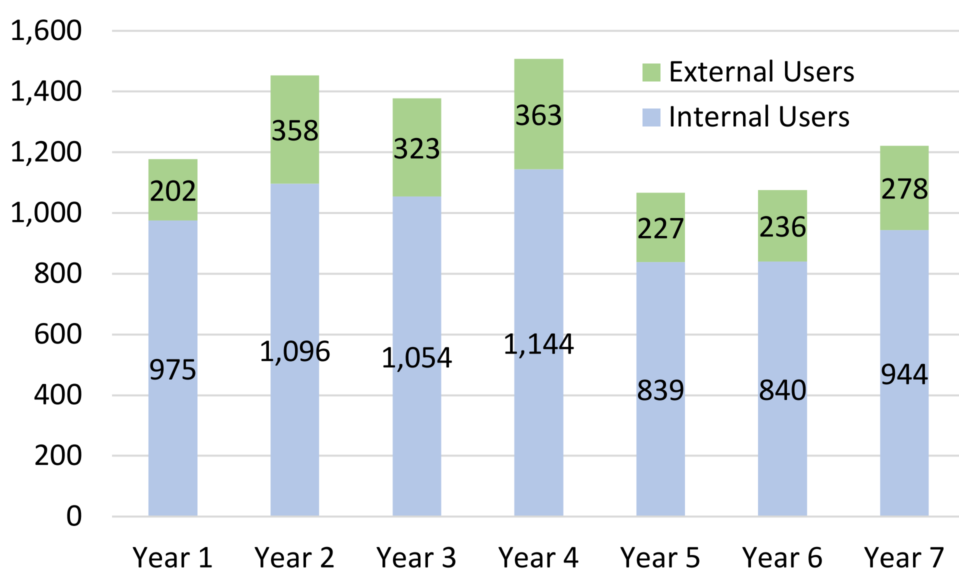
The RTNN's research in Social and Ethical Implications (SEI) of nanotechnology leverages the RTNN team and user base to enhance the instruction and understanding of how humans engage with nanotechnology. The SEI team received IRB approval for semi-structured expert interviews on nanoscience preparedness to resolve agricultural challenges brought on by climate change and the war in Ukraine. The team also completed Expert Interviews on Nano and Agriculture and analyzed content from our Food and Nutrition Security Workshop; data collection and analysis have nearly been completed and an article is planned for Spring 2023. As part of RTNN's social media presence, communications are carefully extending to include a Wikipedia presence while maintaining activity on Facebook, LinkedIn, and Twitter. The SEI team is also researching links between coordinated lab availability, entrepreneurship, and capital growth while working to identify an econometrics expert with a viable method to accomplish this with both validity and reliability. Dr. Berube is also developing an edited volume tentatively entitled: *Nanotechnology: 25 Years Later* as a continuation of his 2006 book (*Nano-Hype: The Truth Behind the Nanotechnology Buzz*), which will include both EHS and SEIN components.

Innovation and Entrepreneurship Activities

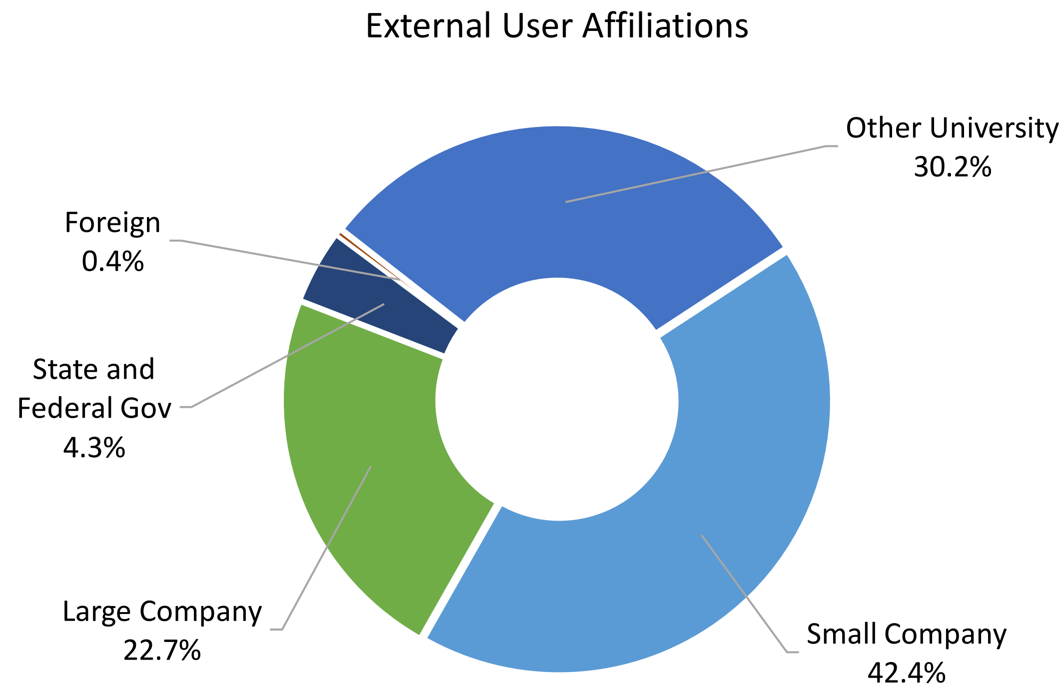
The RTNN serves a critical role in innovation and entrepreneurship through facilities, expertise, and programs. The majority (>55%) of companies that use the facilities have less than 50 employees. The Kickstarter program was designed in consideration of small companies without extensive research funding who may need a proof-of-concept experiment to then enable progress to larger funding, i.e., SBIR/STTR programs – about 28% of all Kickstarter recipients are either start-up/small companies. Many start-up companies spin-out of RTNN Universities and continue to use our facilities in their operation, including Qatch Technologies (>$1.2M SBIR/STTR funding since 2017), Cell Microsystems (>$13.4M SBIR/STTR funding since 2010), Third Floor Materials (>$1.6M SBIR/STTR funding since 2016), Adroit Materials (>$9.8M SBIR/STTR funding since 2016), Smart Material Solutions (>$3.5M SBIR/STTR funding since 2016), IONQ (>$22M private funding since 2015), Voxel Innovations (>$969k SBIR/STTR funding since 2015), and many more.

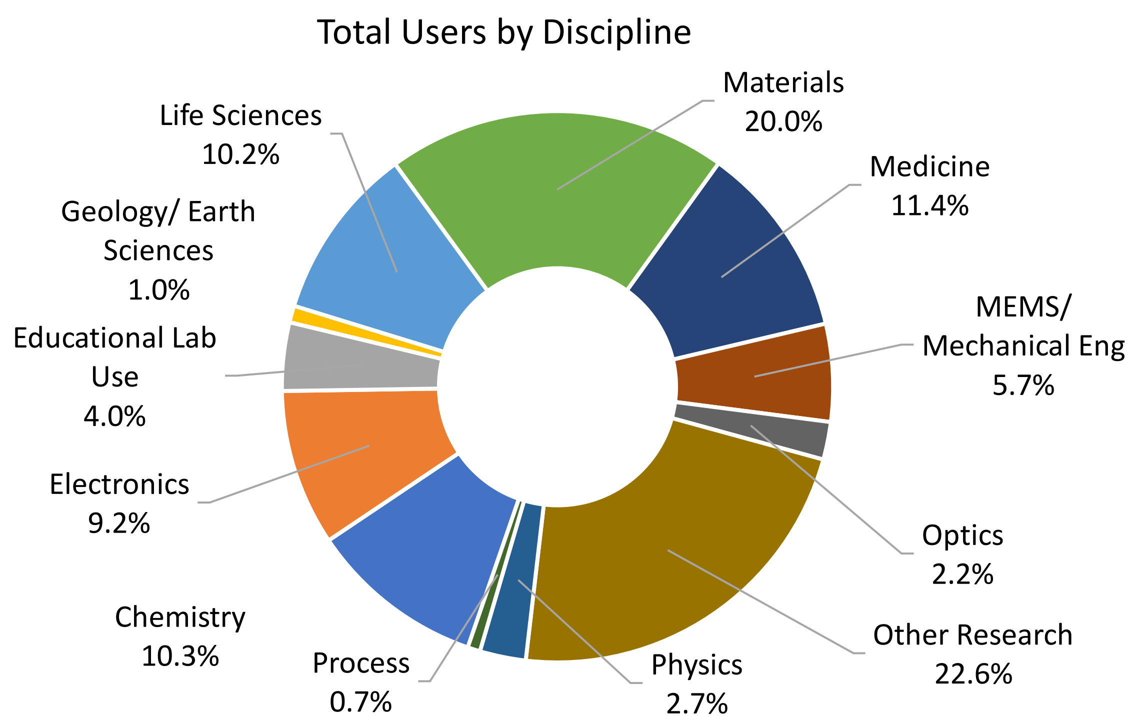
RTNN Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	1,177	1,454	1,377	1,507	1,066	1,076	1,222
Internal Cumulative Users	975	1,096	1,054	1,144	839	840	944
External Cumulative Users	202 (17%)	358 (25%)	323 (23%)	363 (24%)	227 (21%)	236 (22%)	278 (23%)
Total Hours	53,044	51,747	55,684	61,404	43,099	53,491	51,211
Internal Hours	46,908	43,053	46,422	49,685	33,636	43,209	40,837
External Hours	6,136 (12%)	9,694 (17%)	9,263 (17%)	11,719 (19%)	9,463 (22%)	10,282 (19%)	10,374 (20%)
Average Monthly Users	395	422	420	445	308	352	396
Average External Monthly Users	50 (13%)	63 (15%)	71 (17%)	74 (17%)	53 (17%)	67 (19%)	78 (20%)
New Users Trained	433	527	695	627	288	435	492
New External Users Trained	71 (16%)	69 (13%)	82 (12%)	102 (12%)	54 (19%)	74 (17%)	60 (12%)
Hours/User (Internal)	48	39	44	43	40	51	43
Hours/User (External)	30	24	29	32	42	44	37



RTNN Year 7 User Distribution





12.12. San Diego Nanotechnology Infrastructure (SDNI)

Facility, Tools, and Staff Updates

Facility: SDNI's open-access user facilities include the Nano3 Facility for nanoscience, nanoengineering, and nanomedicine, the Microfluidic Medical Device Facility, the Chip-Scale Photonic Testing Facility, the CMRR Materials Characterization Facility that supports research in the areas of magnetics, energy, and quantum devices, and the Electron Microscopy Facility. The focus for SDNI is centered on the Nano3 cleanroom and characterization facility and involvement with the NNCI has resulted in SDNI's expansion to other related areas.

SDNI had all facility operation restrictions lifted during Year 7 and usage hours continued to climb from previous years. User hours for Year 7 have recovered to 94% of pre-pandemic (i.e. Year 4) levels and are about 6% higher than those reported for Year 6. The transition during the pandemic to staff-assisted services allowed users to continue their research when many other options were not available. Resulting from the shift to increased direct services from staff and an increased portion of external utilization, Year 7 site user fees collected were 14% above pre-pandemic (i.e. Year 4), and 11% above Year 6.

SDNI continues to upgrade and customize the capabilities of our FOM scheduling system. We target upgrades that increase usability and expand the information extracted from facility usage. Changes to the system include customized reports, standardized financial data, real-time facility access data, improved registration processing, and batch changes to facility resources.

Tools: With the increased revenue and renewed interest in semiconductor manufacturing, there was significant investment in the facility. In the reporting period, SDNI received $1.6M from the campus to invest in the facility infrastructure. These funds were used to replace existing equipment, expand processing capabilities, and address current processing issues. SDNI also used its own funds to upgrade the TEM and focused ion beam. The overall investment in tools and infrastructure was over $2M in the reporting period. By expanding our tool sets and processing capabilities, we have equipped ourselves to support broader science and technology areas including fundamental and translational research in biomedicine, semiconductors, energy, communications, and quantum materials/devices/systems.

SDNI is currently in the process of purchasing new wet benches. Plans include installing two chlorinated polyvinyl chloride (CPVC) benches and three stainless steel benches to replace five existing wet benches. Planned improvements to the CPVC wet benches include processing stations for hydrofluoric acid (HF), piranha cleaning, acid processing, base processing, and a spinner for puddle etching. The CPVC benches will have quick dump rinse (QDR) stations accommodating up to six-inch wafer cassettes.

SDNI purchased a new Park NX20 AFM for our facility, which was installed in June 2022. The new instrument offers 16 measurement modes to cover a wide range of research needs and a variety of semi-automated features that increase the speed and ease of use. The combination of all these increased capabilities and features will make this tool an invaluable resource for our current and future users.

The two existing electron beam evaporators currently in the facility were outdated and their long-term reliability became questionable. To improve the electronics and user operation of the tools, critical electronic components were upgraded in 2022. Power supplies, beam controllers, film deposition controllers, film deposition monitoring systems, and input/output kits to interface with the electron beam controller have been replaced and tool performance has been greatly increased.

SDNI acquired a Denton 502 thermal evaporator from a local company, bringing the total to two thermal evaporators. We decided to upgrade the vacuum system by installing a turbopump to improve vacuum levels and reduce the pump time. This new tool will be used for all standard evaporation materials and the existing thermal evaporator will allow non-standard materials and experiments.

SDNI continues to make investments in the Electron Microscopy Facility to support the diverse research being performed. When the Talos F200X G2 Transmission Electron Microscope was purchased, users could use selective area electron diffraction (SAED) to analyze the crystal microstructure. To overcome limitations with SAED, SDNI upgraded the TEM to include another powerful electron diffraction mode, nano-beam electron diffraction (NBED). Another need for TEM users, especially in energy storage applications, is a holder capable of cryogenic temperatures and protection from air exposure. A Mel-Build holder equipped with secure O-ring sealing to prevent air exposure to the sample was purchased. Double-tilt functionality allows imaging and analysis of the sample at different orientations. With TEM and STEM-EDS-EELS, the Talos F200X can provide both morphological and chemical information of materials at atomic resolution on beam sensitive materials, further diversifying the utilization of the tool.

The FEI Scios FIB/SEM hardware and software were upgraded to make the tool more serviceable and allow for easier sourcing of parts. The tool now has a new cryogenic stage, tank, heat exchanger, load lock, transfer arm, and workstation control box. With these new upgrades, the cryogenic stage can remain in the cooling state for 10-12 hours, an improvement from the previous duration of 6-8 hours.

Upgrades to the Disco Dicing Saw were completed near the end of 2021. A new computer, touchscreen, camera, and current software were purchased and installed.

Staff: The effects of the pandemic continued to affect the staffing at Nano3. In early 2022, the staffing levels finally reached their pre-pandemic equivalent. Two processing engineers (one Ph.D. level engineer, the other a B.S. level with industry experience) were hired in the summer of 2021 to replace staff members lost to industry. Three new equipment engineers were also hired in the current reporting period. The first hire came from industry with significant experience replacing a senior equipment engineer who retired in June 2021. The two junior-level equipment engineers, only hired at the beginning of 2022, replace a staff member lost at the beginning of the pandemic and another employee departure in late 2021.

The SDNI training program for undergraduate students no longer has university-imposed restrictions limiting staffing levels. We reached pre-pandemic levels of student support only during Year 7. These students support SDNI staff with many functions such as fabrication assistance, training users, repairing equipment, and facility operation. Being extensively involved in the facility provides the students with relevant, hands-on skills desired by employers.

From the inputs of industrial advisors, there exists a gap between school teaching and industrial work environment. In response to this feedback, we have garnered university support to create 25 internship positions over a period of 5 years. Each intern will be assigned to a staff member as her/his mentor. Over the one-year internship period, the intern learns the principles and operation of several tools within the facility and independently operates these tools to assist in the fabrication and characterization of micro- and nanoscale devices.

User Base

SDNI is a valuable resource for academic and industrial researchers focusing on nanoscale material science, engineering, and biotechnology. Since the 23% decrease in user hours from Year 4 to 5 due to the COVID-19 pandemic, hours have steadily increased in Years 6 (14%) and 7 (6%) and are close to pre-pandemic totals. The site has roughly 30% external users in the past two years after starting from around 25% when SDNI was first established. Some of this growth can be attributed to the increased amount of staff services SDNI provides to external users.

In Year 7, SDNI served users from 93 UCSD internal academic groups and 75 external institutions. The breakdown of external user institutions is: 12 non-UCSD US academic, 1 state/federal government, 46 small companies, 15 large companies, and 1 international. Averaging Years 1-6, SDNI annually has served 72 external institutions (9 non-UCSD US academic, 3 state/federal government, 43 small companies, 16 large companies, 1 international) and 92 UCSD internal academic groups.

In parallel with our internal workforce training program, we also helped create a channel between users and industry. SDNI has sponsored workshops for industry to show students their needs and expectations and for students to show industry their learnings beyond course work. One effort attracted 22 companies and around 100 students, being one of the largest workshops for the purpose of workforce development.

Research Highlights and Impact

SDNI enables groundbreaking fundamental and applied research in nano/meso/metamaterials, nanophotonics, nanobiomedicine, and nanomagnetism. Our facility has also contributed, in a significant way, to the development and commercialization of innovative technologies. In the past 12 months, the SDNI facilities have supported over 210 peer-reviewed scientific publications from approximately 75 academic institutes, government labs, and companies.

Convergence Research and Quantum Leap: *Energy-efficient Mott activation neuron for full-hardware implementation of neural networks* (Published in Nature Nanotechnology, 2021): Inspired by the rapid advances in neural sciences and brain functions, a new paradigm in computing and data processing system emerges, which uses the neural network architectures with deep learning and artificial intelligence (DL/AI). SDNI researchers in quantum materials, electrical engineering, and computer sciences have applied a wide variety of tools at SDNI to demonstrate the world's first LeNet-5 network with Mott activation neurons with >98% accuracy on the MNIST dataset. The work lays the foundation for large-scale, highly parallel, and energy-efficient in-memory computing systems for neural networks.

Convergence Research: *3D heterogeneous sensor grids for ultra-resolution human brain signal recording* (Published in Science Translational Medicine, 2022. Highlighted by NSF in a video release): The multidisciplinary, multi-institute team, led by a SDNI researchers, utilized SDNI facilities to develop scalable manufacturing processes and dense connectorization to achieve reconfigurable thin-film, multi-thousand channel neurophysiological recording grids using platinum-nanorods (PtNRGrids). With PtNRGrids, thousands of channels of small low impedance provide unparalleled spatial and temporal resolution over a large cortical area. In the clinical setting, PtNRGrids resolve fine, complex temporal dynamics from the cortical surface in an awake human patient performing grasping tasks and identify the spatial spread and dynamics of epileptic discharges in a patient undergoing epilepsy surgery at 1 mm spatial resolution. Besides its scientific impact, these thin, pliable grids of embedded electrocorticography sensors have significant clinical impact by offering neurosurgeons brain-signal information directly from the surface of the brain's cortex in 100 times higher resolution than what is available today. The high-resolution data in both time and space opens many new possibilities for uncovering new knowledge about how the brain works.

Translational Research: *Carbon-free high-loading silicon anodes enabled by sulfide solid electrolytes* (Published in Science, 2021): The development of silicon anodes for lithium-ion batteries is impeded by poor interfacial stability against liquid electrolytes, which results in poor cycling and shelf life caused by continuous solid electrolyte interphase (SEI) growth between the highly reactive Li-Si alloy and organic liquid electrolytes. Two key challenges to apply Si to LIBs are: (i) stabilizing the Li-Si | electrolyte interface to prevent continuous SEI growth and trapped Li-Si accumulation, and (ii) mitigating growth of new interfaces induced by volume expansion that results in Li+ consumption. The research, led by SDNI, enables the stable operation of a μSi anode by using the interface passivating properties of sulfide solid electrolytes. The research produces a μSi electrode consisting of 99.9 wt % μSi in μSi||SSE||lithium nickel cobalt manganese oxide (NCM811) cells that overcome both the interfacial stability challenges of μSi and the current density limitations of all solid-state batteries (ASSBs). Microsilicon full cells demonstrated in this research achieve high areal current density, wide operating temperature range, and high areal loadings.

Translational Research (Harnessing Data Revolution): *Commercializing bleeding edge nanotechnology to revolutionize single molecule DNA/protein sequencing and DNA data storage for harnessing the data revolution* (Published in PNAS, 2022): Roswell Biotechnologies is a San Diego biotechnology start-up and a beneficiary of SDNI's deep nano-scaled manufacturing capabilities. In collaboration with scientists and engineers from Harvard, UCSD, and Rice University, the Roswell team demonstrates molecular electronics on a semiconductor chip for single-molecule measurement of binding kinetics & enzyme activity. The chip uses single molecules as universal sensor elements in a circuit to create a programmable biosensor with real-time, single-molecule sensitivity and nearly unlimited scalability in sensor pixel density. The sensor is programmed by attaching the desired probe molecule to the molecular wire, via a central, engineered conjugation site. The observed current provides a direct, real-time electronic readout of molecular interactions of the probe. These picoamp-scale current-versus-time measurements are read out from the sensor array in digital form, at a rate of 1000 frames per second, to capture molecular interactions data with high resolution, precision, and throughput. Activity signals can be analyzed with machine learning algorithms to allow reading of the sequence. This ultra-scalable chip opens up the possibility for highly distributed sequencing for personal health or environmental monitoring, and for future ultra-high throughput applications such as Exabyte-scale DNA data storage.

Education and Outreach Activities

We have been working diligently to integrate nanotechnology content to current NGSS-aligned science curricula in California (The California NanoTech 2025 Project) and to network with the other NNCI sites to make an impact nationwide. The following describes our education and outreach accomplishments in the report period.

REU program: In the Summer of 2022, we had a diversified cohort of 6 REU students who worked under the supervision of UCSD faculty and mentors. Introductory lectures on nanotechnology, artificial intelligence, data science, and entrepreneurship were given by leaders in these areas. REU students worked on a nanotechnology-related project and made a presentation on the outcomes of their project at the 2022 NNCI REU Convocation which was held at University of Louisville, KY and hosted by KY Multiscale. Students also presented their research project outcomes at the 2022 UC San Diego Summer Research Conference.

Nanotechnology Summer Institute for Middle and High School Teachers: SDNI organized the weeklong Nanotechnology Summer Institute for Middle and High School Teachers, where 28 teachers were introduced to nanotechnology through lectures, workshops, and hands-on activities. We helped the participants (and continued to support then during the school year following the training) to develop a NGSS-aligned lesson plan that they could bring to their classes for the school year 2022-2023. This program will enable SDNI to reach out to approximately 16,000 students by 2025.

Remote Scanning Electron Microscopy (SEM) Session: SDNI is currently the top performer of the nationwide RAIN (Remotely Accessible Instruments for Nanotechnology) network that includes 28 institutions across the nation. In year 7, we continued to perform remote SEM sessions with K-12 and community college students. A large library of specimens including nanoparticles, nanophotonic structures, MEMS, metallic/ceramic structures, and a large variety of biological samples, were imaged. Following the session, thought-provoking questions about image analyses and feature/function correlations were provided as homework assignments, quizzes, and subjects for discussion sessions between teachers and students.

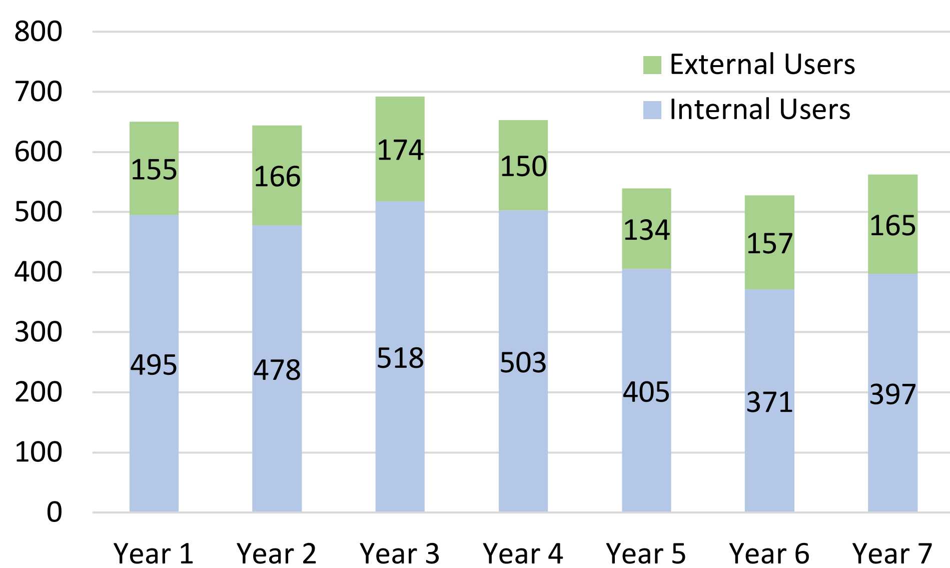
Hands-on Kit for Nanophotonic Education: SDNI's Chip-Scale Photonics Testing Facility (CSPTF) facility has successfully established a full production line for the Integrated Photonic Education Kit (IPEK), including photonic packaging. This enables SDNI to produce enough demo kits to accommodate the growing needs for college and graduate level education, convergence research training projects, and SDNI's workforce development efforts. The IPEK is the first plug & play didactic toolkit that enables hands-on experimental integrated photonics for education institutions. It allows students to experimentally analyze the basic building blocks and concepts used in all integrated photonic devices and will encourage them to participate in STEM education and careers. To further the development of the IPEK, SDNI-CSPTF has completed a full curriculum for the device, and successfully implemented it as part of the course ECE 184: Optical Information Processing and Holography class. The curriculum includes five modules and covers topics ranging from waveguide and component basics to more complex devices such as ring resonators and Mach-Zehnder modulators.

<u>Innovation and Entrepreneurship Activities</u>

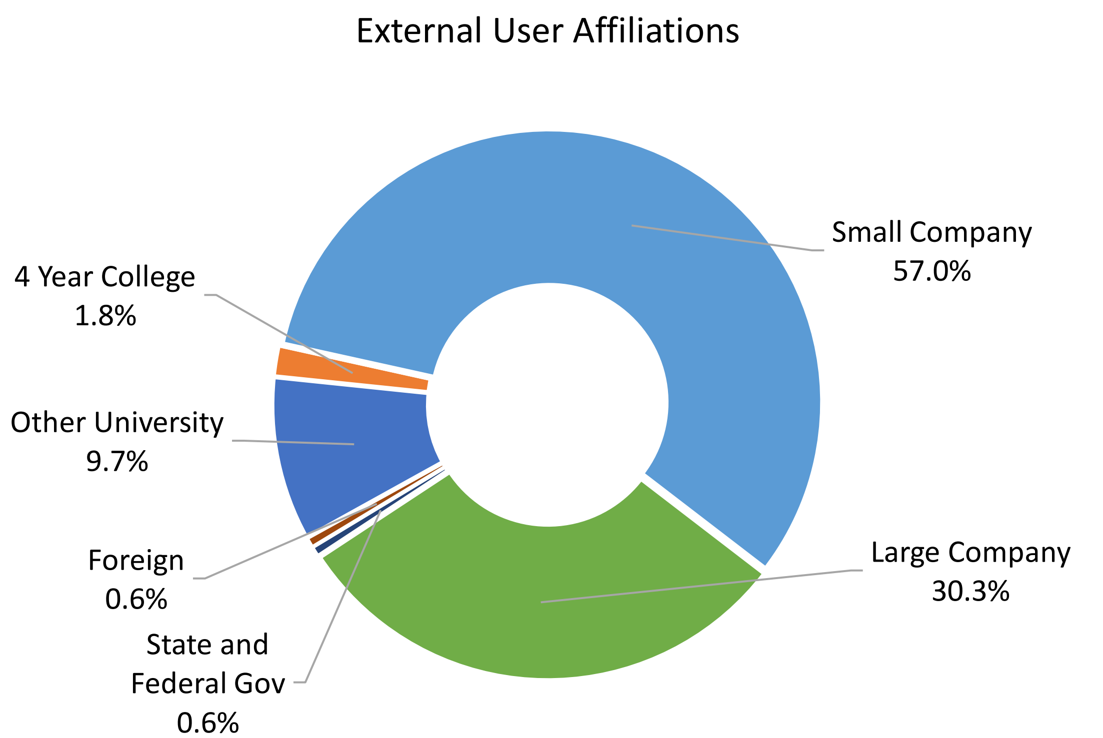
SDNI had two teams selected to participate in the 2022 NNCI Nanotechnology Entrepreneurship Challlenge (NTEC). The program is designed as a pre-NSF I-Corps experience with NTEC providing experiential entrepreneurship education for student-led teams. The SDNI teams were mentored by SDNI Director of Education, Outreach, and Diversity, Dr. Yves Theriault, and Nanoengineering faculty, Professor Sheng Xu. The team's project *Bio-inspired self-powered and flexible wearable device for continuous detection and treatment of Parkinson's Disease* received first place and the other team's project *Functionalized DNA Origami-siRNA Nanotube Complex to Reverse Osteoarthritis* received second place.

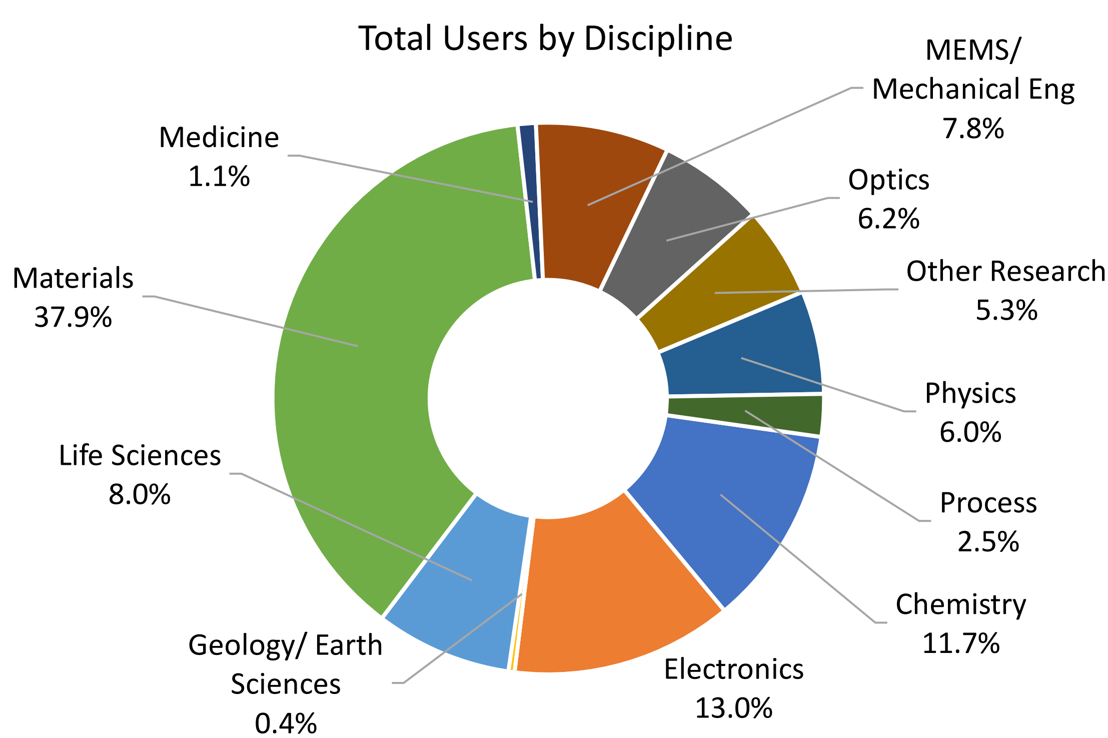
SDNI Site Statistics

Yearly User Data Comparison							
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Total Cumulative Users	650	644	692	653	539	528	562
Internal Cumulative Users	495	478	518	503	405	371	397
External Cumulative Users	155 (24%)	166 (26%)	174 (25%)	150 (23%)	134 (25%)	157 (30%)	165 (29%)
Total Hours	47,893	50,497	49,519	69,367	53,667	61,111	65,051
Internal Hours	40,890	38,890	39,372	56,393	41,316	44,969	45,279
External Hours	7,003 (15%)	11,607 (23%)	10,147 (20%)	12,974 (19%)	12,352 (23%)	16,142 (26%)	19,773 (30%)
Average Monthly Users	290	285	300	296	229	234	260
Average External Monthly Users	49 (17%)	56 (20%)	54 (18%)	50 (17%)	46 (20%)	53 (23%)	63 (24%)
New Users Trained	183	210	225	202	169	152	152
New External Users Trained	34 (19%)	50 (24%)	46 (20%)	40 (20%)	36 (21%)	18 (12%)	18 (12%)
Hours/User (Internal)	83	81	76	112	102	121	114
Hours/User (External)	45	70	58	86	92	103	120



SDNI Year 7 User Distribution





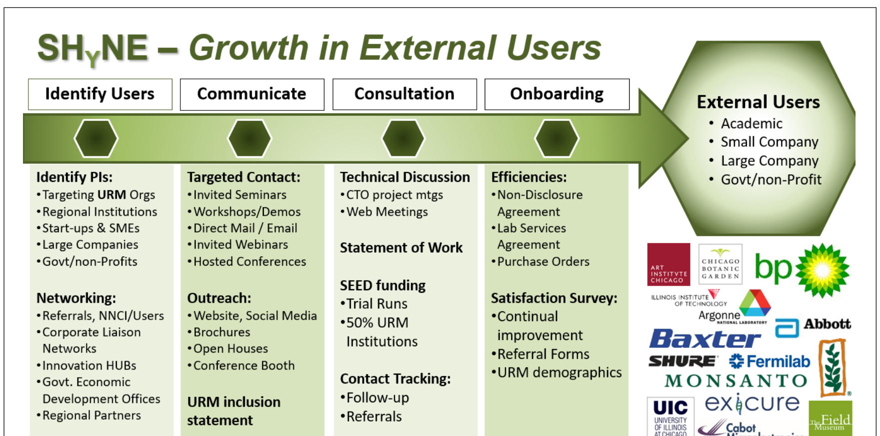
12.13. Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

A joint venture between Northwestern University and University of Chicago, SHyNE Resource represents the Midwest within the NNCI, providing researchers from academia, non-profits, government, and companies large and small with access to world-class 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).

Facility, Tools, and Staff Updates

SHyNE facilities are actively engaged in acquiring and upgrading key equipment within the facilities through a combination of internal and external funding mechanisms. In total, more than **20 new instruments** and numerous tool upgrades were installed in Year 7. **NUFAB**: Raith Voyager 50kV, Osiris Acid Bench, Osiris Spinner Bench; **NU*ANCE*:** Thermo Pathfinder Mountaineer System, IONTOF ToF-SIMS, Protochips Atmosphere, JEOL JIB-4700 FIB/SEM, JEOL JEM 1400 TEM, Gatan OneView Camera, Protochips Axon, Gatan Rio detector, Gatan Moreno, Gatan Elsa, **IMSERC:** Agilent 6230 LC/TOF, Agilent 6130 Quadrupole LC/MS, CryoStar NX70; **Cohen XRD:** Xenocs SAXS system upgrade, Rigaku Ultima 3; **SQI**: Agilent 6230 TOF LMC, **NUCAPT:** CAMECA VCTM, Leica EM VCT500 Vacuum Cryo Transfer system, **PLD:** PVD Linear Shutter, Pfeiffer Vacuum, HPA 250 Residual Gas Analyzer, Micro Photonics HD-25. Maintaining an active and engaged user base for SHyNE facilities is contingent upon the successful recruitment and retention of high-quality staff. Several new staff joined the SHyNE team in Year 7, two of whom are in newly created positions, and many receive partial funding through NNCI. **NUFAB:** Scott Kreager, Core Engineer; **NU*ANCE*:** Kelly Parker, BioCryo Research Associate; Ruari McDonnell, Senior Program Coordinator; Nicholas Gogola, EPIC Assistant Core Scientist; Krysten Villalon, EPIC Core Scientist; **IMSERC:** Nathaniel Barker, Research Associate. **PNF**: three new staff members, new high-speed direct-write optical lithography installed, with plans for two new instruments.

User Base



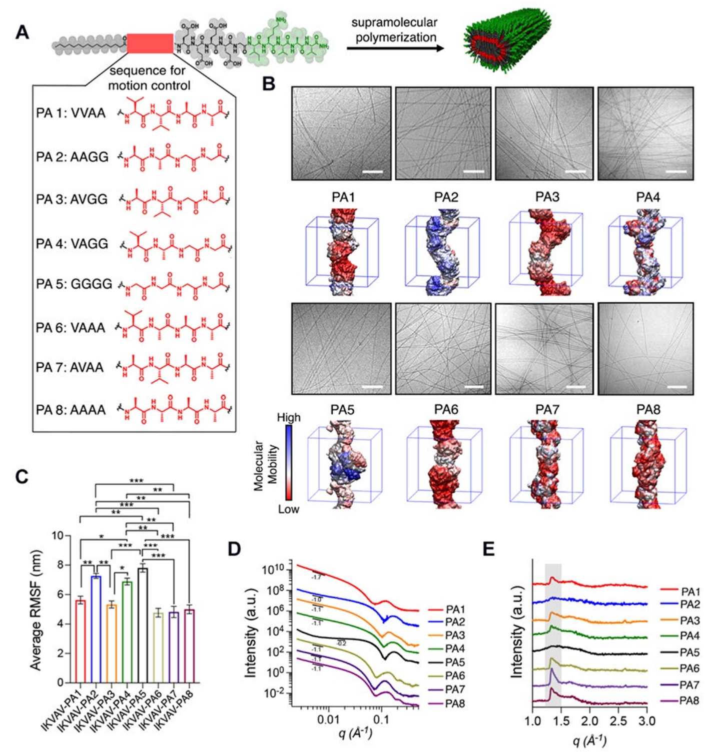
Schematic of SHyNE approach to meeting NSF-NNCI program goals.

SHyNE facilities in Year 7 served nearly **1700 unique users** who logged nearly **180,000 hours** of instrument time generating **$5.4M in revenue**. Northwestern and UChicago shut down in the spring of 2020 for nearly 3 months in response to the novel coronavirus pandemic; Year 7 utilization numbers indicate a full return to pre-pandemic activity. External users this year represented 15% of total users and revenue, a significant increase over Year 1 and another step toward hitting our steady-state goal of 20%. PNF/UC is beginning to see high external users with post-pandemic outreach.

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 communication strategies including: exhibitions at conferences and trade shows, production of web portals, marketing videos and promotional materials, networking with alumni, coordination with university-wide corporate engagement and media relations offices, and an active social media presence. In Year 7, 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 Professor Brian Chaplin at University of Illinois at Chicago, and early-stage startups Fonase, and Caporus. In Years 8-10, SHyNE will continue to focus on recruiting additional external academic, industry, and government users through an active marketing campaign and expansion of our SEED program.

<u>Research Highlights and Impact</u>

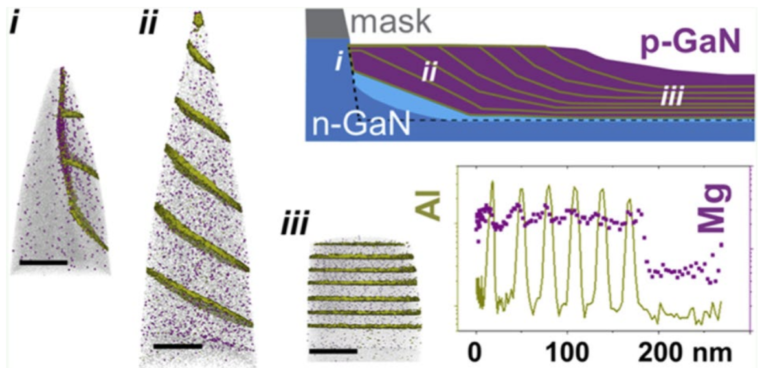
The Peptide Synthesis Core (PS Core) staff worked together with Stupp group of SQI on a groundbreaking study developing materials for a new injectable therapy that harnesses “dancing molecules” to reverse paralysis and repair tissue after severe spinal cord injuries. The peptide amphiphiles (PAs) that self-assemble into peptide fibril scaffolds were enhanced with two signaling peptide sequences designed to promote nerve regeneration: one that reduces glial scarring and another that induces blood vessel formation. By mutating the peptide sequence of the amphiphilic monomers in nonbioactive domains, the motions of molecules within the scaffold fibrils were intensified. The mutation with the most intense dynamics resulted in corticospinal axon regrowth and myelination, functional revascularization, and motor neuron survival. The PS Core staff synthesized, purified, and characterized a library of peptide



*(A) Specific chemical structures of IKVAV PA molecules used and molecular graphics representation of a supramolecular nanofiber displaying the IKVAV bioactive signal. (B) Cryo-TEM images of IKVAV PAs in the library and their corresponding color-coded representation of RMSF values for single IKVAV PA filaments. (C) Bar graphs of the average RMSF values of the different IKVAV PA molecules (error bars correspond to 3 independent simulations; *P<0.05, **P<0.01, ***P<0.001, one-way ANOVA with Bonferroni). (D) SAXS scattering patterns and (E) WAXS profiles of the different IKVAV PA nanofibers (the scattering intensities were offset vertically for clarity; the Bragg peak corresponding to the β-sheet spacing around 1.35 Å is framed in a gray box). Scale bars: 200 nm.*

amphiphiles (PAs) for the study. The PAs were freeze-dried and further analyzed at ANTEC.

Nonplanar GaN p−n junctions formed by selective area regrowth were analyzed using pulsed laser atom probe tomography. Dilute Al marker layers were used to map the evolution of the p-GaN growth interface, enabling extraction of time-varying growth rates for nonpolar, semipolar, and polar surfaces from the trench edge to the center, respectively. The Mg dopant concentration is facet dependent and varies inversely with the growth rate for the semipolar facets that grow rapidly away from the trench sidewalls. The negligible growth on the vertical sidewall of the trench coincides with an order of magnitude higher Mg concentration and substantial clustering of likely inactive dopants. A high Mg concentration is also observed near the regrowth interface of polar and semipolar planes, which we attribute to etching damage. We conclude that device fabrication processes employing selective area regrowth on nonplanar interfaces should consider both the spatial and temporal dependencies of growth rate that lead to nonuniform doping and explore growth conditions that could reduce variations in growth rate when nonuniform doping would adversely affect device performance.



APT reconstructions from selected regions (i), (ii), and (iii) in nonplanar GaN p−n junctions. Ga atoms are shown as gray dots, and Mg atoms are shown as purple spheres. Regions in which xAl > 0.4 atom % are delineated by dark-yellow isosurfaces . Scale bars are 50 nm.

Education and Outreach Activities

Educations and Outreach are critical part of SHyNE's mission and include academic courses with laboratory components, monthly user meetings, REU & RET programs, hands-on workshops, seminars, vendor symposia/demos, facility tours/demos (K-12, higher-ed, public), nano-journalism and related web and social media communications. In Year 7 we held several major workshops and lectures, assisted with **25 courses**, hosted **30+ seminars and exhibitions** and provided tours for **academic, international, and industry participants**. SHyNE sponsored **five REU students** in a unique, facilities-oriented REU program that exposed undergraduates to advanced instrumentation as a key component of their projects. This year, SHyNE also participated in a new 10-week paid internship with Chicago State University and the Office of Research and hosted intern, Ebony Banks. Over 25 workshops and demos were held, including a Special Topics in SEM and Microanalysis 2-day Workshop with Oxford Instruments and Hitachi. SHyNE continued its partnership with **Science in Society (SiS)**, a Northwestern University research center dedicated to science education and public engagement, through the collaborative Magnifying Minds Program. The program partners with urban K-12 teachers, administrators, and youth development agencies to create high-quality, long-term, impactful science learning opportunities for underserved youth. SHyNE also hosted the Midwest Microscopy & Microanalysis Society Spring meeting, iNano Spring Meeting, Career Day for Girls, and the 2nd Annual Women In Microscopy Conference. This event, hosted virtually by SHyNE and the MSA Student Council, highlighted the work of female researchers, product specialists, and laboratory managers from universities, national labs, and microscope vendors with almost 200 attendees from over 25 different countries. SHyNE continues its *Nano-Journalism* program with School of

Communications PhD student & science content producer, Mohammad Behroozian. Mohammad is creating educational video content to excite youth about nanoscience and nanotechnology. In an effort to extend our presence in **social media** and engage with the broader community, SHyNE has launched successful campaigns including our "Women in Nano" campaign which occurs annually in addition to a new Earth Day week-long campaign highlighting SHyNE facility users who focus on environmental research.

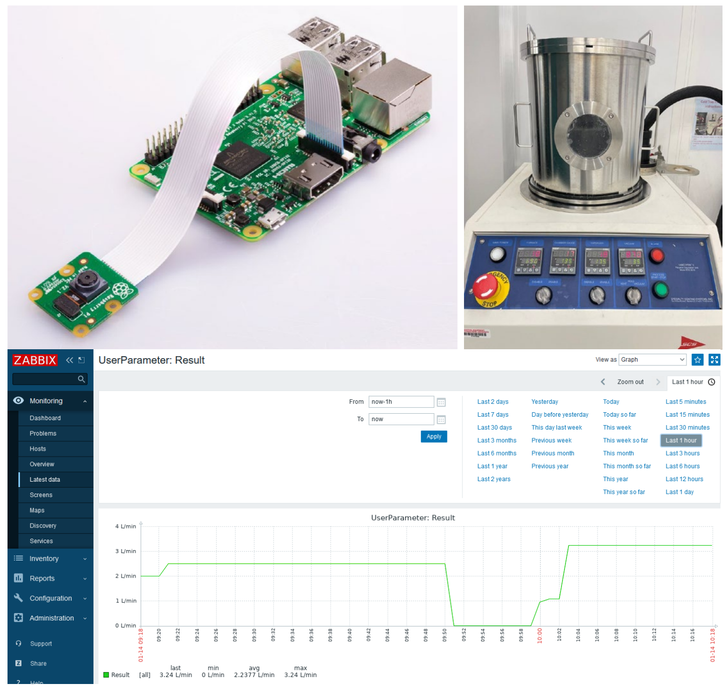
2022 Chicago State undergraduate Intern, Ebony Banks, training with SHyNE science staff, Eric Roth, on 200kV TEM.

SHyNE Resource, collaborating with Northwestern's Medill School of Journalism and the School of Communication, has established a novel Nano-Journalism focus within the existing Health, Environment and Science Journalism program. In 2019, we were excited to Mohammad Behroozian join the team! Mohammad is a PhD student in Northwestern University's School of Communication working with Dr. Ellen Wartella's Children, Media and Human Development Lab, Mohammad studies educational media for wartime to inform productions for children living in warzones. He joins SHyNE as a Nanoscience journalist and content producer, responsible for creating educational content to excite youth about nanoscience and nanotechnology. Mohammad is currently producing two videos to highlight the OHM (Oleophilic, Hydrophobic Multifunctional) sponge with great potential for managing oil spills and environmental remediation, more broadly. He also began a series of short video interviews created for social media to discuss and highlight NU*ANCE*'s "Art of Science" Image contest winners and the science and thought behind winning entries. This series will also be expanded to include educational content for outreach to middle-school students.

Computation Activities

Computational Imaging Efforts in S/TEM at NU*ANCE*: The large amount of data produced by novel direct detectors (Gatan K2-IS, K3-IS) recently installed, ~4Tb/hr, can no longer be effectively analyzed by human intuition and experience alone. NU*ANCE*/SHyNE are implementing strategies to improve experiment design, execution, analysis, and data sharing. We have substantially reduced the collection time or radiative dose of conventional electron microscopy experiments. A significant need exists for improved methods of collecting spatially resolved spectroscopic signals at electron doses low enough for the preservation of sensitive structures or subsequent investigation with a correlated technique, and/or for the acceleration of conventional spectrum images for the investigation of spatially confined biological-inorganic complex structures, engineered hybrid soft/hard ordered materials. Through development of "smart" sampling algorithm, we accelerate a low-dose experimental analytical imaging of materials that is applicable to arbitrary S/TEM imaging. In contrast to static sampling schemes or denoising, our method can produce spatially accurate spectrum maps at high speeds/low doses with weakly informative prior information, and no direct processing or manipulation of spectral data (no sparsity constraints). By maximizing the application of electron dose to areas with meaningful information or contrast on-the-fly, this approach may allow for the efficient characterization of radically larger regions of interest or materials/interfaces that are sensitive to accumulated dose.

Equipment and facility predictive maintenance system with artificial intelligence: With the continued advancement of sensor technology, equipment manufacturers are integrating more sensors into the systems to improve their reliability. Recording and interpreting the sensor readings are key when it comes to equipment maintenance and troubleshooting. However, the sensor data is not always accessible and usually can only be understood by well-trained technicians. Based on years of equipment/facility maintenance experience, artificial intelligence and cloud technology, NUFAB's **Ying Jia** has developed a central facility management system to store, display, and analyze the sensor data in real time. This system evaluates the equipment's condition, predicts the future trends, toward maintenance recommendations, and can be monitored remotely, with push notifications to designated facility managers.

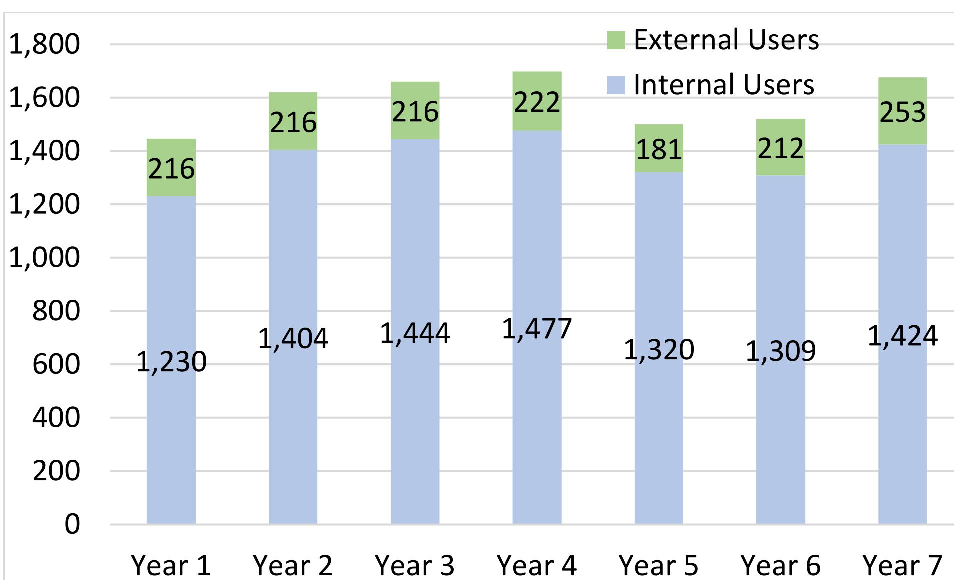


Raspberry Pi with camera feed into Zabbix dashboard and server. Applies Tensor Flow multi-classification image processing algorithm to read vacuum output numbers on tools that cannot be monitored

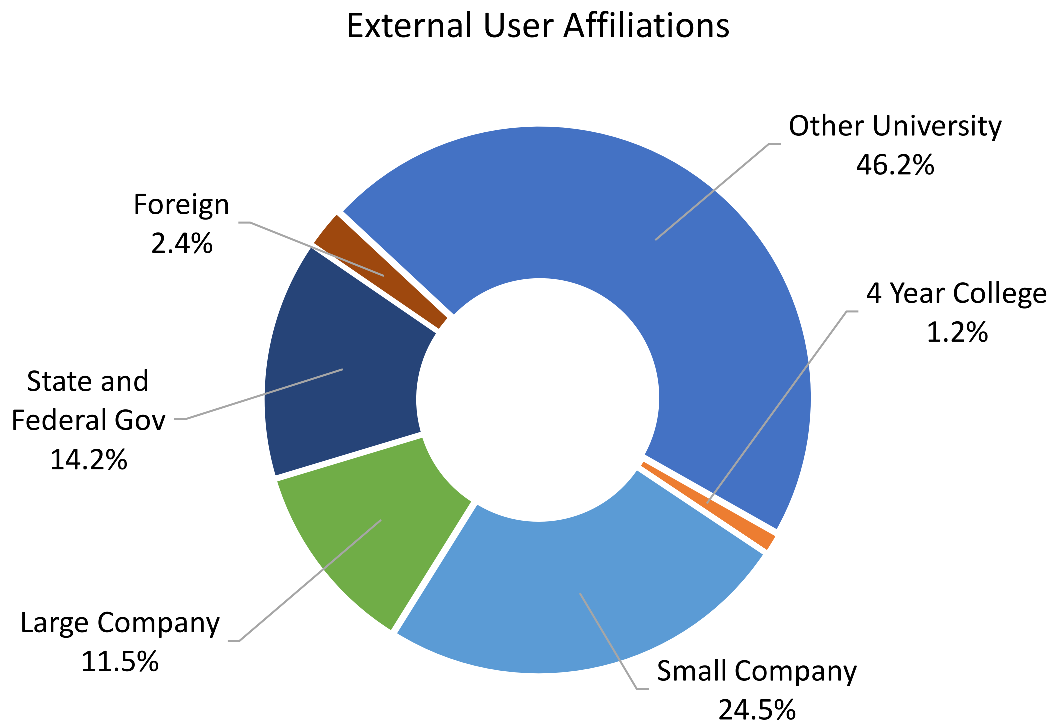
In summary, SHyNE/NU*ANCE* implementations are synchronized with the rise of artificial intelligence ecosystems and associated machine learning algorithms to accelerate innovation in a wide variety of scientific disciplines. We expect that in the coming years, the latest data analysis tools and techniques will gain a greater foothold into facility environment and revolutionize this environment in ways that leave it better positioned to address major scientific challenges.

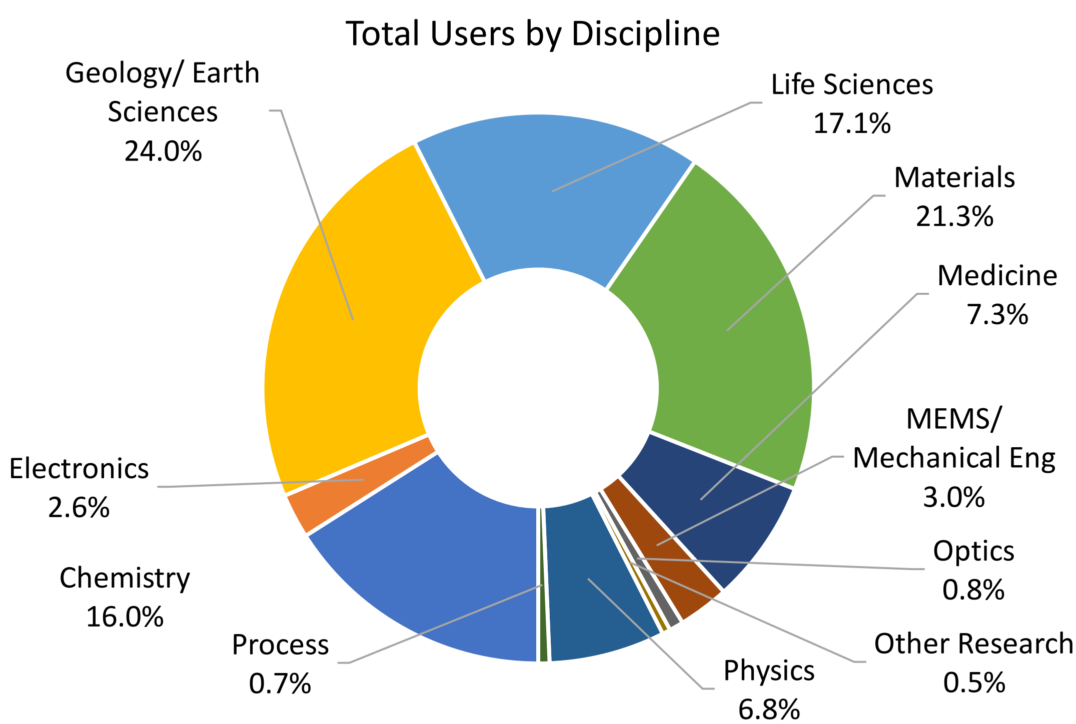
SHyNE Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	1,446	1,620	1,660	1,699	1,501	1,521	1,677
Internal Cumulative Users	1,230	1,404	1,444	1,477	1,320	1,309	1,424
External Cumulative Users	216 (15%)	216 (13%)	216 (13%)	222 (13%)	181 (12%)	212 (14%)	253 (15%)
Total Hours	138,000	132,673	137,375	202,844	139,175	159,720	179,802
Internal Hours	128,838	127,127	131,206	192,434	132,177	150,425	167,794
External Hours	9,162 (7%)	5,545 (4%)	6,169 (4%)	10,410 (5%)	6,998 (5%)	9,294 (6%)	12,008 (7%)
Average Monthly Users	679	802	797	829	606	693	759
Average External Monthly Users	54 (8%)	54 (7%)	52 (7%)	61 (7%)	41 (7%)	54 (8%)	61 (8%)
New Users Trained	699	698	605	649	340	597	649
New External Users Trained	152 (22%)	140 (20%)	86 (14%)	120 (18%)	66 (19%)	121 (20%)	137 (21%)
Hours/User (Internal)	105	91	91	130	100	115	118
Hours/User (External)	42	26	29	47	39	44	47



SHyNE Year 7 User Distribution





12.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Facility, Tools, and Staff Updates

SENIC continues to facilitate the "3 universities, 2 locations, 1 site" mindset and partnership between the Georgia Tech Institute for Electronics and Nanotechnology (IEN) and the Joint School of Nanoscience and Nanoengineering (JSNN). Our strategic goals, as developed with the help of our advisory board and expressed in our NNCI renewal proposal in 2020, are to (1) develop and serve a diverse user base, (2) develop strong synergies between partners, (3) expand capabilities based on future research trends, (4) develop education and outreach and societal and ethical implications programs targeting the SE, and (5) assist the NNCI Network in becoming more than the sum of its parts.

During Year 7, the IEN Micro/Nano Fabrication Facility hired 3 new staff members: a Process Equipment Engineer II to support ALD, micromachining, and 3D printing capabilities, a Process Equipment Engineer I for biocleanroom operation, equipment maintenance, training, and user support, and a Laboratory and Facilities Coordinator to support laboratory fit-up, routine operation, material inventory and day-to-day support of research users, staff, and faculty. Renovations underway in the Pettit Microelectronics Building include adding water sprinklers to the cleanroom level and surrounding spaces to bring them into building code compliance as well as planned changes for upgrading the acid neutralization system. We have also continued renovating cleanroom space to relocate advanced packaging and photovoltaics research activity into the Pettit Microelectronics Building cleanroom. Georgia Tech conducted a feasibility study for completion of the remaining shelled-out cleanroom space (8,500 sq. ft.) on the first floor and additional space (4,000 sq. ft.) in the basement of the Marcus Nanotechnology Building, which will help with consolidation of the cleanroom toolset and provide additional spaces for educational activities and classified research projects. Finally, Georgia Tech conducted a feasibility study for a new building adjacent and connected to the current Marcus Nanotechnology Building that would support research with a 200 mm toolset and complimentary labs and offices.

JSNN continued to strengthen its administrative and technical support, with the creation of the Joint School's Institute for Research Technologies (JSIRT) in Spring 2022. The purpose of the Institute is to accelerate research and innovation through state-of-art research facilities, and collaborative partnerships with industry driven by the brainpower of the JSNN faculty. The Institute will serve as a hub for convergence research strengthened by industry partnerships and academic expertise. As part of the JSIRT implementation, access to tools, resources and service requests are being transitioned to Facility Online Manager (FOM). FOM@JSNN, an online equipment, resources, and accounting management software, became available for all users starting in April 2022. JSRIT technical support team provides user consultation, training, process and characterization support, remote jobs, and data analysis, if requested by the user. Moreover, JSNN has created special project spaces to address industry users' specific needs.

During the past project year, SENIC has continued to add new tools/capabilities and upgrade existing tools at both Georgia Tech IEN and JSNN. Decisions regarding tool purchases and upgrades are informed by the annual NNCI user survey, dedicated equipment need surveys and questionnaires, as well as input from conferences and workshops. University support of core facility equipment benefits the goals of SENIC and NNCI in making state-of-the-art nanofabrication and characterization tools accessible to a broad and diverse user base. New tool purchases and upgrades this past year included:

New Tools:

- Keyence VK-X3000 3D Surface Profiler
- Disco 3360 Dicing Saw
- Veeco Fiji G2 Atomic Layer Deposition
- Thermo Fisher Helios FIB/SEM
- Thermo Fisher Chemi-SEM Variable Pressure SEM
- Nikon X-Ray Computed Tomography CT XT H225 ST2x (NSF MRI)
- JEOL JSM-IT800(HL) FE SEM (USDA NIFA-EGP)
- Oxford FlexAL Atomic Layer Deposition
- Kurt J. Lesker ALD150LX Atomic Layer Deposition
- Suss MA/BA8 Gen4 Mask Aligner
- AJA ATC-2200-UHV Sputterer
- Plasma-Therm HDPCVD Chemical Vapor Deposition
- Plasma-Therm Versaline ICP SiC Etching System
- SSI Solaris 150 Rapid Thermal Processing
- Optec WS Flex IR Femtosecond Laser Micromachining System
- WITecalpha300r Confocal Raman
- Evident FV3000 Laser Confocal Microscope
- Beckman Cytoflex Flow Cytometer
- Other support and analytical tools including Ultramicrotome, ICP-MS, UPLC, GC-MS, UV-Vis-NIR, FTIR, BET, TGA

Tool Upgrades:

- EVG 520 Wafer Bonder
- Heidelberg MLA150 Maskless Lithography
- Nanoscribe GT2 3D Printer

User Base

User growth, particularly from non-traditional areas that have not used nanotechnology core facilities in the past, requires dedicated marketing and outreach programs. Since the start of the NNCI, SENIC has streamlined its user recruitment efforts based on feedback from the annual user survey on how users learn about SENIC and sharing of best practices among sites. In 2018, the NNCI subcommittee on "Building the User Base" identified awareness, accessibility and affordability as the three key limitations for growing the user base. To create SENIC **awareness**, we use websites, SENIC newsletter, social media presence, and visits to universities and companies in the southeast, particularly along the I-85 corridor. To facilitate these visits, we recruit current and past users at these institutions as "SENIC Ambassadors" who assist with organization and local promotion. To target the **accessibility** challenge, we continue to provide remote work capabilities, where staff perform the work on behalf of the user rather than the user doing the work on site. Seed grant programs seek to address the **affordability** challenge, and SENIC continues to support the IEN Facility Seed Grant Program and the Catalyst Program.

Marketing of SENIC continued through the website as well as promotional and communication efforts through email and social media, with SENIC-specific efforts on Facebook, LinkedIn, and Twitter. A quarterly SENIC newsletter, initiated in 2018, is emailed to over 3,000 current and potential users along with other stakeholders. Year 7 issues were sent in December 2021, and March, June, and September 2022. The SENIC website (http://senic.gatech.edu/) was updated with new content, including the latest information on education and professional development activities such as the RET program, Summer Institute for Middle School Teachers, seminars, and hands-on user short courses.

In support of its vision to strengthen and accelerate discovery in nanoscience and nanoengineering across the US, the SENIC Catalyst Program provides researchers limited (up to $1,000) free access to the SENIC facilities to aid in research, obtain preliminary data, conduct proof-of-concept studies, or for educational purposes. During Year 7, new Catalyst awards were made to researchers from Clemson University, University of Florida, Clark Atlanta University, Berry College, and Wake Forest University. Since the start of the program in 2019, 33 projects have been funded.

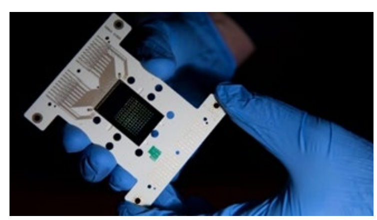
As stated in our renewal proposal, SENIC is exploring an expansion of our relationship with the Center for Nanophase Material Science (CNMS) at Oak Ridge National Laboratory (ORNL). In particular, we have begun to develop a pathway for joint user/project support, where a SENIC user can get easy access to ONRL resources not available in SENIC facilities and vice versa. The first step in this process was an exchange of visits by facility staff to Georgia Tech and CNMS in October 2022.

During this past year of the NNCI program (Oct. 2021 - Sept. 2022), the SENIC facilities have served 1,301 individual users, including 266 external users (29% growth since Year 5) representing 86 companies, 21 colleges and universities, and 13 other institutions, including pre-college schools. Several users have accessed capabilities at both SENIC locations with minimal difficulty. Most users access the facilities on-site, although 175 users obtained services remotely, and some users operated in both on-site and remote fashions. Monthly users averaged 563 (a 51% increase compared to Year 5), and on average 42 new users were trained each month (505 total during the reporting period).

Research Highlights and Impact

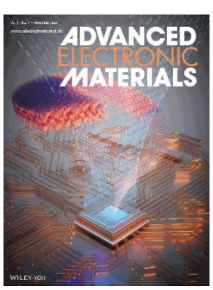
Notable new academic users of the SENIC facilities this past year come from Wingate University, while new industry users include Micromize, Andson Biotech, Saras Microdevices, Chemical Insights Research Institute, Berkshire, and Elevate Textiles, to name a few. Some example research highlights include:

Growing DNA for Archival Data Storage (N. Guise, Georgia Tech Research Institute)



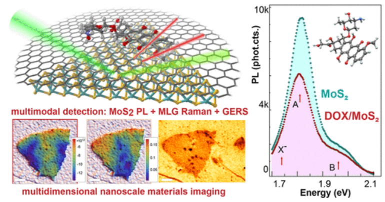
Researchers at GTRI, in collaboration with companies Twist Bioscience and Roswell Biotechnologies, have made significant advances in developing a microdevice for growing strands of DNA that would be used for high-density, low-cost, archival data storage. This work is part of the Scalable Molecular Archival Software and Hardware (SMASH) project, supported by the Intelligence Advanced Research Projects Activity (IARPA) Molecular Information Storage (MIST) program.

Promising Material for Computer Memory (J. Kacher, N. Bassiri-Gharb, and A. Khan, Georgia Tech)



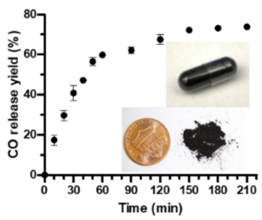
Antiferroelectrics have potential applications in modern computer memory devices where they have been shown to have greater energy efficiency and faster read and write speeds than conventional memories. An interdisciplinary team of Georgia Tech researchers (ME, MSE, and ECE) has discovered promising behavior in zirconium dioxide. This work was supported by the National Science Foundation, the Semiconductor Research Corporation, the Defense Threat Reduction Agency, the European Regional Development Fund, and ANID FONDECYT in Chile and was published in *Advanced Electronic Materials*.

Multidimensional Imaging for Multimodal Label-free Biosensing (S.V. Rotkin, Penn State, S. Aravamudhan, NCA&T, T. Ignatova, UNCG)



Researchers have developed a multidimensional optical imaging technique to map subdiffractional distributions for doping and strain and understand the role of those for modulation of the electronic properties of a material. The work was funded by the National Science Foundation and published in *ACS Nano*.

Activated Charcoal-based Formulation for Oral Delivery of Carbon Monoxide (B. Wang, Georgia State University and C. Tan, University of Mississippi)



A novel orally bioavailable solid formulation to deliver the gaseous signaling molecule carbon monoxide (CO) was created. The solid dispersion formulation addresses key issues for delivery of the CO prodrug oxalyl saccharin. This work was supported by the National Institutes of Health and published in *Int. J. Pharm.*

Scholarly impact can be measured indirectly with more than 600 publications, presentations, and patents benefiting from SENIC facilities in CY2021. Using a Google Scholar search, approximately 250 of these 2021 publications (and more than 800 publications 2015-2021) acknowledged the SENIC NSF award number. Furthermore, the SENIC SEI program produced an analysis of 1500+ publications (2016-2020) demonstrating diverse collaborations and enhanced research impact (see more below).

SENIC facilities supported multiple laboratory courses from Fall 2021 to Summer 2022. The Georgia Tech cleanroom supported 5 courses from Mechanical, Electrical and Computer, and Chemical and Biomolecular Engineering, while 3 more courses from Materials Science and Engineering were supported by the Materials Characterization Facility. JSNN facilities support an additional 8 courses for graduate students in Nanoscience and Nanoengineering. These courses had nearly 300 students enrolled. Over the academic year from Fall 2021 to Summer 2022, more than 330 degrees were awarded to current or former SENIC users at Georgia Tech and JSNN: 75 Bachelors, 106 Masters, and 147 Doctorates.

Additional impact of SENIC is indicated by centers and other large programs that are enabled by the supported core facilities. In 2021, NSF named Georgia Tech the lead institute of a new Industry-University Cooperative Research Center (IUCRC) titled **Electronic-Photonic Integrated Circuits for Aerospace (EPICA)**. Integrated photonics is a key enabling technology in the commercial, defense, and scientific sectors, and aerospace and spaceborne applications present unique challenges due to the extreme environments in which devices must operate. EPICA was proposed by faculty from the Georgia Electronic Design Center (GEDC), a center within the IEN, which utilizes SENIC facilities. JSNN and the U.S. Army Combat Capabilities Development Command (DEVCOM) Soldier Center created a joint program called **Innovation Collaborative Laboratory for Nanotechnologies to Empower the Future Soldier (ICONS)** to develop technologies, including sustainable materials and sensors, for soldier protection. In addition, using funding from a DOE Energy Frontier Research Center (EFRC) grant, North Carolina A&T State University opened a new center called **Center for Electrochemical Dynamics and Reactions on**

Surfaces (CEDARS) to work on splitting hydrogen and oxygen from water to produce clean hydrogen for energy use.

While economic impact can be difficult to quantify, select examples from Year 7 indicate that SENIC-supported startup companies are achieving success:

- **Carbice Corp.**, a Georgia Tech startup which develops carbon nanotube technology for electronics cooling, opened its first manufacturing facility (23,000 square feet) in Atlanta in August 2022.
- A new startup company from Georgia Tech, **Andson Biotech**, is hoping to make the development and production of gene and cell therapies easier and faster. The company, created based on research in the lab of Prof. Andrei Fedorov (ME), is a partnership with the NSF ERC Center for Cell Manufacturing Technologies (CMaT), and is also backed by the Y Combinator accelerator.
- **BioCircuit Technologies** (a spinoff from **Axion Biosystems**) received a 5-year $4.6 million award from NIH shared with partnering laboratories at the Medical University of South Carolina and the National Center for Adaptive Neurotechnologies at the Stratton VA Medical Center in Albany, NY.

Education and Outreach Activities

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 5,800 individuals from young children to adults. The COVID-19 pandemic continues to affect the programming being offered with the number of people reached still less than pre-pandemic numbers.

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 2 students underrepresented in biomedical sciences a research opportunity, focused workshops, and courses to prepare them for graduate school. JSNN also hosted 2 interns this past year from Forsyth Technical Community College's Nanotechnology and Biotechnology programs as well as 2 additional interns during the summer of 2022 from Alamance Community College's Biotechnology program. In addition, JSNN provided research training to five incoming NC A&T undergraduates in microfluidics and biomedical applications, as part of the NIH-funded ESTEEMED program. Georgia Tech, inspired by JSNN's programs, started their own paid, technical college internship in spring 2020, with the first students participating in 2022. IEN has established a strong relationship with the Technical College System of Georgia and has hosted visits by faculty and students. In addition, IEN hosted four high school interns to assist with the RAIN network providing virtual access to local students. Due to a lapse in funding, the Southeastern Undergraduate Internship in Nanotechnology at Georgia Tech was not held during summer 2022; a proposal for further REU funding is currently pending at NSF. In addition to internships, SENIC provides opportunities to undergraduates to work in the facilities as student assistants.

Each academic year, JSNN hosts a weekly seminar and IEN hosts a bi-monthly seminar series entitled Nano@Tech, held in-person with live streaming on YouTube. JSNN also hosts a virtual journal club. Georgia Tech's NanoFANS Forum, a biannual symposium at the intersection of life sciences and nanotechnology, was held in October 2021 (“Organ-on-a-Chip Technology”) and May 2022 (“Micro- and Nanotechnology Commercialization: Opportunities and Challenges”).

SENIC has been active in providing outreach to K-12 students, educators, and the general public. SENIC at Georgia Tech is the lead site (with MINIC, SHyNE, and NNF) of the NSF-supported Research Experiences for Teachers across the National Nanotechnology Coordinated Infrastructure collaborative program. The second cohort of this program was held during summer 2022. In addition to research, all of the teachers participated in regular virtual meetings and a nano-careers webinar series featuring industry speakers who are also users of site facilities. The summer 2022 Nanotechnology Summer Institute for Middle School Teachers (NanoSIMST) program was held in-person at Georgia Tech with a cohort of 15 teachers from across Georgia who participated in 6 hours/day of instruction for 5 days. Teachers also participated in a cleanroom tour, listened to guest speakers, and alumni of the program shared their implementation strategies. Through an ongoing partnership with the Guilford County School System, JSNN provided professional development sessions to middle school and high school science teachers. We continued to offer remote sessions to students and teachers with the Hitachi SEM through May 2022. As schools and community groups began to reopen from the pandemic, we began "Rise to Nano" sessions for local schools and community organizations. We also opened the facility to host a Boy Scouts Nano Night and the Find Your STEM conference for girls. "Rise to Nano" sessions and open facilities for school and community groups have continued into the fall of 2022. In July 2022, JSNN hosted the ExPlorers Program for 17 underrepresented high school students and 4 high school teachers. This was a week-long program involving interactive hands-on experiences with the nanoscale, applications of nanotechnology, phosphorus sustainability, agriculture, and ethics in science. Georgia Tech is continuing to offer virtual hour-long class trips for middle and high school students. Staff are invited to join a teacher’s virtual classroom and present an introduction to nanotechnology with demonstrations and hands-on activities; teachers receive the materials prior to the virtual class trip. This past summer, Georgia Tech IEN staff also assisted with Chip Camp, a program created by Micron Technologies to introduce 8^{th} and 9^{th} grade students to semiconductor manufacturing. In October 2022, JSNN hosted a Nanotechnology Day Celebration with STEM demonstrations for K-12 students, the NanoImpacts Conference 2022 (“Semiconductor Synthetic Biology and Beyond”), and an Undergraduate Research Symposium for STEM majors.

Societal and Ethical Implications Activities

The aim of the SEI work at SENIC is to develop tools and techniques to measure the impact of SENIC on societal sectors. The results are designed to provide SENIC with information about its impact and facilitate use across the network by forming the basis for toolkits that other NNCI sites can use to replicate this work. In Year 6, we completed and distributed two impact toolkits: “Economic Impact of NNCI-Funded Nanofabrication and Characterization Facilities: A Case Study and Toolkit” and “Mapping Research Outputs: A Case Study and Toolkit.” The latter presented a method for analyzing Web of Science publication records linked to NNCI sites through the NNCI grant number and applied this to a case study of 444 SENIC publication records. During Year 7, a larger study, looking at 1,644 publications (2015-2020) provided by SENIC users as part of our annual data collection, was conducted. This analysis was recently published in the “Journal of Nanoparticle Research” (24:243, 2022) and established that, compared to the overall field of nanoscience and nanotechnology, SENIC authored work is more collaborative, more heavily viewed and downloaded, and more highly cited.

Towards the end of year 7, work began on the next phase of SEI analysis at SENIC. This analysis will explore where in the economy the skills developed through users' research work at SENIC are deployed. We are using LinkedIn and other sources to find the current professional affiliations of current and past SENIC users. This will establish the breadth of SENICs impact across industries and around the country. Again, we will develop a case study and toolkit that other NNCI sites can use to replicate the analysis to make visible their broader societal impact.

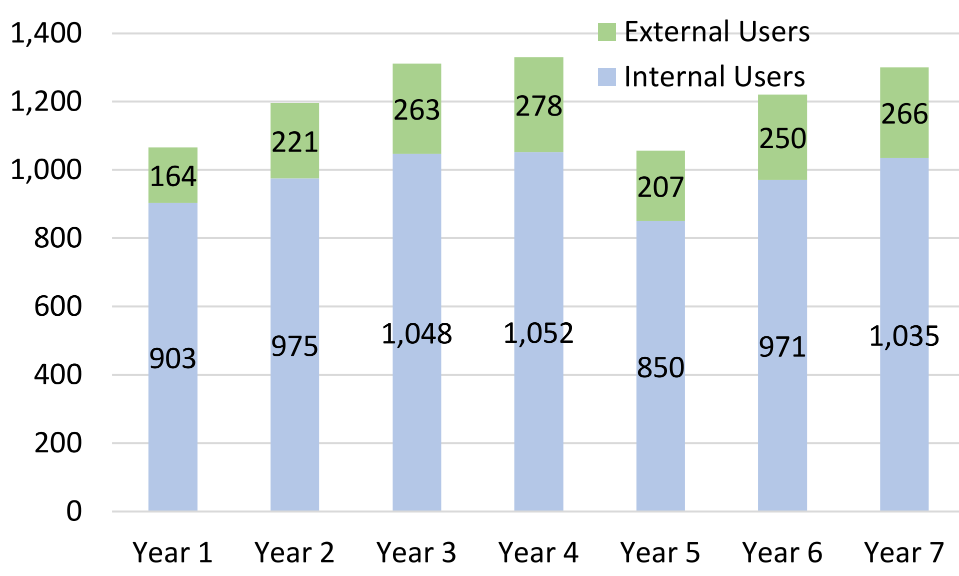
Innovation and Entrepreneurship Activities

SENIC participated in the first NNCI network-wide Nanotechnology Entrepreneurship Challenge (NTEC). SENIC and NanoEarth sponsored a team led by NC A&T State University student Wesley Williams which won the Diversity Award. The project "Molecularly-Imprinted Nanoparticle (MPI) Nanoparticles for the Sensing and Remediation of Toxic Incident Anthropogenically-Derived Nanoplastics in the Hydrosphere" was supervised by SENIC Co-PI Shyam Aravamudhan. In addition, Dr. Paul Joseph is a member of the Innovation & Entrepreneurship working group and also participated in the NTEC showcase event.

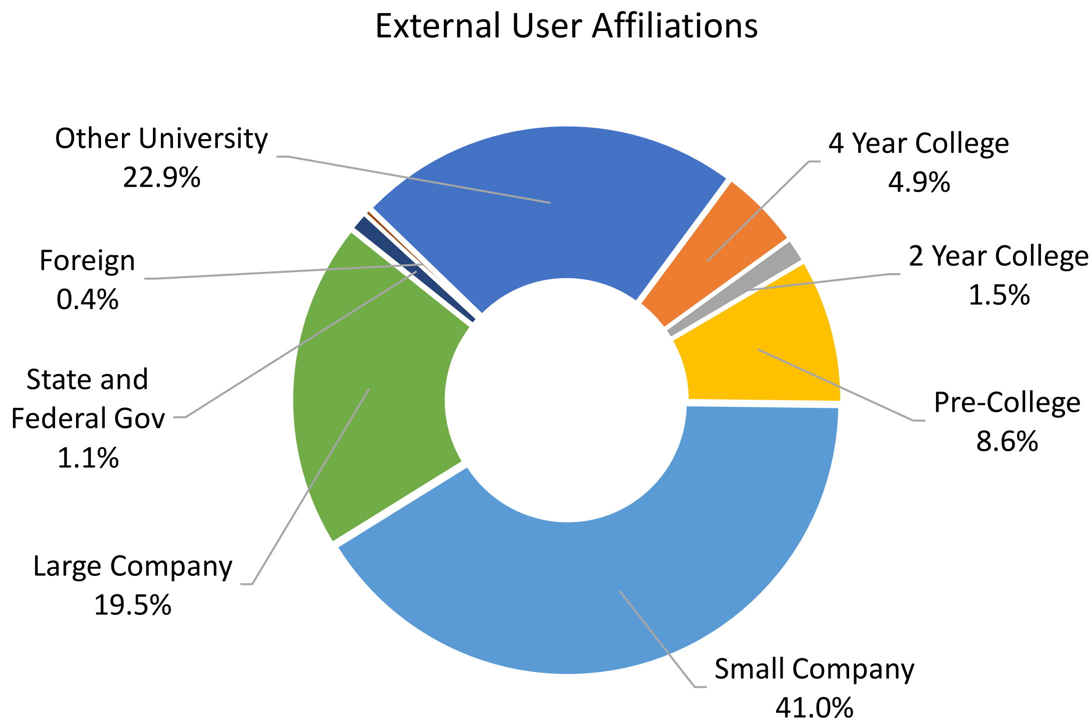
SENIC Site Statistics

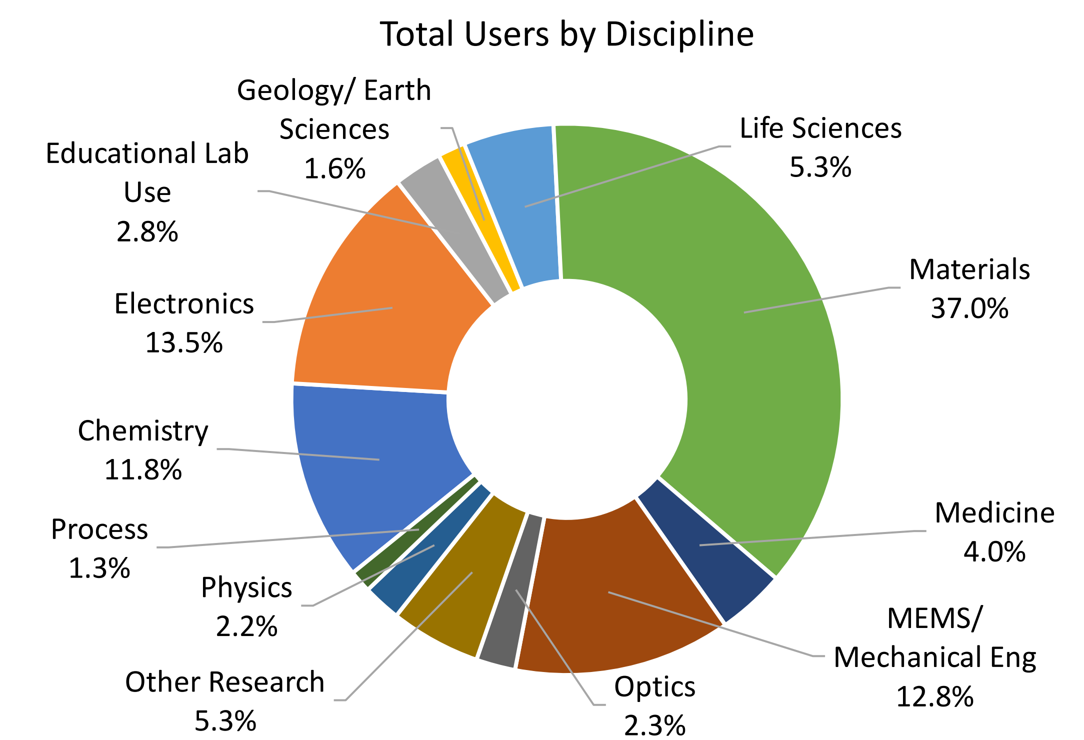
Yearly User Data Comparison	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Total Cumulative Users	1,067	1,196	1,311	1,330	1,057	1,221	1,301
Internal Cumulative Users	903	975	1,048	1,052	850	971	1,035
External Cumulative Users	164 (15%)	221 (18%)	263 (20%)	278 (21%)	207 (20%)	250 (20%)	266 (20%)
Total Hours	79,581	85,275	99,118	101,571	66,611	92,998	109,049
Internal Hours	71,659	73,499	85,730	88,282	58,620	80,751	96,276
External Hours	7,922 (10%)	11,733 (14%)	13,388 (14%)	13,289 (13%)	7,991 (12%)	12,247 (13%)	12,773 (12%)
Average Monthly Users	447	498	546	576	373	499	563
Average External Monthly Users	60 (13%)	63 (13%)	83 (15%)	89 (15%)	51 (14%)	75 (15%)	73 (13%)
New Users Trained	313	313	386	502*	248	453	505
New External Users Trained	67 (21%)	110 (35%)	123 (32%)	132 (26%)	45 (18%)	80 (18%)	124 (25%)
Hours/User (Internal)	79	75	82	84	69	83	93
Hours/User (External)	48	53	51	48	39	49	48

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



SENIC Year 7 User Distribution





12.15. Texas Nanofabrication Facility (TNF)

Facility, Tools, and Staff Updates

The Texas Nanofabrication Facility (TNF) at the University of Texas at Austin (UT) is composed of the Microelectronics Research Center (MRC), the Texas Materials Institute (TMI), and nanomanufacturing fab (nm-Fab). NNCI-TNF has 22,000 sq. ft. of cleanroom space (class 100 and 1000) and 20,000 sq. ft. of labs.

The MRC cleanroom provides extensive nanofabrication capabilities, TMI provides state-of-the-art metrology tools, while the nm-Fab has developed and provides novel nanomanufacturing tools in the areas of roll-to-roll manufacturing (deposition and etch), and high speed, large area nanoimprinting. TNF is well positioned geographically in the Austin high-tech hub, within the Dallas/Fort Worth-Houston-San Antonio triangle, with no competing universities having comparable infrastructure in nanotechnology in this region of the country. Since Texas, in general, and Austin in particular, have a strong industry base in nanotechnology, TNF has a large external user cohort, especially in terms of small companies. We also serve academic institutions in Texas, and the neighboring states. We also have users from other parts of the US, and the rest of the world. We have enabled and fostered breakthrough nano-innovation in the areas of electronics, healthcare and energy, all of which have significant presence in the Southwest, while establishing educational activities in nanotechnology directed at engaging underrepresented minorities (URM), particularly Hispanics and women. We have added two staff members in our cleanroom to assist with new user training and equipment maintenance in the area of plasma and reactive ion etching.

TNF has recently invested heavily in advanced plasma etching, deposition, and metrology tools. The nmFab has installed a novel roll-to-roll atomic layer deposition system on flexible substrates, and a roll-to-roll etch system. A Scios Dual-beam Focused Ion Beam and a JEOL Aberration Corrected TEM funded by Univ. of Texas have been installed. A new JEOL E-Beam lithography 8100 FS system funded by Univ. of Texas has been ordered, and will be delivered in early 2023. The State of Texas has provided 110M$ to upgrade and expand the TNF cleanroom. We will add 10,000 sq. ft. cleanroom space to the facility by 2024. Facilities are being added for heterogeneous integration of CMOS +X devices.

User Base

Work done at TNF has led to approximately 100 high impact papers and patents. TNF has also enabled technology development by 40 small companies, many supported by SBIR and STTR grants from NSF, DoD, etc. Several of these projects address the NSF Big 10 Ideas, or other federal initiatives.

In Year 7, TNF averaged 4,492 total laboratory usage hours per month, and generated revenue of $112,000 per month through user fees. Average laboratory hours and user fee revenue has increased from Year 6. User profiles including demographics and research fields (i.e. disciplines) are reported voluntarily through an online survey by each user during the orientation session. Over half of the TNF users self-declared their research project to be related to Materials (26%), Electronics (18%), or Optics (13%) disciplines. The percentage of External Users in Year 7 is 21%, consistent with Year 6.

Research Highlights and Impact

We share some vignettes showcasing examples of research highlights.

Small Company User (2010-2022): Nanohmics

Nanohmics Inc. developed broadband anti-reflective nanostructures to reduce the reflection losses at optical interfaces in the mid-wave and long-wave infrared spectrum on a variety of IR window materials. A lithography-free manufacturing process was developed to fabricate high-aspect ratio sub-wavelength random anti-reflective surface structures (rARSS) on ZnSe, ZnS, GaAs, Ge, Si, and AMTIR. The key innovations in the process were generating a random metal nanoparticle etch mask and developing reactive ion etch recipes to produce structures with the desired geometry and height. The fabrication process does not depend on lithography and was designed to be applied to optical elements with a wide range in size, and surfaces with varying degrees of curvature. A portion of the work was performed at the UT Austin Microelectronic Research cleanroom facilities, including the dry etching, rapid thermal annealing, and scanning electron microscopy.

Small Company User (2011-2022): Applied Novel Devices (AND) with Skywater (Minnesota)

A new class of Si power MOSFET technology with sub-30um substrate was developed. The technology enables 2x lower output charge (Q_{oss}) and superior specific on-resistance ($SR_{DS(ON)}$) at gate drive as low as 2.5V compared to the state-of-the-art low-voltage (<60V) MOSFETs. Near-zero reverse-recovery charge/losses for all voltage applications is also inherent to the new power MOSFET. Manufacturing with self-aligned and low-complexity process has been established in a high-volume 8-inch Si foundry. Thin-Crystalline Technology is utilized to yield mechanically handleable sub-30um substrate. Finally, the novel device architecture is well-suited for SiC and GaN-like wide-bandgap (WBG) devices as it inherently yields enhancement-mode WBG MOSFETs.

The transfer characteristics of the proposed MOSFET show industry-record, near-ideal subthreshold slope ~ 60mV/dec. This enables low threshold voltage (V_{th}) and superior $R_{DS(ON)}$ at gate drive as low as 2.5V, while maintaining very low leakage current. High density architecture and sub-30nm substrate can yield near-ideal $SR_{DS(ON)}$ even in low voltage-range without the use of split-gate or superjunction architecture. The breakdown voltage characteristics of the new device are also excellent with well-controlled short-channel effects. The drain-source capacitance is essentially eliminated, yielding low output capacitance (C_{oss}) and at least 2x better Q_{oss} Figure-of-Merit (FoM). Without shielding the gate by split-gate or superjunction techniques, the gate-drain capacitance (C_{rss}) or charge (Q_{gd}) of the proposed device is higher and could limit performance in some applications, e.g., high-side MOSFET in hard-switching, high-frequency applications. The elimination of drain-source coupling also enables near-zero reverse recovery losses without noticeable impact to diode/third-quadrant turn-on voltage. This can be a major benefit in high power applications and can eliminate external Schottky diodes.

Small Company User (2015-2022): GraphAudio

GraphAudio 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. Work included optimizing baseline graphene process flow to further improve reliability, reproducibility, yield and performance of our 16mm-diameter, multilayer graphene diaphragms for audio speaker applications. A total of 178 16mm transducer engineering samples were fabricated, assembled and delivered to potential customers for evaluation. Work focused on demonstrating feasibility of novel graphene-based transducers for applications in acoustic sensing, micro-speakers, microphones and ultrasonic transducers in mobile, consumer and enterprise electronics. Recent work included process development activities to optimize graphene growth and related Ni anneal and Ni etch processes. To eliminate unwanted surface roughness in large-area (16-20 mm-diameter) graphene suspensions for audio speaker applications, the UT metrology and process equipment were used to identify key process variables affecting surface roughness and to optimize these processes. Figure 1 shows the significant improvements to defect levels and surface roughness achieved after optimizing the graphene growth and overall process flow, which is key to reliability, reproducibility, yield and performance.

Internal Academic User: Prof. Ed Yu (UT Austin NSF MRSEC Director)

High-Performance Metal-Insulator-Silicon Photoanodes for Solar Powered Water Oxidation

In work supported by CBET and DMR, the latter through the Center for Dynamics and Control of Materials: an NSF MRSEC, researchers in Edward Yu's laboratory have demonstrated a low-cost, scalable approach for fabrication of high-performance, extremely stable photoanodes for solar-powered water oxidation. Such devices are a key element in systems for using the power in solar illumination to split water molecules into hydrogen and oxygen. A fundamental issue plaguing conventional semiconductor photoelectrodes is that semiconductor materials that are efficient absorbers of solar illumination, e.g., silicon, are easily corroded in the liquid environment in which solar-driven photoelectrochemical reactions typically must occur. Incorporation of a wide-bandgap electrically insulating protective layer atop the semiconductor to separate the semiconductor from the solution has been explored quite extensively as an approach to improve stability, resulting in the development of metal-insulator-semiconductor (MIS) photoelectrodes. However, MIS photoelectrodes must contend with the challenge of providing efficient transport of photogenerated carriers across the insulator to the catalyst (typically metal) at the device-liquid interface. The most typical solution is to use an extremely thin (few nanometers or less in thickness) insulating layer to facilitate tunneling by photogenerated carriers, but thin insulating layers are extremely likely to compromise stability, particularly over the long term. An alternate approach for achieving, simultaneously, high stability and efficient transport of photogenerated carriers is to engineer structures in which conductivity across the insulator is enhanced only in the immediate vicinity of the catalysts, so that the remainder of the insulating layer remains pristine with its protective functionality unaffected.

Internal Academic User: Prof. Ananth Dodabalapur (ECE Department)

Indium gallium zin oxide (IGZO) thin-film transistors with channel lengths 50-200 nm

A new design for short channel length thin-film transistors (TFTs) is proposed and demonstrated with indium gallium zinc oxide (IGZO) [1]. The principal advantages of the new design arise from two distinct effects: (i) Nanospike array electrodes produce field-emission enhanced charge injection from the source/drain contacts to the semiconductor and lead to higher currents, current densities, and carrier velocities. (ii) Quasi-three-dimensional gate control at low gate voltages leading to improved turn-off characteristics, better sub-threshold swing and reduced drain voltage dependence of sub-threshold behavior. These advantages are very beneficial for back-end-of-the-line (BEOL) TFTs and will also apply to most other semiconductor material TFTs with Schottky contacts.

A similar device geometry has also been demonstrated for organic semiconductor based TFTs. The electric-field enhancement of the nanospike contact electrodes results in more effective charge carrier injection across the Schottky barrier between the contact metal and semiconductor, when compared to conventional flat contact electrodes. Initial studies have been performed with semiconductors pentacene and dinaphtho[2,3-*b*:2',2'-*f*]thieno[3,2-*b*]thiophene (DNTT). The results show that contact resistance can be reduced using the nanospike design by at least 10× relative to the contact resistance of flat electrodes when using the same source and drain metal.

External National Lab User: Prof. Incorvia (Univ. Texas) and Dr. C. Bennett (Sandia National Labs)

Metaplastic and energy efficient biocompatible graphene artificial synaptic transistors for neuromorphic computing

CMOS-based computing systems that employ the von Neumann architecture are relatively limited when it comes to parallel data storage and processing. In contrast, the human brain is a living computational signal processing unit that operates with extreme parallelism and energy efficiency. Although numerous neuromorphic electronic devices have emerged in the last decade, most of them are rigid or contain materials that are toxic to biological systems. In this work, we report on biocompatible bilayer graphene- based artificial synaptic transistors (BLAST) capable of mimicking synaptic behavior. The BLAST devices leverage a dry ion-selective membrane, enabling long-term potentiation, with ~50 aJ/μm^2 switching energy efficiency, at least an order of magnitude lower than previous reports on two-dimensional material-based artificial synapses. The devices show unique metaplasticity, a useful feature for generalizable deep neural networks, and we demonstrate that metaplastic BLASTs outperform ideal linear synapses in classic image classification tasks. With switching energy well below the 1 fJ energy estimated per biological synapse, the proposed devices are powerful candidates for bio-interfaced online learning, bridging the gap between artificial and biological neural networks.CVD grown graphene was covered with a 200 nm thin layer of PMMA for transfer. After etching copper in ammonium persulfate (see above), the graphene was transferred onto the wafer with pre-fabricated Au/Ti (10/50 nm thick) markers. A photoresist was used to protect the graphene channel areas during exposure to oxygen plasma. The stack of 10 nm Ti and 90 nm Au was e-beam assisted evaporated on the wafer through a pre-defined structure of lift-off resists to form source and drain electrical connections. Photostructurable polyimide, HD8820 was used in the last step to form the passivation. Spin-coated at 5000 rpm, exposed at i-line UV light, developed in 0.26% TMAH, and hard baked at 350°C, the polyimide forms a 3 µm thick passivation. The devices were then diced and spin-coated with the liquid Nafion-117 containing solution (Sigma-Aldrich) three times (3000 rpm, 150° C bake for 20 mins), forming a 666.7±28.9 µm thick layer.

Education and Outreach Activities

We have initiated a year-round REU program with Austin Community College where five students are being trained at the TNF MRC cleanroom. The current cohort includes two women and three URMs. TMI's facility managers, Dr. Raluca Gearba and Dr. Karalee Jarvis, participated in the GirlDay event at UT Austin. This is a yearly event organized by the Women in Engineering Program meant to give elementary and middle school students a chance to explore STEM through grade-appropriate hands-on activities.

Societal and Ethical Implications Activities

Lee Ann Kahlor, a risk and science communication expert at the University of Texas at Austin has led the social and ethical implications (SEI) team for NNCI-TNF for the last seven years. This year, we completed the SEI@TNF website, which covers introductory information about NNCI, TNF, and SEI, including the training module we developed in prior years. It also will provide nano-ethic related local and online educational resources for our audience(s). The SEI website is available from the main TNF website. As it becomes more populated with content, TNF will push the link out to other nodes. Although there are other websites out there with Nano Ethics content, this one is maintained locally, which gives us direct control over updating and responding to feedback so that its usefulness can be maximized for the SEI folks.

Computation Activities

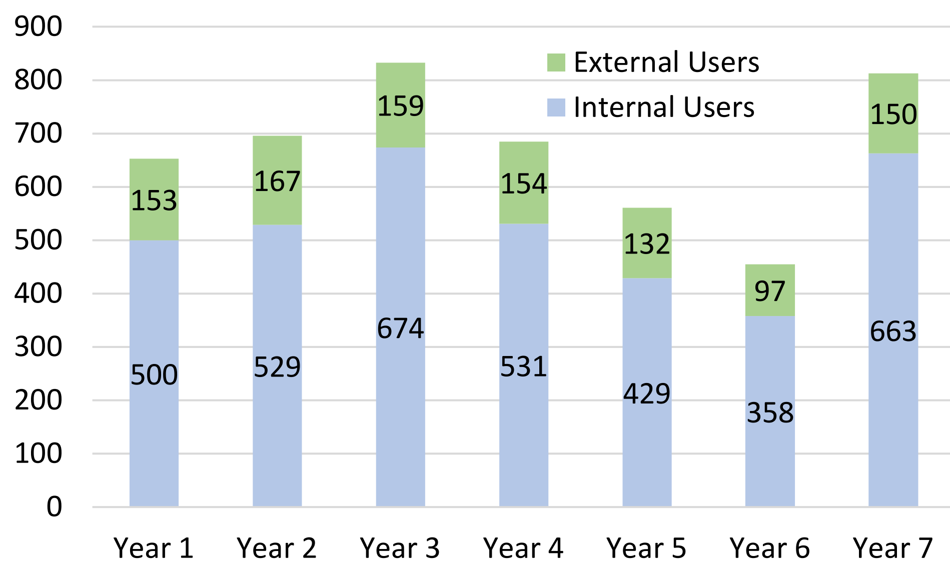
Modeling and simulation efforts performed with, in part, NNCI support have focused on understanding and guiding subsequent experimental efforts planned within our NNCI facilities, and in collaboration with colleagues at sister sites to present a series of seminars on modeling and simulation of interest to the NNCI community.

In addition, Frank Register has worked with Azad Naeemi at Georgia Tech and Dragica Vasileska at Arizona State University on a talk series addressing modeling and simulation. Specifically, as an illustrative example of the power of simulation, Register presented a talk focused on the essential physics of charge transport in nano-scale FETs, the modeling thereof, the resulting performance expectations with continued scaling of not only n-channel Si FETs, but also FETs made with alternative channel material, Ge and InGaAs. The value of simulation was demonstrated via results qualitatively contrasting with the conventional expectations, as well as the identification of the essential physics responsible for those contrasting results.

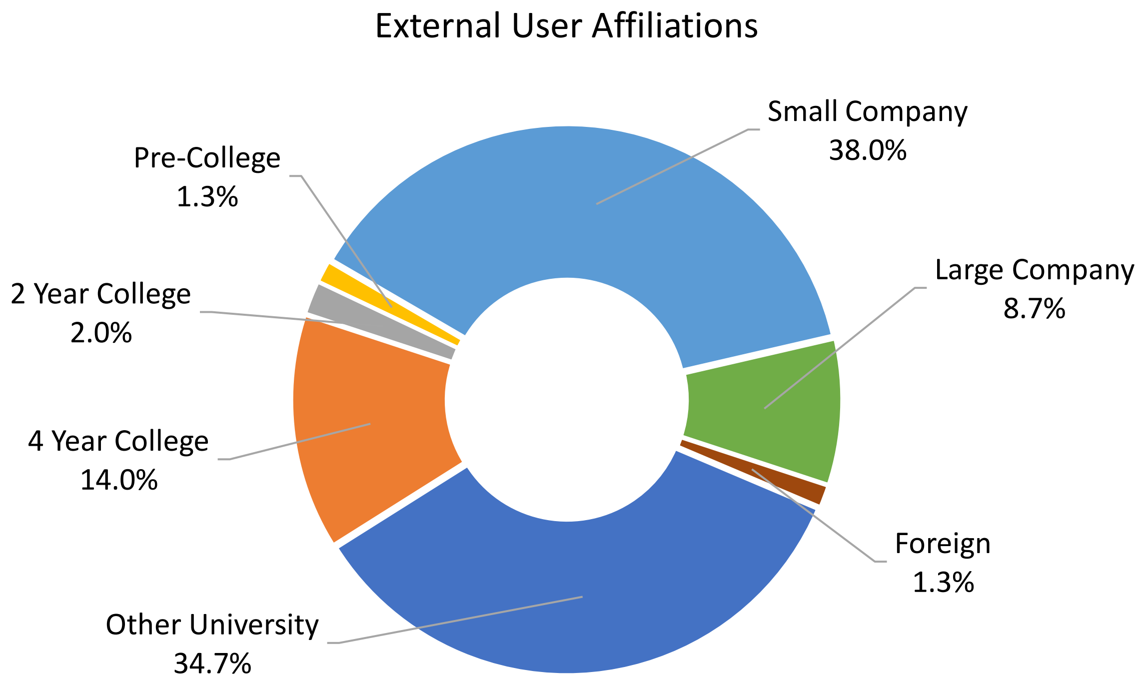
Modeling and simulation efforts performed with, in part, NNCI support have focused on understanding and guiding subsequent experimental efforts planned within our NNCI facilities, and in collaboration with colleagues at sister sites to present a series of seminars on modeling and simulation of interest to the NNCI community. One study has focused on the band alignment properties of 2D material heterostructures beyond the electron affinity rule, which results from charge redistribution in real space between the layers. Such alignments are relevant for, e.g., 2D material based optoelectronic and tunneling devices, or simply channel confinement in 2D material-based FETs.

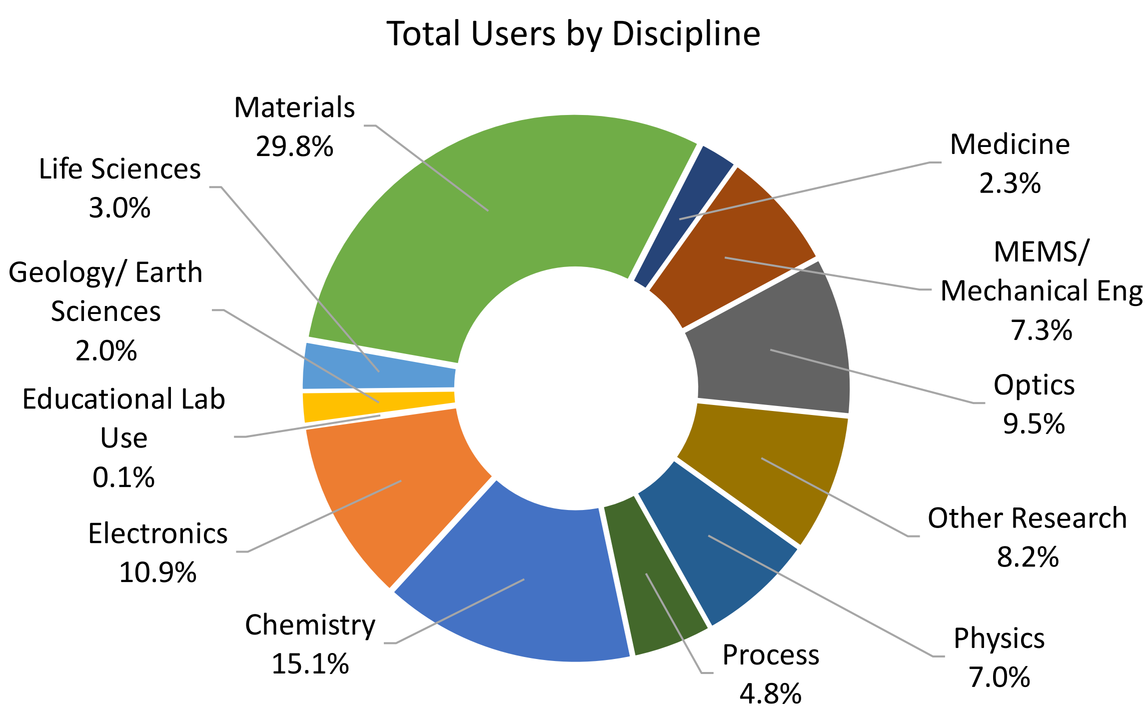
TNF Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	653	696	833	685	581	455	813
Internal Cumulative Users	500	529	674	531	429	358	663
External Cumulative Users	153 (23%)	167 (24%)	159 (19%)	154 (22%)	132 (24%)	97 (21%)	150 (18%)
Total Hours	67,570	58,354	63,645	65,166	38,229	53,901	65,193
Internal Hours	53,484	45,952	46,464	48,254	28,263	41,159	51,438
External Hours	14,084 (21%)	12,402 (21%)	17,181 (27%)	16,912 (26%)	9,966 (26%)	12,742 (24%)	13,755 (21%)
Average Monthly Users	244	272	287	315	216	246	337
Average External Monthly Users	45 (18%)	50 (19%)	59 (21%)	65 (21%)	45 (21%)	53 (22%)	66 (20%)
New Users Trained	99	193	80	62	34	38	54
New External Users Trained	48 (48%)	45 (23%)	33 (41%)	29 (47%)	16 (47%)	10 (26%)	18 (33%)
Hours/User (Internal)	107	87	69	91	66	115	78
Hours/User (External)	92	74	108	110	76	131	92



TNF Year 7 User Distribution





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

Facility, Tools, and Staff Updates

Based on emergent discussions at the 2021 NNCI Annual Conference, it was evident that the pandemic exacerbated staff retention issues across the network. Due to personal reasons, several NanoEarth team members (Ya-Peng Yu, Elizabeth Cantando, Charles Lowry, and John Sanchez) transitioned during this reporting cycle. Four new team members have joined the NanoEarth team. New team members include Sheryl Singerling (TEM Specialist), Sylvianne Velasquez (Diversity and Outreach Coordinator), Jonathan Angle (FIB and SIMS Specialist), and Bipin Lade (Postdoctoral Associate).

Supported by NSF-MRI (EAR-2018840) and Virginia Tech funds, a JEOL JXA-iHP200F Field Emission Electron Probe Microanalyzer (FE-EPMA) has been added to the facility. EPMA analysis is a critical and multi-functional technique for chemical characterization of natural and synthetic solid materials. EPMA is used widely in geosciences and planetary research, especially involving mineral formation process. EPMA is also becoming increasingly relevant to studies of synthetic inorganic solids related to, for example, energy storage and CO_2 sequestration. It provides quantification of the compositions of materials at the micrometer scale and provides valuable 'pre-processing' links to other instrumentation at the facility including transmission electron microscopy (TEM) and secondary ion mass spectrometry (SIMS). The EPMA increases the facility's capabilities, including simultaneous cathodoluminescence imaging and trace/major elemental mapping (from B to U).

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.

NanoEarth's MUNI (Multicultural and Underserved Nanoscience Initiative) provides financial support for individuals engaging with NanoEarth for research or educational purposes. Due to continuing pandemic concerns, in our seventh year, many MUNI users continued to engage with NanoEarth in a remote capacity.

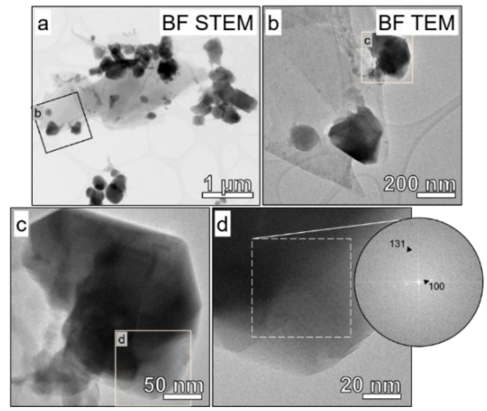
Research Highlights and Impact

Linsey Marr, NanoEarth co-PI and previous Deputy Director, leads the recently awarded Multidisciplinary InvesTIGation to Ease inFLUenza (MITAGATE FLU) team of researchers from Virginia Tech, the University of Michigan, the University of Pittsburg, Emory University, and Georgetown University to investigate the transmission of flu in childcare settings. NanoEarth's staff and unique aerosol facilities and instrumentation as part of the NCFL facilities in Kelly Hall are well equipped to provide the necessary characterization support for the $8.8 million Flu Lab award. More information about MITIGATE FLU is available in this VT News Article.

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

Leading Academic Highlight – Characterization of incidental nanomaterials from wildland-urban fires: Fires generate numerous combustion products. Wildland fires tend to consume organic material, whereas urban fires consume a wide variety of substances from building materials to household items to industrial solvents and more. Since the nature of the material consumed can have important implications for the environment as well as human health, the focus of this research is the identification and characterization of metal-based incidental nanomaterials present in fire ash from the wildland-urban interface, utilizing transmission electron microscopy (TEM).

To date, this project has observed numerous types of metallic nanomaterials, and these include Fe, Ti-, Zn-, and Cr,Cu,As-bearing nanoparticles (NPs). The Fe-bearing NPs are of particular interest owing to the fact that TEM work determined the Fe-bearing NPs are predominantly the iron oxide mineral magnetite ($Fe^{2+}Fe^{3+}{}_2O_4$), which has been linked to neurodegenerative diseases and could potentially contribute to global temperature increases. Future study will focus on other metal-bearing NPs and their potential impacts on the environment and human health.

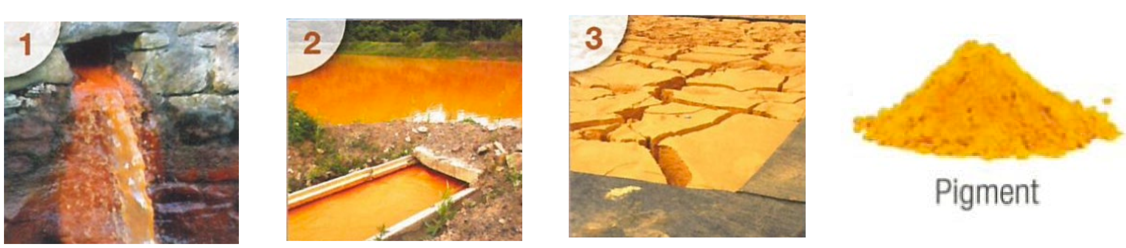


Transmission electron microscopy (TEM) images of an ash aggregate containing Fe-bearing nanoparticles identified as the iron oxide mineral magnetite (darker particles in a–d).

This research is funded under NSF award number CBET 2101983 Rapid Collaboration Proposal: Characterization, Quantification, and Transport of Incidental Nanomaterials from Wildland-Urban Fires in Surface Waters. It also received funding support from NanoEarth's MUNI.

Leading Industry Highlight – Developing commercial pigments from nanoparticles recovered from mine waste: Acid mine drainage (AMD) is a result of coal and mineral mining that negatively impacts ecosystem health and soil and water quality at thousands of sites worldwide. Hoover Color (a division of Cathay Industries, USA) in Hiwassee, VA is using metals recovered from coal AMD waste in a line of pigments called EnvironOxide™. Their properties meet those of conventional pigments, and they have the added benefit of being the result of an environmental restoration effort.

X-ray diffraction characterization work performed at NanoEarth demonstrated that the pigments sourced from AMD consist of nanosized iron hydroxide or oxide particles. The extreme small sizes of the particles may explain why they exhibit better transparency, dispersibility, and tinting strength compared with their conventional counterparts.



1) AMD discharging from an abandoned coal mine, 2) Engineered AMD neutralization and settling ponds, and 3) Iron hydroxide precipitates ready to be harvested.

<u>Education and Outreach Activities</u>

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 5 new shows developed for ***Pulse of the Planet*** this year about nano-related research and technology, and how it is changing the world, very much built for public consumption in a highly constructive format. *Pulse of the Planet* highlights the most interesting projects that come to us from external users, local site researchers, and impactful research at other NNCI sites with those individuals personally interviewed for each episode. This year's episodes featured Karen Sorber, Chief Executive Officer and Cofounder of Micronic Technologies, discussing their innovative technology for revolutionizing water treatment and recovering waste products and nanoparticles. *Pulse of the Planet* is heard on over 265 NPR radio stations by 1.1M listeners per week and are available as podcasts on Stitcher and iTunes. A full list of episodes with links to each program, which credit the National Science Foundation by name, are available on the NanoEarth website.
- **HBCU/MSI Research Summit**: NanoEarth participated in the 2021 HBCU/MSI Research Summit organized by Virginia Tech's Office of Recruitment and Diversity Initiatives. 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. Through these partnerships we seek to enhance the quality of research and graduate education by placing equity, diversity, and inclusion at the forefront of our pursuit of excellence. Our goals in hosting the annual research summit include: 1) Research: fostering cross-institutional research partnerships between HBCUs, MSIs and Virginia Tech; 2) Recruitment: Providing current HBCU and MSI students with a preview of Virginia Tech's graduate programs, allowing Virginia Tech graduate programs a key opportunity to recruit prospective students; and 3) Shared Degrees: Facilitate discussions about the feasibility of shared degree programs between the HBCUs and MSIs and Virginia Tech programs.
- Once again, NanoEarth sponsored the Spring 2022 NNCI **NanoTechnology Entrepreneurship Challenge (NTEC)**, which kicked off on March 14, 2021. This year marked the first time that the NTEC program was made available across the NNCI. The NTEC program aims to accelerate innovative nanotechnology transfer from the university to the private sector. The NTEC program encourages diverse, student-led teams to apply nanotechnology-based ideas to sustainability challenges in areas like public health, agriculture, clean water, and renewable energy. Winning teams receive seed funds to help develop their idea, as well as business development assistance and mentorship. The seven-week "pre-I-Corps" program culminates in a virtual "Launch Lunch" in May, where invited guests from the local entrepreneurship ecosystem review the NTEC program and vote to select the top NTEC team. The objectives of NTEC program, which has supported more than 30 student-led entrepreneurship teams since 2014, are to:
    - Encourage entrepreneurship through diverse, student-led teams.
    - Provide seed funding to help student-led teams advance innovative nanotechnologies towards solving real-world problems in society.

  - Encourage commercialization of nanotechnologies available through Virginia Tech Intellectual Properties (www.vtip.org).
  - Educate students on the technology transfer process.

  2022 Reach & Impact: 14 students across 8 student-led teams; 1 team lead by a student from an HBCU; 1 team led by a female entrepreneur

- In coordination with the research community, NanoEarth hosted the second annual Nano EES-RC workshop on May 16-18, 2022. Unfortunately, due to pandemic-related uncertainties, the decision was made to once again host this workshop fully virtually. The workshop was designed for nano-novices in Earth, environmental, agricultural, water, geoscience, or related fields. Please refer to the Research Community report for details.
  - The workshop demonstrated the practical aspects of applying the tools and knowledge of nanoscience to study planetary and environmental samples through two case studies. Specifically, the focus was on using electron imaging, spectroscopy, and x-ray diffraction methods to study natural materials at the nanoscale. The two case studies covered sample collection in the field, sample preparation/preservation, and instrumental data acquisition, reduction, and representation. The workshop included presentations, demonstrations, discussions with live polls and ample time for Q&A to explore modern advances of nanoscience as applied to the Earth and environmental sciences.
  - On the third day of the workshop, attendees had the opportunity to sign-up for virtual meetings with experts in topics of interest. Participants attended the meeting sessions for one-on-one or small group interactions with session leaders to talk directly about their research interests, and to solicit advice and feedback.
  - The workshop content and session recordings are available online.

- Representing NanoEarth in the NNCI Plenty of Beauty at the Bottom image contest, Mohsen Hosseini, Ph.D. candidate in chemical engineering, and William Ducker, professor of chemical engineering, won the "Most Whimsical" category for their entry "Lotus on Anti-SARS-CoV-2 Coating". Winners receive funding for travel to a professional conference of their choice and NanoEarth received a framed copy of the winning photo to display in our facilities. A detailed article about the winning image and associated research is available via VT News.

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.

An exciting new SEI activity at NanoEarth is a National Science Foundation Research Traineeship (NRT) focused on the Convergence at the Interfaces of Policy, Data Science, and Environmental Science and Engineering to Combat Antimicrobial Resistance (CIP-CAR) led by NanoEarth co-

PI Amy Pruden. Trainees will engage in transdisciplinary team-based research incorporating data analytics, environmental science and engineering, environmental chemistry, stakeholder engagement, public health, and policy to advance DNA sequencing of wastewater as a powerful tool to identify forms of antimicrobial resistance circulating in the community and inform environmental and public health policy, practice, and interventions. More information about the program is available on the program website and in this VT News Article.

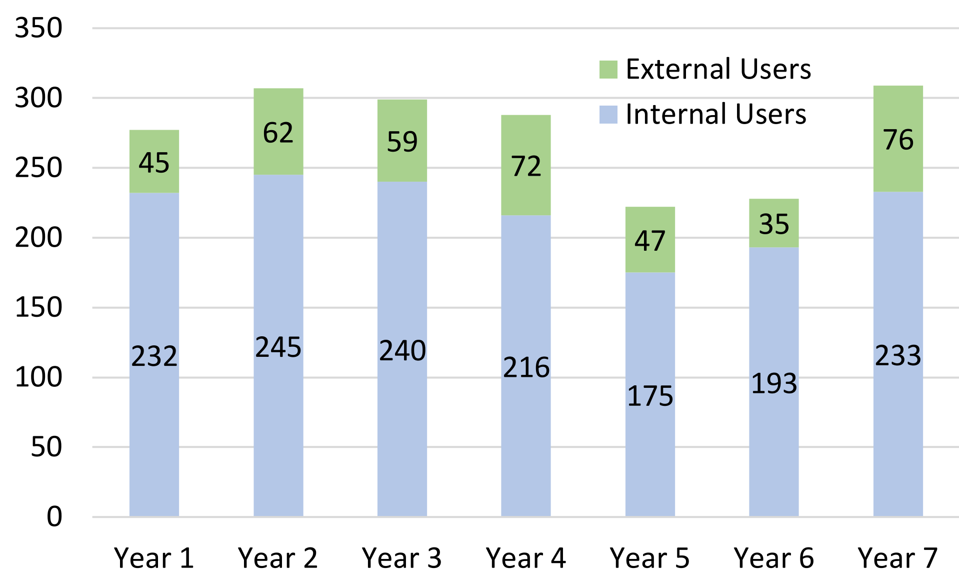
Innovation and Entrepreneurship Activities

NanoEarth continued to operate its core innovation and entrepreneurship (I&E) programs including the industry seminar series, the NanoTechnology Entrepreneurship Challenge (NTEC), and the Entrepreneur-in-Residence (EiR) program. Additionally, NanoEarth supported multiple ongoing collaborative projects with industry partners GeoMat, LLC, and Micronic Technologies, Inc. Though Virginia Tech did not host an REU program this year, Dr. Hull supported the implementation of the Research AND Entrepreneurship Experience for Undergraduates (REEU) at other NNCI sites. Following is a summary of NanoEarth I&E highlights since October 1, 2021:

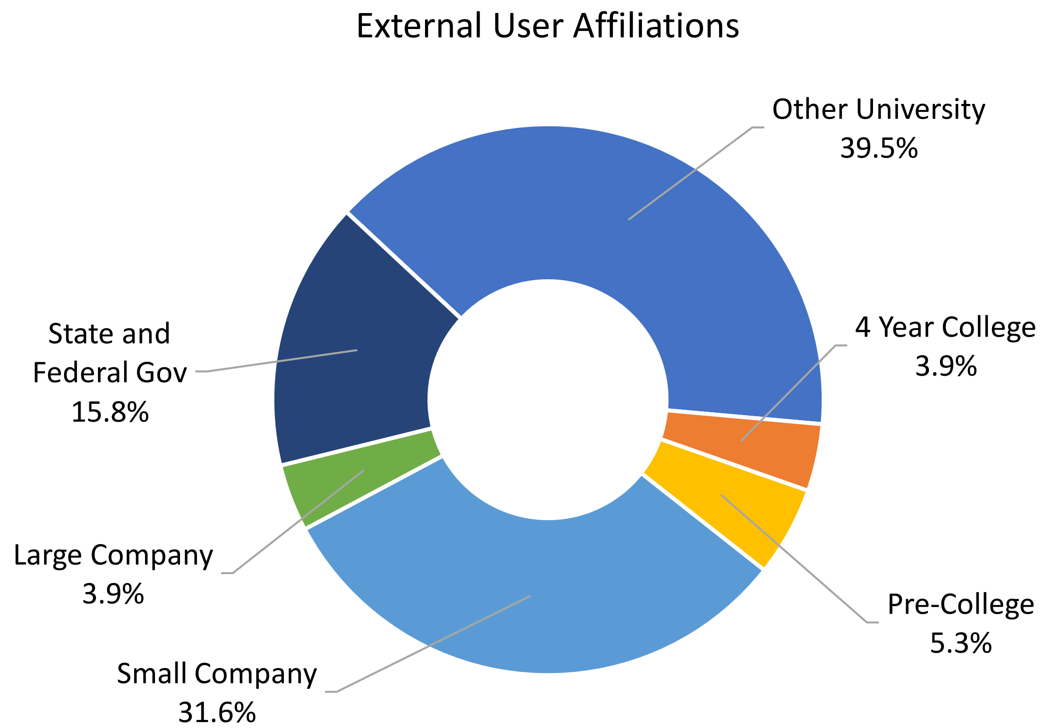
- NanoEarth hosted Ramesh Ralyia, Head of Research and Development at the Indian Farmers Fertiliser Cooperative Limited (IFFCO), India, and Co-founder of Smart Aerosol Technologies, USA, for a NanoEarth Industry Seminar on April 5th, 2022. Dr. Raliya discussed nanofertilizer for sustainable and precision agriculture.
- NanoEarth hosted Kevin Dreher, Dreher Toxicology Consulting, LLC, for a NanoEarth Industry Seminar on September 27, 2022. Dr. Dreher discussed pulmonary in vitro toxicity of copper carbonate particles employed as outdoor wood preservative.
- During March through May 2022, NanoEarth ran its annual NTEC program, which is highlighted in this report.
- New industry engagements this reporting period included GP Nichols & Company (Knoxville, TN), and ITA International (Blacksburg, VA)
- Ongoing industry engagements included Hoover Color (Hiwassee, VA, see included highlight), GeoMat LLC (Columbia, SC), EAM Consulting LLC (Spring Green, WI), AcumenIST (Belgium), CSI: Create. Solve. Innovate. LLC (Blacksburg, VA), and Micronic Technologies (Bristol, VA).
- Through his role as EiR, Dr. Hull mentored two faculty members who are considering start-ups and contributed to the mentorship of 14 entrepreneurial students via the NTEC challenge.

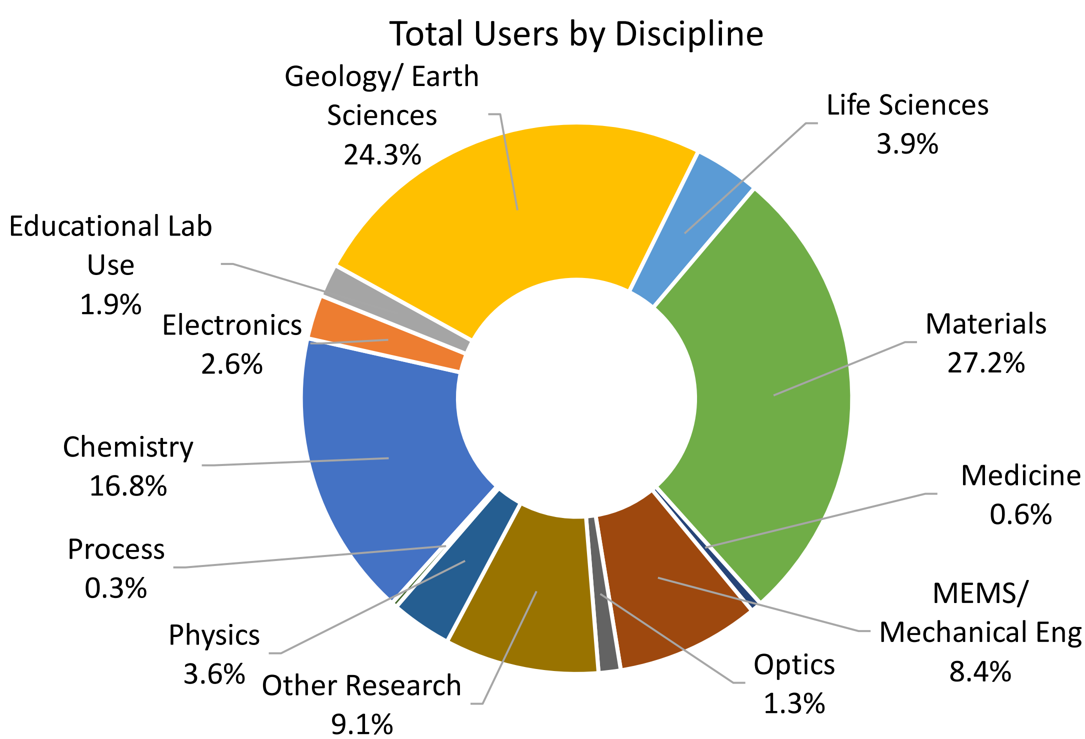
NanoEarth Site Statistics

Yearly User Data Comparison							
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Total Cumulative Users	277	307	299	288	222	228	309
Internal Cumulative Users	232	245	240	216	175	193	233
External Cumulative Users	45 (16%)	62 (20%)	59 (20%)	72 (25%)	47 (21%)	35 (15%)	76 (25%)
Total Hours	7,627	18,056	16,455	15,291	10,710	11,706	18,736
Internal Hours	6,196	14,277	14,073	11,622	8,174	9,748	15,882
External Hours	1,431 (19%)	3,779 (21%)	2,382 (14%)	3,669 (24%)	2,536 (24%)	1,958 (17%)	2,854 (15%)
Average Monthly Users	78	90	93	91	61	83	100
Average External Monthly Users	9 (12%)	14 (15%)	13 (14%)	18 (20%)	10 (16%)	13 (16%)	20 (20%)
New Users Trained	277	134	94	80	49	72	123
New External Users Trained	45 (16%)	27 (20%)	0 (0%)	0 (0%)	0 (0%)	3 (4%)	10 (8%)
Hours/User (Internal)	27	58	59	54	47	51	68
Hours/User (External)	32	61	40	51	54	56	38



NanoEarth Year 7 User Distribution





13. Program Plans for Year 8

Year 6 marked the start of the 5-year renewal of the NNCI. However, many of the programs for the Coordinating Office (see Section 2 for details) remain the same as in the first five years. The Coordinating Office will continue to: (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 overarching goal remains to ***make the network greater than the sum of its parts*** to the benefit of our user communities.

The roles of the Coordinating Office (CO) were defined 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."

Starting in Year 6, the CO added a fourth Associate Director, Dr. Matt Hull from Virginia Tech, to initiate and coordinate network wide activities in the area of innovation and entrepreneurship. The other three Associate Directors of the CO will continue to coordinate activities in Education & Outreach, Societal and Ethical Implications, and Computation across the network.

In Year 8, the CO will continue to support Subcommittees and Working Groups, the NNCI website, the NNCI Annual Conference, as well as the new Research Communities, which are a new network-wide effort for Years 6-10. 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, Working Groups and Research Communities. 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 8.

A number of specific activities planned for Year 8 are highlighted below:

- *NNCI Website*: The CO will continue to add new and revise existing content to the nnci.net webpage. Such content includes new pages for the Innovation Ecosystem.
- *NNCI Annual Conference:* The 8th NNCI Annual Conference will be hosted by nano@stanford and held at Stanford University, October 25-27, 2023. The current plan is that this year's conference will be a hybrid event with in-person events for those who can travel accompanied by live streaming for those who cannot.
- *REU Convocation*: The Year 8 REU Convocation will be hosted by MONT and held at Montana State University in Bozeman, MT, August 6-8, 2023, as an in-person event.
- *2023 Workshop on Nanotechnology Infrastructure of the Future:* The CO will work with a committee led by Debbie Senesky (nano@stanford) to organize a workshop on nanotechnology infrastructure of the future to be held in July 2023 in Washington, DC.
- *Research Communities*: The CO will continue to support the current six Research Communities: "Transform Quantum", "Understanding the Rules of Life", "Growing Convergence Research", "Nano Earth Systems", "Nano for IoT" and "Microelectronics/Semiconductors". These research communities are described more fully in Section 7.
- *Staff Exchange Program*: Originally proposed by the Global & Regional Interactions Subcommittee, the CO will continue to support a staff exchange program in Year 8. While staff exchanges were not possible in Years 5 and 6 because of the pandemic-related travel restrictions, some use of this mechanism occurred in Year 7 and was described above. Funds to support this program have been included in the CO renewal budget.
- *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).
- *User Survey:* The CO will administer this survey again in summer 2023.
- *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 Year 8, the collection of data on funding sources supporting research done at NNCI facilities will be repeated (for Year 7 usage), as well as the collection of information on courses supported (started in Year 7) and degrees awarded to NNCI users (started in Year 6).

- *NNCI Impact:* The CO will continue to work with the Metrics and Assessment Subcommittee to define NNCI societal and 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 National and International Connections:* As a focus effort for Years 6-10, 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. The goal is to promote capabilities, improve user support, share best practices and develop strategies for future infrastructure programs.
- *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.