National Nanotechnology Coordinated Infrastructure

NNCI Coordinating Office Annual Report (Year 9)
April 1, 2024 – March 31, 2025
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NNCI Coordinating Office Annual Report 2025

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1. NNCI Overview

1.1. Introduction

The National Nanotechnology Coordinated Infrastructure (NNCI) is an NSF-funded network of academic nanofabrication and characterization sites and their partners, formed to advance research in nanoscale science, engineering and technology. The NNCI site awards were the culmination of a competition conducted by NSF, under Program Solicitation NSF 15-519, which was generated as a result of input from the science and engineering community following the completion of the National Nanotechnology Infrastructure Network (NNIN, 2004-2015). Over 50 proposals from potential NNCI sites were submitted, and ultimately 16 awards were made. 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, for 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.

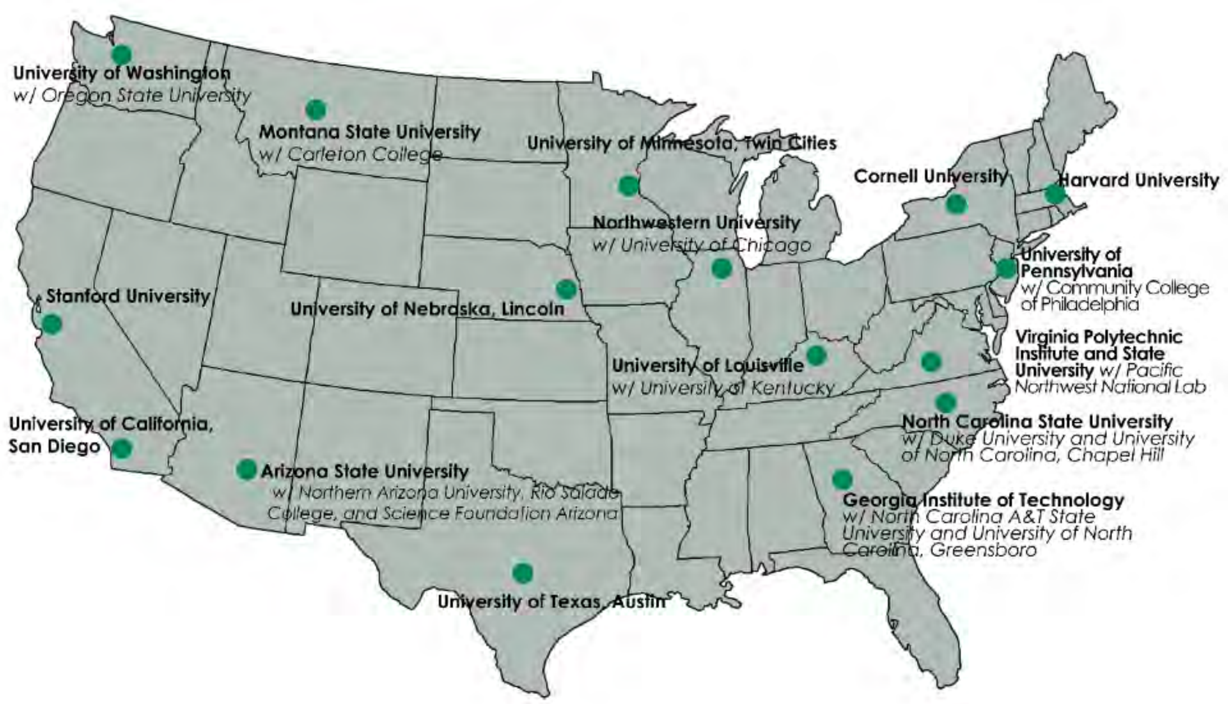


Figure 1: US Map with Locations of the 16 NNCI Sites (Years 6-10)

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), societal & ethical implications (SEI) programs,** and **innovation and entrepreneurship** in nanotechnology programs.

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 9 by more nearly 15,000 users including 3,800 external users, representing nearly 220 US academic institutions, more than 800 small and large companies, 44 government and non-profit institutions, as well as more than 40 foreign entities. Overall, these users have amassed more than 1.1 million tool hours. During Year 9, the network trained more than 5,600 new users. These statistics represent positive growth trends since Year 5 (post-pandemic) similar to those seen during the first four years of NNCI (2015-2019) prior to disruptions of the COVID-19 pandemic, suggesting a return to nearly normal operations.

This report summarizes the activities and progress for Year 9 of the Georgia Tech Coordinating Office of the NNCI, from April 1, 2024 - March 31, 2025. NNCI sites are funded via separate cooperative agreements between NSF and each site, with reporting of site-specific data and activities corresponding to Year 9 (October 1, 2023 – September 30, 2024).

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 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 in some user categories 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 9 (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 several 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	ASU NanoFab Eyring Materials Center Advanced Electronics and Photonics Core Facility Nano in Society User Facility

Rio Salado College Science Foundation Arizona	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 that assist both internal and external facility users supported by NNCI funds are not included in this count. In general, Site Leadership includes Site Directors and Deputy, Associate, and 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 the 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 Dr. David Gottfried (Associate Director, Georgia Tech Institute for Matter and Systems and Director, SENIC) as **Director**. Dr. Gottfried oversees the Coordinating Office day-to-day operations, assisted by **Program Manager** Amy Duke (Research Administrative Manager, Georgia Tech IMS and Program Manager, SENIC). Four **Associate Directors** manage the network activities in specific areas. Dr. Mikkel Thomas (Associate Director, Georgia Tech IMS and Director of E/O, SENIC) coordinates the NNCI education and outreach (E&O) programs. 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 (Director, Virginia Tech NCFL and Associate Director, NanoEarth) coordinates innovation and entrepreneurship (I&E) programs. This Coordinating Office staff meets monthly by conference call.

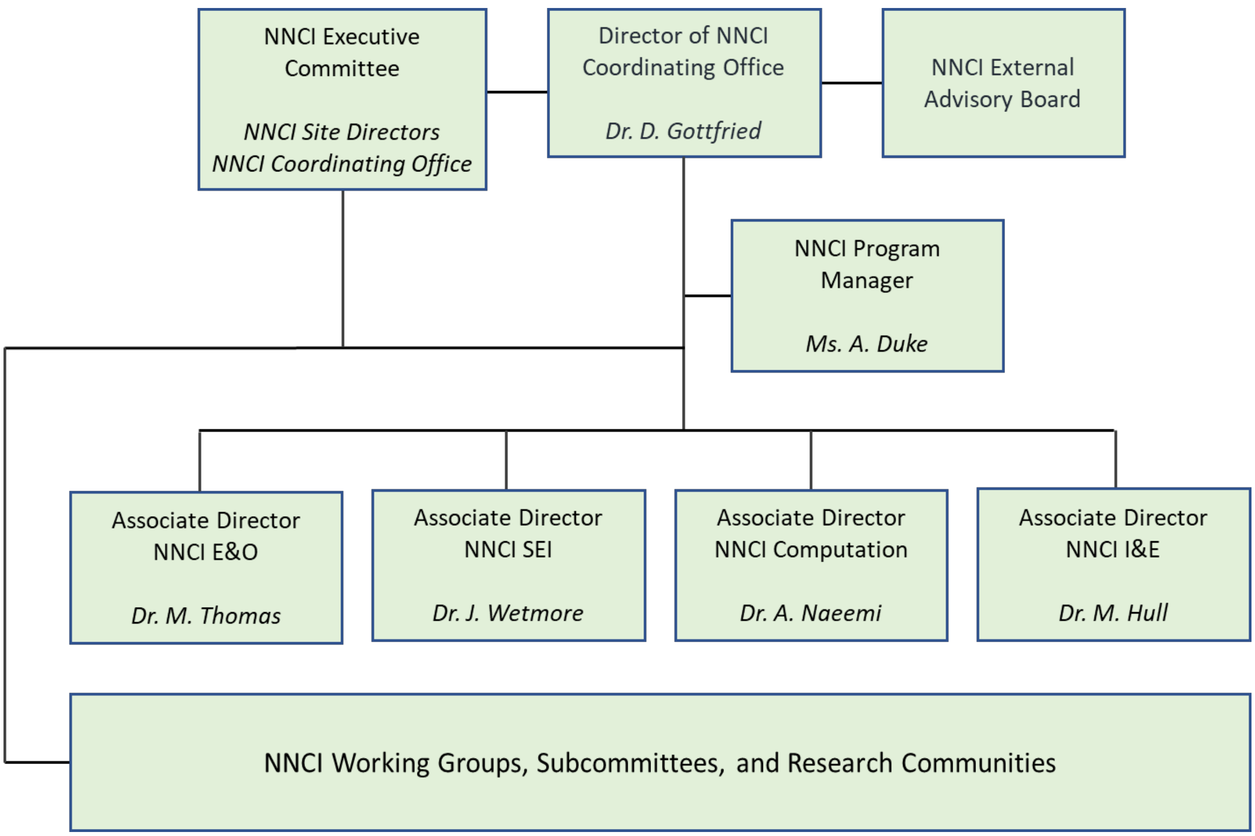


Figure 2: NNCI Coordinating Office Organizational Chart (Years 6-10). Revised May 2023.

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 Dr. Bumb was added to the board in 2024. Table 3 shows the Advisory Board members and their affiliations as of January 2025.

Table 3: NNCI External Advisory Board

Name	Affiliation
Dr. Ambika Bumb	Deputy Executive Director, Bipartisan Commission on Biodefense
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
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 to10-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 2024) is provided in Appendix 14.1.

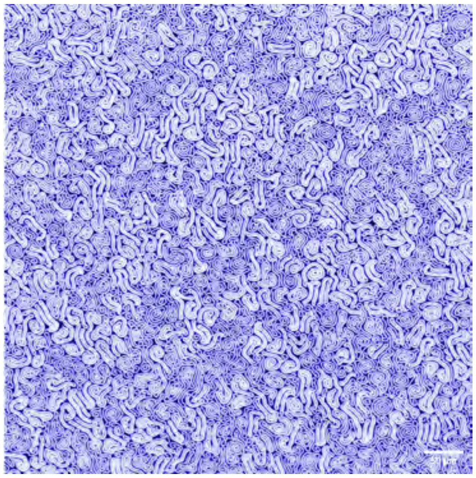
4. Associate Director Reports

4.1. Education and Outreach

The mission of the NNCI Education and Outreach (E&O) effort 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.

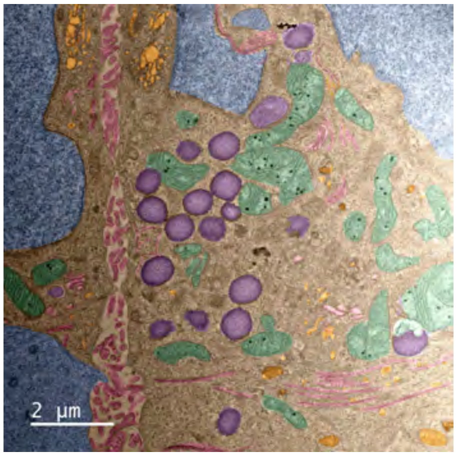
The 16 sites of the NNCI each have separate E&O programs in order to address these goals. Throughout NNCI Year 9, E&O coordinators reached more than 70,000 people, achieved in personal/virtual interactions through classroom visits, teacher workshops, remote sessions, short courses, seminars, symposia, community events, conference booths, tours, internships, REUs, and RETs. This reach is a significant increase from the previous year (47,000 people) and significantly surpasses that in Year 5 (33,000 people), returning to pre-pandemic levels and growth. All sites have returned to their pre-pandemic formats, while still using the virtual programs developed during the pandemic. Of the people reached this past year, 39% are K-12 students, 7% post-secondary students (undergraduate and graduate students), 5% educators (K-12 teachers and community/technical college faculty), 40% general public, and 10% professionals (short course and workshop participants, seminar attendees, etc.). Outreach to K-12 students continues to increase compared to the previous year, and overall reach has surpassed pre-pandemic levels. Programs for educators increased participation to nearly 3,200 teachers and community or technical college faculty, an increase of 45% over last year. The number of post-secondary students and professionals reached also increased to more than 11,600 (increased from 10,300 in Year 8) as more sites offered webinars, virtual symposia, and other online options. The 70,000 figure also does not include Nebraska Nanoscale Facility's traveling museum exhibit, NanoEarth's "Pulse of the Planet" radio programs, or the "Nanooze" magazines distributed by the Cornell Nanoscale Science and Technology Facility. Also not included are the students enrolled in the online courses offered through RTNN and nano@Stanford. These programs in total reached more than 173,000 additional individuals.

In celebration of National Nanotechnology Day, the NNCI again hosted its image contest, *Plenty of Beauty at the Bottom*. Twelve sites submitted 32 images created at one of their facilities during the past two years in three categories: Most Stunning, Most Unique Capability, and Most Whimsical. Public voting took place from Sept. 20-27, 2024, with sites promoting the contest through their various channels. More than 2,100 votes were cast to determine the winner in each category, and the winners were announced on National Nanotechnology Day, October 9, 2024. In addition to the winning entries shown below, honorable mentions were awarded to entries from NNI (Most Stunning), nano@Stanford (Most Whimsical), and SHyNE (Most Unique Capability).



2024 Most Stunning (MiNIC)

2024 Most Whimsical (NanoEarth)



2024 Most Unique Capability (SHyNE)

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 strategies for approaching the workforce needs of the microelectronics and semiconductor industries. 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 try to reach groups historically underrepresented in STEM fields. Several sites have forged relationships with the native American population in their area. MONT, RTNN, NNF, and NCI-SW have seen increased efforts in this population. MONT hosted 70 high school students and 20 educators from Salish Kootenai College for NanoCamp, a 3-day event at the Montana State University campus. Students spent a day in Yellowstone National Park making connections with the natural world and nanoscience. Graduate students from several disciplines led the excursion, framing different aspects of nano-scale research within the park. The students then spent another day on campus in MONT facilities. They were able to make silver nanoparticles then look at their particles in the SEM. The students engaged with MONT users, PIs, and staff in several departments. Students were also shown other aspects of campus and college life, spending time at the new MSU American Indian Hall and learning about support and resources for Native students. RTNN participated in the Waccamaw-Siouan STEM Day. This event in its fourth year brought in 330 attendees from 17 tribal nations. Staff from RTNN were able to present nano concepts to the attendees of the event. NCI-SW participated in the Girl Scout STEM weekend at the Navajo Nation. They were able to interact with girls who remember them from the previous summer, building bonds and reinforcing the nanotechnology concepts they were teaching.

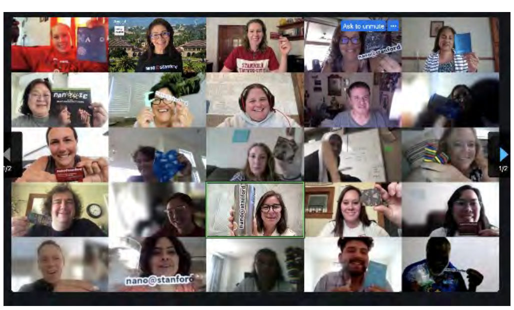
Salish Kootenai Students in Yellowstone

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, Micron, 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). The Associate Director for Education and Outreach for the NNCI coordinating office holds monthly meetings with the PI for MNT-EC, Dr. Jared Ashcroft, in order to better align their activities. 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 off-site, on-site, or virtual visits. SENIC's virtual class trips, in which middle and high school teachers invite staff to join their classroom, reached nearly 1,000 students and helped strengthen connections with school districts across Georgia. SENIC also partnered with the America Association of University Women (AAUW) to host the "Find Your STEM" conference, held during Women's History Month. The conference exposed middle and high school aged girls to potential careers in STEM. During the event, SENIC brought in professionals from various STEM disciplines and career sectors to talk about their journeys in STEM and how they had gotten to where they are now. CNF continued their ATLAS (Accelerated Training for Labor Advancement in Semiconductors) Program in 2024. This program brings high school seniors from the Tompkins, Seneca Tioga (TST) BOCES New Visions Engineering program for an in depth look at the world of micro and nanofabrication. During the two-week course, students enter into the CNF cleanroom and learn about the key areas of cleanroom operation. CNF also partnered with Micron Technology on their Micron Chip Camp. The camp is designed for middle school students and exposes them to STEM and semiconductor activities. As part of the Penn LENS program, MANTH takes 10th and 11th grade students into their cleanroom to participate in a hands-on photolithography lab. MiNIC partnered with Girls Inc. to teach a summer camp class called "Introduction to Nanotechnology."

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, completed its third cohort of teachers in summer 2023. A new proposal was submitted in January 2024 by SENIC, MiNIC, and NNF and funded in August 2024 by the NSF. During the summer of 2024, three sites hosted RETs on their campus: SDNI, NNF, and SENIC.

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. SDNI hosted 28 high school and middle school teachers during their in-person session. Nano@Stanford offered NanoSIMST in 2024 as a virtual workshop to further expand the reach of the program and enrolled 37 teachers in 17 states sponsored by eleven NNCI sites including Stanford (SHyNE, MANTH, MONT, CNS, RTNN, MiNIC, SDNI, NCI-SW, KY-Multiscale, and NanoEarth). As a network, NNCI trained over 100 teachers in the NanoSIMST program in 2024. Another resource used during NanoSIMST and available to the community are video recordings of talks on nanotechnology careers posted on the NNCI YouTube channel: "X/Nano: The enabling Potential of a Career in Nanotechnology" (Matt Hull, NanoEarth) has nearly 900 views and "Careers in



NanoSIMST Virtual Session led by nano@stanford

Nanotechnology: Opportunities for STEM Students" (Jim Marti, MiNIC) has more than 2,500 views. The nano@Stanford education coordinator maintains a listserv for educators that have participated in an NNCI program, as well as interested teachers who have not yet had the chance to participate. 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. Four NNCI sites (SDNI, NCI-SW, SENIC, and CNF) participated in the Microelectronics and Nanomanufacturing Certificate Program. This NSF funded program targets veterans and their families for training in microelectronics and nanotechnology. The 12-week program is designed to prepare veterans for the microelectronics and semiconductor workforce. Students are recruited from partner community/technical colleges. They receive virtual lectures from researchers at Penn State University and then receive hands-on training in the NNCI facilities. SHyNE hosted the 4th annual *Women in Microscopy Conference* with over 350 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. KY-Multiscale hosted their Nano+Additive Manufacturing Summit in the summer of 2024. The Nano+Additive Manufacturing Summit is an annual event dedicated to bringing together researchers/users 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. MANTH partnered with Drexel University to work on their Manufacturing Career Accelerator Program. The program is designed to prepare students for working in careers in manufacturing. During the six-week program, MANTH provided 22 students with hands-on training in the area of photolithography. In partnership with local industrial partners, MiNIC developed a technician retraining program. The program uses online modules to train individuals in microfabrication. The program is designed to allow participants to progress at their own pace while still working at their current job.

Thirteen NNCI sites were able to have their Research Experience for Undergraduates (REU) programs this past summer. All of the sites participated in a network-wide series of lectures organized by Jessica Hauer of NCI-SW and Yves Theriault of SDNI, in collaboration with the NNCI Assoc. Director for Education and Outreach and local REU coordinators. The NNCI REU Convocation was hosted by The University of Nebraska (NNF) on August 5-7, 2024. The convocation was a 3-day event and featured over 90 student short talks and posters on their summer research. They also heard keynote talks from academia,

NNCI REU Convocation 2024 Attendees at the Univ. of Nebraska.

industry, and the NSF, discussion of entrepreneurship, a career panel, and they learned about follow-up research opportunities in Japan.

In further support of undergraduates, nano@stanford's internship program in nanotechnology and microelectronics trained 25 students from 11 local community colleges. Of these 25 students, 60% were female and 76% were from groups underrepresented in science and technology. The interns were trained to work in a Class 100 cleanroom and gained technical skills in process control, equipment maintenance, deposition, etching, lithography, and metrology, while also building essential skills (communication, teamwork, and leadership, for example) through leading intern meetings, training new lab users, speaking about their experiences at TechConnect, and posting to their shared Instagram page. Out of 36 interns that have participated in nano@Stanfords's program since 2018, 19 have transferred to 4-year institutions, 2 have accepted full-time jobs at startups, 1 participated in two REUs at Harvard, 1 interned at Intel during summer 2024, 1 was a summer research assistant in a Stanford professor's lab, 1 was hired as full-time staff at the Stanford Nanofabrication Facility, 1 is now an MSE Masters student at Stanford University, and 1 is a Ph.D. candidate at MIT. MONT received a $10,000 grant from Micron through their Northwest University Semiconductor Network to develop a weeklong solar cell course for undergraduates and community college students. They have also implemented a three-session course, "Intro to Microfab," with the Photonics and Laser Technology Program at Gallatin College, their local community college. NanoEarth partnered with the Virginia Tech Office of Recruitment and Diversity Initiatives on the VT HBCU/MSI Summit. The summit served three purposes: 1. Explore possible research collaborations between Virginia Tech and HBCU/MSIs 2. Facilitate discussions regarding the feasibility of shared degree programs between Virginia Tech and HBCUs/MSIs. 3. Develop pathways for students at the HBCUs/MSIs to matriculate to or transfer to Virginia Tech.

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 and took part in the Greensboro Science Center Extravaganza in partnership with JSNN (SENIC). nano@Stanford held their inaugural Community STEMFest, reaching about 3,000 participants with over 20 hands-on STEM activity stations, tours, and demonstrations, including experiential learning with nano@stanford's tabletop SEM. Three different museums in the state of Nebraska hosted NNF's traveling nanoscience exhibit over the past year: The Kearney Children's Museum, the Strategic Air Command and Aerospace Museum, and the Hastings Museum of Natural and Cultural History. More than 146,000 people were able to interact with this exhibit during that time. SENIC organized the Georgia Tech Science and Engineering Day as part of the annual Atlanta Science Festival. More than 5,000 campus visitors interacted with more than 50 demonstrations of work that is being done on Georgia Tech's campus.

Georgia Tech Science and Engineering 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 *Workforce Development and Community Colleges* working group (Section 6.7), led by Andrew Lingley (MONT), includes information on approaches for addressing workforce readiness. The report of the *Evaluation and Assessment* working group (Section 6.8), 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.

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. This past year he was assisted by research assistant Toby Shulruff, a PhD candidate in the Human and Social Dimensions of Science & Technology PhD program at Arizona State University.

Over the past year, the NNCI Coordinating Office has advanced SEI efforts in three primary ways: (1) Coordinating with the four main SEI sites in the NNCI; (2) Small events and meetings within the NNCI and beyond; and (3) Coordination of two major events: The Winter School on Emerging Technologies and the Science Outside the Lab Washington, DC programs.

Coordination of NNCI-SEI Sites:

SEI work continues to be largely advanced by four NNCI sites with significant SEI expertise and commitment. Dr. Lee Ann Kahlor at TNF continues to develop SEI lab training and is working with a number of other NNCI sites to determine the ways in which SEI makes its way into classrooms and presentations (https://sites.utexas.edu/nnci-sei/sei-education/sei-training-video/). Over the last year, Dr. David Berube at RTNN has led an assessment (including exit surveys) of the RTNN user base to determine a broad number of factors including satisfaction levels and new instruments that would be desired. He has also analyzed the ways in which nanotechnology might be able to address climate change [Jones et al. "Positioning Nanotechnology to address Climate Change," *Environment Systems and Decisions*, 2024]. The SENIC site's SEI efforts have been coordinated by Dr. Diana Hicks, Professor in the School of Public Policy at Georgia Tech. Dr. Hicks worked with graduate student Sergio Pelaez to examine how patent applications include and present public values to track the relationship between technology and societal problem solving. One of their findings was that university and female inventors are more likely to present public values in their patent applications.

Unfortunately, due to illness and conflicts, not everyone was able to gather at the SEI workshop that accompanied the annual meeting at the University of Louisville in October 2024. Dr. Hicks gave an in-depth presentation of her patent work, and Dr. Wetmore presented an overall SEI update and led attendees from across the network in an interactive exercise that explored issues of risk, informed consent, expertise, and authority in nano-medicine and life extension technologies.

Events:

In addition to coordinating the other core SEI Sites, Dr. Wetmore has been extending the reach of SEI throughout the NNCI via forums, panels, and online workshops. In July 2024 he led an REU/RET webinar on "Research, Public Values, and Money," which brought together participants from a number of NNCI REU and RET programs. In May 2024, the SEI team organized an NNCI webinar entitled "Philanthropic Funding of Scientific Research," that brought together a panel of program managers from American philanthropies who fund science to discuss their process and how scientists and engineers can get involved. The panel included: Josh Greenberg (Sloan Foundation), Evan Michelson (Sloan Foundation), and Ian Philp (Spitzer Trust),

Wetmore also served on the "Responsible Development" panel of the National Nanotechnology Coordination Office (NNCO) conference "Celebrating the 20th Anniversary of the 21st Century Nanotechnology Research and Development Act" at the National Academy of Sciences, Washington, DC, March 5. He shared much of the work developed and deployed by the SEI program of the NNCI.

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. While the first four Winter Schools were sponsored by the NSF-funded Center for Nanotechnology in Society, the NNCI has now sponsored seven, which made the 2024 school the 11th annual event. After pivoting focus during the pandemic, the Winter School has brought social science, natural science, and engineering graduate students together to address a concern that graduate students across the disciplines are increasingly interested in – increasing their impact. The winter school uses a cohort approach to train, mentor, and inspire young scholars (see photo of 2024 cohort below).

The 2024 Winter School was led by a team including Vasiliki Rahimzadeh (Baylor College of Medicine), Dalton George (ASU/Rice University), Toby Shulruff (ASU), ASU Staff Deron Ash and Bethany Lang, and Jameson Wetmore.

Throughout the seven-day program participants met with a series of scholars and professionals to help them develop unique ways to increase the chances that their work will make a difference in the world well beyond their laboratories. Scholars from ASU and across the United States (including NNCO deputy director Quinn Spadola and NNCI associate director for entrepreneurship Matt Hull) developed interactive activities to help the participants think through possible avenues including community engagement, citizen science, liaising with governments, teaching and mentorship, policy, partnerships, and the media.

The 2025 winter school, again held January 3-10, was coordinated by the same team as the 2024 version. It marked the twelfth annual winter school program and welcomed students from across the United States plus some from Canadian, British, Australian, Indian, and Brazilian universities. This year's program is similar to the previous ones with the addition of ten program alums (from 2016-2022) who have returned to share their experiences and help to develop future Winter School programing.

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 2024 we helped to organize two SOtL programs.

The first was focused on Energy and Energy Transitions and was funded by the University of Pennsylvania. That program was initiated by the Mid-Atlantic Nanotechnology Hub (MANTH)'s education coordinator, Kristin Field. Field participated in the NNCI sponsored faculty SOtL in 2023 and was excited to offer more students at UPenn an opportunity to better connect their work to decision-makers in Washington, DC. Wetmore helped organize the program, arranged for a coordinator to lead it, and recruited 2023 SOtL participant Benjamin Shindel (Northwestern) to serve as TA. The feedback was overwhelmingly positive. While there was uncertainty prior to the workshop as to whether there would be funding to run it again, the experience led all involved to work hard to secure additional funding and we are currently on track to help organize a second Energy SOtL for the University of Pennsylvania to be held in May 2025. 2024 SOtL participant Dimitris Boufidis (UPenn) has agreed to serve as the TA.

Unfortunately, we did not end up running a bespoke SOtL program for faculty in 2024. While the 2023 program was very successful, there was not enough interest amongst NNCI science and engineering faculty in 2024, so we decided to postpone the event to May 2025. The NNCI Coordinating Office will be funding small stipends to help offset the travel costs for young faculty. Our hope is that better marketing this year will allow us to once again run what we see as a very important program.

Demand for the 2024 graduate student SOtL was again very high with 70 applications. The application pool was so strong that we increased the size of the program from the traditional 15 to 17.

The 17 participating graduate students represented 10 NNCI universities: UNC Greensboro, University of Minnesota, Georgia Tech, University of Texas, University of Washington, Harvard University, Northwestern University, Stanford University, University of Pennsylvania, and UCSD (photo at right). During the first week of June the participants met with nearly 50 science policy professionals including NSF program managers, EPA regulators, NAS program managers, science staff at the Organization of American States, a federal judge, and the directors of the NNCO.

At the end of the program ASU conducted an independent survey of the students, and the feedback was overwhelmingly positive. Of the 11 students who responded, 10 said they were "extremely satisfied" with the program and 1 was "satisfied." 100% said they were extremely likely to recommend the program to a colleague. The survey also demonstrated a shift in students' attitudes toward policy. Prior to participating in SOtL 11% strongly agreed that they "should engage with policymakers to ensure that political debate is informed by the best available knowledge." After SOtL that percentage rose to 78%.

The survey also gave students a chance to write about their experience and all the respondents offered explanations of how they benefited. One student stated:

> It really opened my eyes to how science policy goes from idea, to legislation, to execution. Seeing all three branches of government actually at work was much more informative than any classroom experience ever could be, and I feel like a more informed citizen in general, not just a more informed scientist.

Another participant noted that:

> As a Science & Technology Policy researcher, participating in SOtL has shifted my perspective on policy-relevant research. I need to research and distill the results in a way that is easily accessible to policymakers. This may require some form of policy entrepreneurship on my part to ensure the uptake of my findings and recommendations.

For the first time this past year we also surveyed the speakers who participated in the program. We received 11 responses, and they unanimously agreed they would all "definitely" be interested in presenting at the program again. In addition, 9 of the 11 "definitely agreed" that they would recommend that colleagues present at the program as well. We also asked the speakers more detailed questions about their experiences. For instance, we have had anecdotal evidence that not only do the students learn from the program, but that the speakers do as well, and the survey was able to confirm this. One speaker indicated:

> I was able to gain insights into the research projects on multiple transformative technologies and learn about the perspectives of very qualified students on some of the policy questions currently being asked around diplomatic and policy circles. The dialogue with the group provided opportunities to share ideas and brainstorm about approaches to improve the current policy options in areas such as Artificial Intelligence.

A number of our speakers are SOtL alums and in the survey they credited the program as being a crucial part of their career trajectory. Cumulatively this evidence demonstrates that NNCI's Science Outside the Lab program not only is a great educational experience for participants, but it is also having an influence on science policy and policymakers in Washington, DC as well.

From its onset, 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 also spread that understanding throughout their communities and with colleagues. Thus, in the 2024 program all of the participants were trained in basic techniques to bring what they learned in the program back to their home institutions. 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 have been 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. Dimitris Boufidis at UPenn not only has been active in his local science policy club, in October he gave a talk at the Greek Embassy in DC. Two cohorts of students from the University of North Carolina at Greensboro have been active as well. Mau Cabo, Jr. (2024 alum), Nooshin KianvashRad (2024 alum), and Bukola Adesanmi (2023 alum) helped to establish the Future Science Policy Leaders Club at UNCG.

In addition to the successful 2024 program, we continue to hear great things from our alums. During the pandemic we organized two virtual SOtL programs (2021 and 2022). There was significant concern that, because they were held online, these programs would not have nearly the same impact as the versions held in person in Washington, DC. We're happy to report that at the very least the online format was inspiring enough to give participants sufficient training and exposure to US federal science policy to help them secure high-profile government fellowships. Three alums from our 2021 online cohort have been awarded AAAS S&T Policy fellowships: Levi Helm (ASU) is at USAID, Anisha Singh (Stanford) is a Congressional Fellow, and Connie Hsueh (Stanford) was a Congressional Fellow. Furthermore, 2024 SOtL participant Amnahir Pena-Alcantara (Stanford) was recently awarded a White House Fellowship and is currently working in the Chief of Staff's office at the National Institute of Standards and Technology (NIST).

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 and can be accessed via https://nanohub.org/groups/nnci_computation. So far, 10 sites have reported collectively more than 65 commercial simulation tools and 40 internally developed simulation tools available for internal and/or external users (with and without fee).

In addition to software resources, 9 supercomputers or major computing clusters are available at various sites. Most of these hardware resources serve internal users, with the exceptions of the UT-Austin computing cluster which can be accessed by external users for 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 at ASU (NCI-SW) has developed a self-paced short course on device and process simulation. This 5-week course is roughly equivalent to 1 credit hour and is similar in structure to nanoHUB University courses (https://nanohub.org/resources/40061). The course consists of lectures, quizzes, and projects and is based on Silvaco TCAD software. The course lectures and slides are publicly available on nanoHUB, and since September 2024 the course has had more than 340 users.

On the modeling and simulation side, Prof. Frank Register and his collaborators at UT-Austin (TNF) have developed phase-field models to study domain formation in ferroelectric field-effect transistors (FeFETs). The models self-consistently solve 2-D Poisson's equation and Landau energy state, providing important insights regarding the impact of ferroelectric domain dynamics on the device's electrostatics and transport properties including substantial changes in gate and source to drain tunneling. The UT-Austin team has also developed a phase-field modeling framework for multi-domain magnetic tunnel junctions. They have developed an analytical model of magnetic tunnel junctions by solving electrostatic Green's function and used the model to study the impact of domain patterns on tunnel magnetic resistance (TMR) and the switching speed. Because of the analytic nature of the models, they can be used as the basis for compact model development for circuit-level simulations.

Prof. Vasileska and her team have developed a modeling framework for wide bandgap devices such as 4H SiC vertically diffused MOSFETs (VDMOS). The framework is based on a 3D Full-band Monte Carlo device simulator with real-space treatment of the electron-electron and electron-impurity interactions. Prof. Vasileska has also collaborated with Prof. Goodnick at ASU to model hot carriers solar cells. These solar cells can have substantially higher efficiencies compared to the existing solar cells as they can capture hot carriers that are generated with high energy photons before they relax and lose their energy in the form of heat. However, successful demonstration of hot carriers solar cells has been hindered by many challenges including the lack of simulation tools that can be used for material-device optimization and design. The modeling framework developed by the ASU team provides researchers with an important tool for such kind of design exploration.

Prof. Azad Naeemi's team at the Georgia Institute of Technology (SENIC) have developed an open-source process design kit (PDK) for the most advanced Si CMOS technology node. This PDK, which is now publicly available at https://github.com/azadnaeemi/GT3, aims to address the gap between industry and academia, providing all the necessary collaterals for full chip design and an end-to-end design-technology co-optimization (DTCO), which could be used to assess the impact of various technology options on the system-level performance of a microchip. The PDK provides a standard cell library with over 60 cells, each with various functions and drive strengths based on TCAD-modeled gate-all-around nanosheet FETs and interconnect layers based on the latest lithography assumptions and design rules for the 3nm CMOS Technology.

4.4. Innovation and Entrepreneurship

The Innovation & Entrepreneurship (I&E) initiative continues to implement and refine programs focused on fostering a diverse and inclusive NNCI-wide innovation ecosystem. The I&E working group meets quarterly to establish and execute the NNCI I&E agenda and includes representatives from 14 of the 16 NNCI sites. To date, 93 students from 59 student/post-doc-led teams representing nine NNCI sites have participated in the NNCI Nanotechnology Entrepreneurship Challenge (NTEC), a seven-week pre-I-Corps™ Virtual Accelerator program for training nano-savvy entrepreneurs. A dedicated LinkedIn community has been established to help connect NTEC alumni. In 2025, a dedicated "Future Innovators" session at the TechConnect meeting in Austin, TX, will feature live pitches from the top three NTEC teams. Seven I&E webinars have been held, each hosted by a different NNCI site, and covering topics ranging from "What Investors are Looking for in Early Stage Start-ups" to "Lab-to-Fab" to "How to Engage with Diverse Student Populations in Entrepreneurship." The NNCI Research and Entrepreneurship Experience for Undergraduates (REEUs), which offers a gentle entrepreneurship introduction to NSF REU students, entered its fourth year and has reached 120 students across eight NNCI sites. The "Pain to Pitch 180™" program, which was launched in collaboration with the ASU Winter School, entered its second year.

Background

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. Also 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 around 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 2024, the NNCI I&E Working Group (Figure 3) met quarterly on the following dates: February 1st (Q1), May 7th (Q2), August 22nd (Q3), and October 28th (Q4). Once again, the Q4 meeting coincided with the NNCI Annual Meeting, which was hosted this year at Louisville. The I&E WG contributed by leading a translational panel discussion with representatives from the local Louisville/Lexington innovation ecosystem. The agenda for the session is listed below:

Agenda for I&E Translational Session at 2024 NNCI Annual Meeting, Univ. of Louisville

- 2:15- 2:20PM Welcome & Intro to Louisville/Lexington Innovation Ecosystem
  Matthew Hull, Assoc. Director, Innovation & Entrepreneurship, NNCI and NanoEarth
- 2:20 – 2:30PM Panelist #1 Univ. of Louisville Translational Resource
  William Metcalf, Univ. of Louisville
- 2:30 – 2:40PM Panelist #2 Univ. of Louisville Start-Up
  Thad Druffel, Bert Thin Films, LLC
- 2:40 – 3:00PM Panelist #3 Univ. of Kentucky Start-Up
  Cameron Lippert, Electramet

- 3:00 – 3:45PM Panel Discussion (moderated by M. Hull)

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 complement and support those of other NNCI working groups.

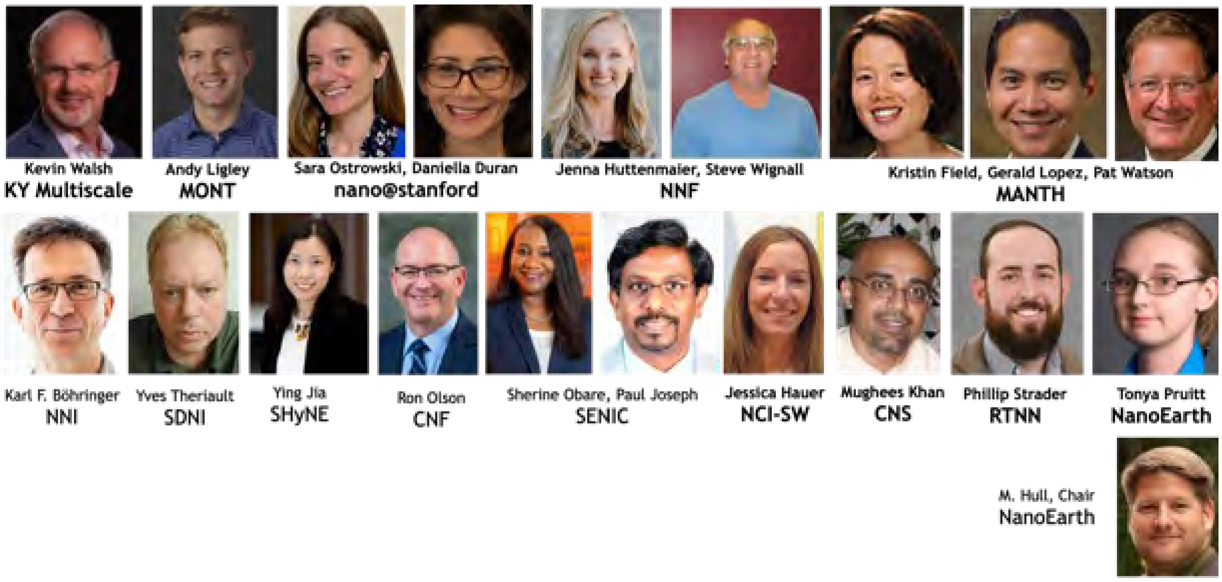


Figure 3: The 2024 NNCI I&E Working Group included representatives from 14 NNCI sites.

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
- **Goals** – establishing and refining I&E goals for the remainder of NNCI

NNCI Site-Specific I&E Activities

In addition to the I&E activities organized through the NNCI I&E WG, 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 I&E WG meetings. Some notable I&E activities organized by individual sites are listed and summarized below:

- In January 2024, the "Pain to Pitch 180™" experience was delivered once again in collaboration with the ASU Winter School to immerse attendees in the commercialization process. Participants had 180 minutes to uncover a pain point and pitch a solution.
- On September 27, 2024, Dr. Ron Olson, Dr. Judy Cha, and the Cornell Nanoscale Science and Technology Facility (CNF) continued their annual New York State Nanotechnology Network (NNN) Symposium, which helps connect students and industry participants from across the state.
- Dr. Kevin Walsh and colleagues from the Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY Multiscale) hosted the 2024 NNCI Nano+Additive Manufacturing Summit July 30-31. The event featured examples of regional start-ups focused on nano/AM.

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 2024, the number of NNCI sites participating in the REEU program, increased to eight (Figure 4). REEU modules are offered in collaboration with the NNCI Assoc. Director for E&O (Mikkel Thomas) and local REU coordinators. In 2021-2024, 120 REU students participated in the program. In 2024, NNCI Assoc. Director for I&E (Matthew Hull) gave two live REEU seminars at NanoEarth and SDNI. Both programs were shared with other sites, virtually.

Figure 4: 2021-2024 REEU Participation: 8 sites and 120 REU students engaged.

Interest in industry research careers remains high among REU students participating in the NNCI REEU program. More than half of all REEU participants indicated that careers in "industry research" or "entrepreneurship" were of greatest interest to them. In 2024, more than 60% of REEU participants indicated that they had considered becoming an entrepreneur (Figure 5). Across all years, about half of the REEU participants claimed that they did not know much about entrepreneurship (Figure 5). Students claiming to know "a good bit" about entrepreneurship remains at about 15%.

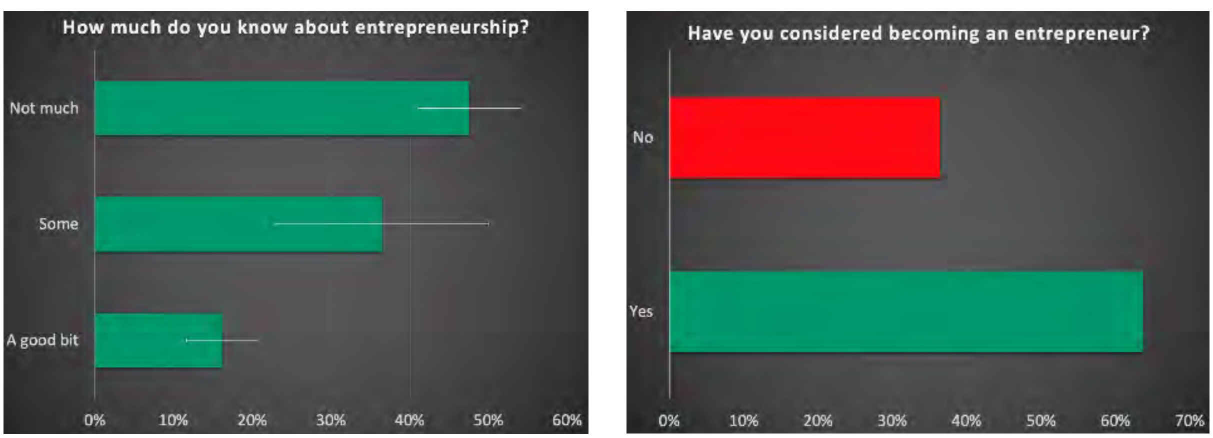


Figure 5: Feedback to date (2021-2024) from REU students participating in the NNCI REEU module when asked (left) about the type of career interests that interests them the most, and (right) whether they have considered becoming an entrepreneur (2024 only).

Overall, the students continue to express a favorable opinion of entrepreneurship, using terms like "creativity" and "innovation" 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. Some negative terms shared include “long hours”, “sacrifice”, and “selling out”.

Figure 6: Word clouds based on student responses from two REEU sessions (2024) when asked “What comes to mind when you think of entrepreneurship?”

<u>NNCI I&E Seminar Series</u>

To date, seven I&E seminars 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 2024, the I&E WG hosted two industry seminars. The first seminar was held on March 11, 2024 and was delivered by a panel including Jacques Chirazi, Director of Student Entrepreneurship and The Basement Blackstone Launchpad Campus Director, UC San Diego; Christine Liou, Assistant Director of the Basement, UC San Diego; and Yves Theriault, Program Manager for Education and Outreach at the Qualcomm Institute, UC San Diego and SDNI Executive Director of Education & Outreach. The panel was moderated by M. Hull. The seminar/panel discussion was entitled “How to Engage with Diverse Student Populations in Entrepreneurship.” The seminar was organized by the NNCI Coordinating Office in collaboration with Dr. Yves Theriault of SDNI.

The second seminar was held on September 17, 2024 and was delivered by a panel including Yossi Feinberg, Adams Distinguished Professor of Management and Professor of Economics, Stanford University; Jennifer Dionne, Professor of Materials Science and, by courtesy, of Radiology, Stanford University, and Chan Zuckerberg Investigator, Co-Founder of Pumpkinseed; and Keegan Cooke, Director, Stanford Ecopreneurship, Stanford University. The panel was moderated by M. Hull. The seminar/panel discussion was entitled “From Lab to Launch: Stanford’s Entrepreneurial

Ecosystem." The seminar was organized by the NNCI Coordinating Office in collaboration with Dr. Sara Ostrowski of nano@stanford.

Planning is currently underway for the 2025 seminar series and should be announced in February 2025. Live online attendance at the seven previous seminars totaled over 200 guests, but the majority of attendees continue to view the archived seminars on the NNCI YouTube channel, asynchronously. 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. 2024 marked the third year of the NNCI-wide NTEC program and 15 student-led teams participated. Teams consisted of 21 students from seven different NNCI sites who took part in a seven-week NNCI Virtual Accelerator program. The program began March 11th and concluded April 30th, 2024, with an NNCI Virtual Showcase event. Table 4 summarizes the 2024 NNCI NTEC cohort projects.

Table 4: 2024 NNCI NTEC Cohort

Student Lead(s)	NNCI Site	Award	Mentor(s)	Title
Freddy Garcia et al.	SDNI	Diversity	Oscar Vazquez Mena, Yves Theriault	Portable High Resolution Ultrasound Device for Point-of-Care Brain Stroke Diagnosis and Intervention – acoustic metamaterials for brain injury
Lana Chung	SDNI	Diversity	Yves Theriault, Ivonne Gonzalez Gamboa	Dermatology Face Mask – Nonprescription (Dermatiq Mask MD) – biodegradable bio-cellulose crystalline nanofibers-based face mask for facial microbiome
Kylie Chang	MANTH	Regular	Gerald Lopez	LilyLoop – substrate composed of cellulose nanofibrils and Ti nanowires for moisture absorption + medical data
Elizabeth Teeters	RTNN	Regular	Marshall Brain	Apex Analytics – nano-enabled path to miniaturized sensors for health in contact sports
Julia Chang	RTNN	Diversity	Phillip Strader	OneOK solution to "semiconductor high threshold" dilemma: the

				autonomous fabrication of multi-dimensional semiconductor arrays
Saowaluk Soonthornkit et al.	NNI	Regular	Zhenxing Feng	Durable double perovskite SrCoIrO3 electrocatalyst for acidic media water electrolyzer
Abhijeet Mali et al.	SENIC (JSNN)	Diversity	Lifeng Zhang	Nanofiller-Reinforced Environmentally Friendly Epoxy/Bio-binder System for Lighter and Stronger Composite Materials
Evan McDowell	SENIC (JSNN)	Diversity	Jeffrey Alston	From waste to wood: innovative decking alternatives for a sustainable future
Yusif Abdul-Rashid	SENIC (JSNN)	Diversity	Kerui Wu	Developing a novel approach for pancreatic cancer screening
Sindhu Yalavarthi	SENIC (JSNN)	Diversity	Kerui Wu	Engineering antigen-presenting nanovesicle for personalized cancer immunotherapy
Tony Wang	SENIC (GT)	Regular	Paul Joseph	An electromagnetic micromanipulation system integrated with CT scan for neurosurgery
Bipin Lade	NanoEarth	Diversity	Marc Michel	Sustainable flocculation process of microplastics and nanoplastics in water induced by food-grade hydrophobic polymer
Fatimah AlNasser	nano@stanford	Regular	Swaroop Kommera	Nanofluidic investigation of paramagnetic fluids at the subsurface
Joshua Yang	nano@stanford	Regular	Lavendra Yadav Mandyam	Chip-scale Ti:Sapphire Lasers and Amplifiers
Pingyu Wang	nano@stanford	Regular	Nicholas Melosh	SeedSolace – sensing solutions for smarter farming

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 7 shows a zoom capture from the 2024 NNCI NTEC showcase.

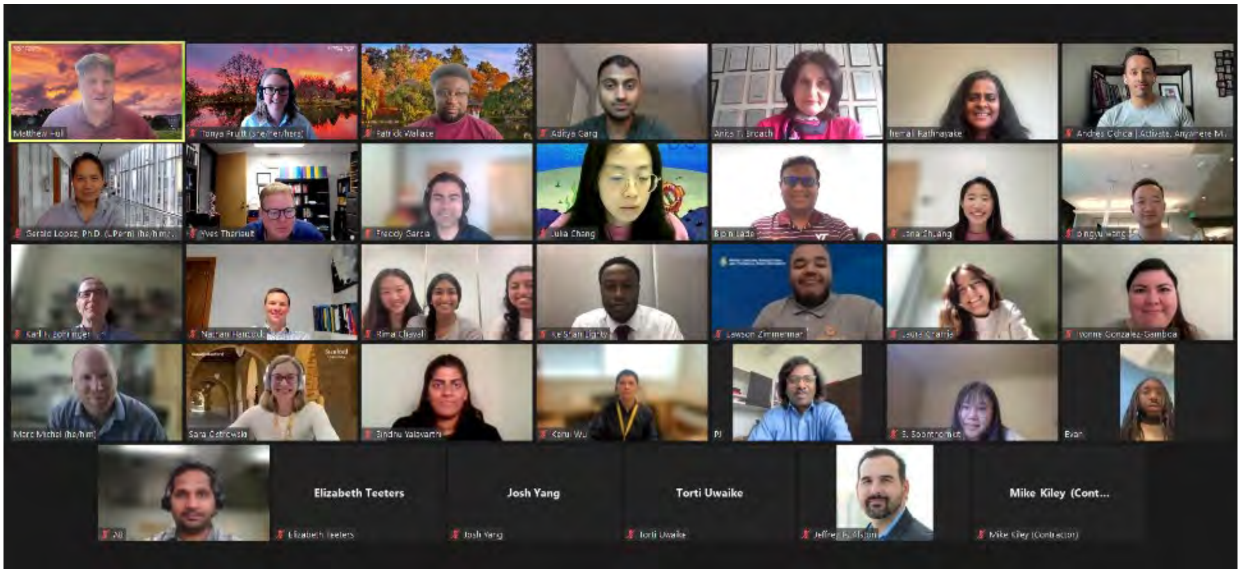


Figure 7: Zoom capture from the 2024 NNCI NTEC Showcase

The 2024 top overall NTEC team as well as the top Diversity Award team was led by Freddy Garcia and included Beeta Zamani and Laura Charria (SDNI). Johua Yang (nano@stanford) and Abhijeet Mali along with Torti Uwaike, Ke'Shan Lighty, and Lawson Zimmerman (SENIC-JSNN) received second and third place honors, respectively (Figure 8).

Figure 8: Top NNCI NTEC Teams of 2024. Left: nano@Stanford's Josh Yang (lead) and Lavendra Yadav Mandyman (mentor); Center: Top Overall Team, UCSD's Freddy Garcia, Beeta Zamani, Laura Charria (leads) and Yves Theriault (mentor – center image, second from left); Right: SENIC's Abhijeet Mali, Tortil Uwaike, Ke'Shan Lighty Lawson Zimmerman (leads) and Lifeng Zhang (mentor).

The NTEC program is implemented across NNCI sites on an entirely voluntary basis (there is no requirement for sites to participate). Figure 9 summarizes the schedule for the 2025 NNCI NTEC program. Tentatively, the program will be announced by the NNCI Coordinating Office on January 8, 2025 with applications due February 11, 2025 (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).

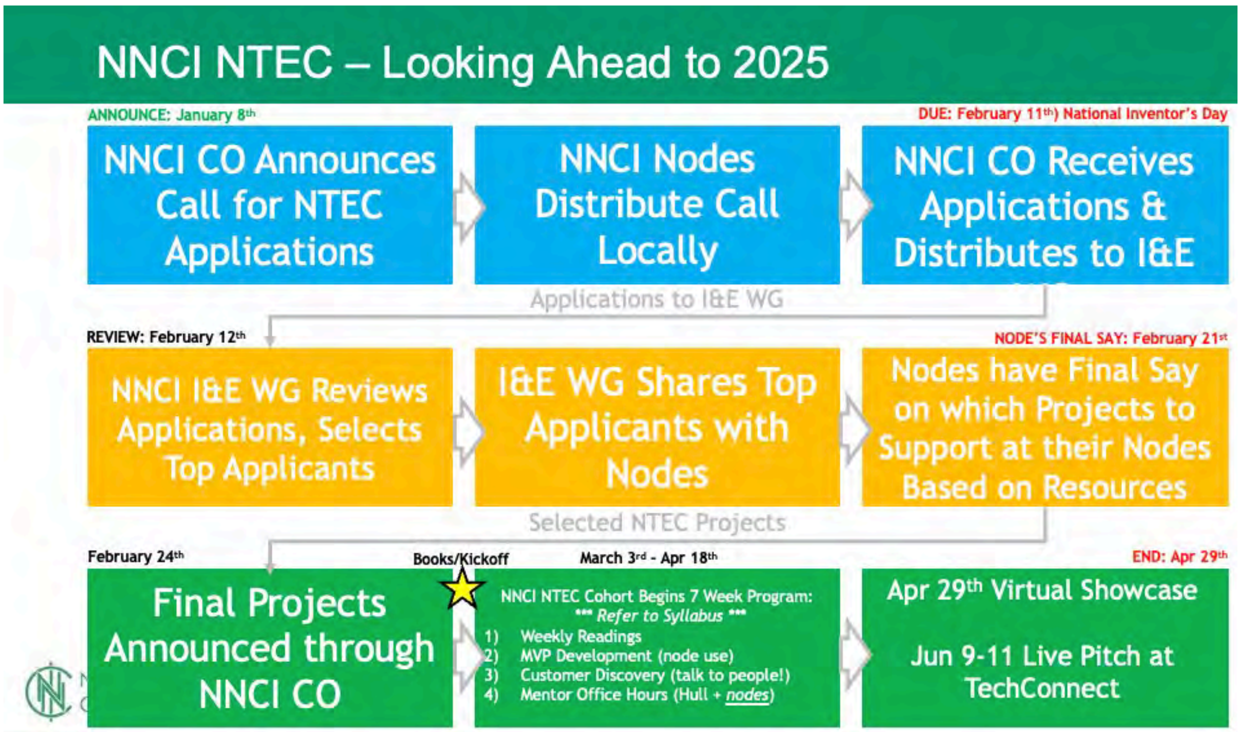


Figure 9: Timeline for the 2025 NNCI NTEC Program

In 2025, once again, an additional $20,000 will be available from the NNCI coordinating office to support NTEC awards at NNCI sites. This funding will allow the allocation of up to $1,000 per site with $4,000 available as an incentive for top teams. We anticipate a single award type of $1,000 per award. Winning teams will 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. New in 2025 will be the inclusion of a weekly "entrepreneurship fireside chat" to be offered by guest speakers from across NNCI sites. The 2025 NNCI-wide virtual NTEC showcase is expected to occur in late April 2025. New in 2025 we expect to invite the top three NTEC teams (from the virtual showcase) to participate in a live pitch event during a special "Future Innovators" session at the TechConnect

World Innovation Conference & Expo to be held in Austin, TX, June 9-11, 2025. The live event is expected to offer a unique opportunity to recognize the top student/post-doc innovators and entrepreneurs from across the NNCI.

Entrepreneurs-in-Residence (EiR)

Currently, there are four identified NNCI EiRs as shown in Table 5. The I&E Assoc. Director serves as the NNCI EiR in situations where a site-specific EiR has not been identified. In 2025, we will continue to 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 5: NNCI Site Entrepreneurs-in-Residence

Site	EiR
MONT	Trevor Huffmaster
SDNI	Yves Theriault (students and postdocs)
NNI	Mike Robinson
NanoEarth	Matthew Hull
NNCI (when no local site EiR is available)	Matthew Hull

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 6). 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 replaced by the new Associate Director and working group. The New Equipment and Research subcommittee was refocused on Research and Funding Opportunities. A new subcommittee on Nanotechnology Infrastructure of the Future was added. During 2023, two of the subcommittees completed their work and were sunsetted, as indicated below. Reports of the subcommittees on current and future activities are presented below as provided by the subcommittee chairs.

Table 6: NNCI Executive Committee Subcommittees (2024)

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 – sunset 2023	Jim Cahoon (RTNN), Chris Ober (CNF)
Nanotechnology Infrastructure of the Future	Debbie Senesky (nano@stanford)
Building the User Base – sunset 2023	Shyam Aravamudhan (SENIC)

5.1. Diversity Subcommittee

The following describes Diversity, Equity, and Inclusion (DEI) Initiatives across the NNCI in 2024:

Harvard CNS

This year we celebrated completion of the 1st Quantum Noir. Quantum Noir is a meeting/summer school focused on connecting scientists of color, and others, to each other and to the greater

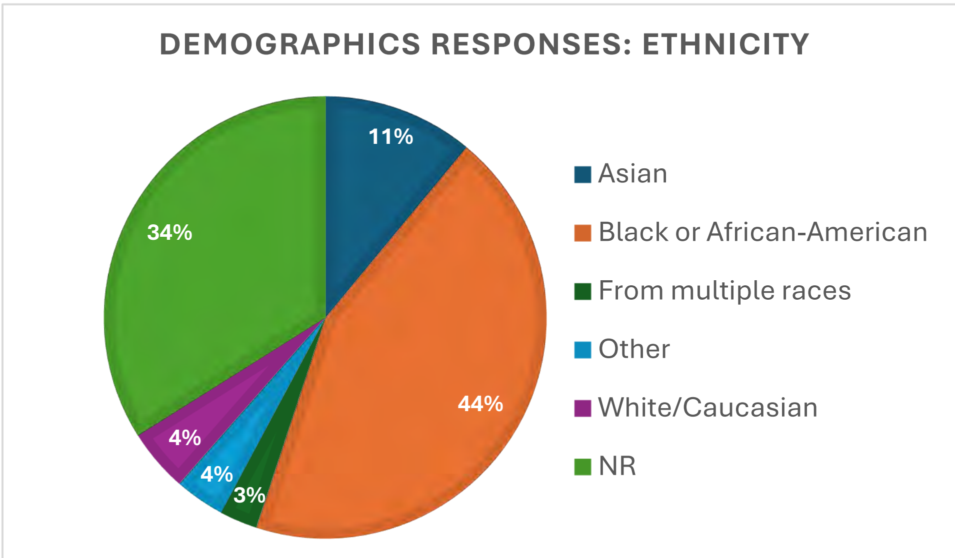
Quantum research community. Modeled somewhat after the Conference for African American Researchers in the Mathematical Sciences (CAARMS), Quantum Noir has a community building focus, but also has a topical focus, similar to a Gordon Research Conference. This past year the primary theme was an overall mapping of Quantum Information, Quantum Networking, and Quantum Materials, from fundamental principles to device advances and implementations and an overall view of the system possibilities and applications.

Topical sessions explored for the First Meeting held June 11-14, 2024:

- *Quantum/Nano Materials (theory / experiments)*
- *Quantum Devices (systems / applications)*
- *Quantum Bio (systems / devices / applications)*
- *NanoPhotonics (systems / devices / applications)*
- *Poster Session (Grad Student focused / student travel support provided)*
- *Start-up landscape*
- *Funding Agencies*

The program was assembled by a geographically diverse program committee which was comprised of faculty and industry researchers of color from around the nation. The initial members are Chairman William L. Wilson (PI), Harvard University, and Co-Chairs Dean Nadya Mason, University of Chicago; Professor Charles Brown Yale University; Dean Kimani Toussaint, Brown University; Professor Deji Akinwande, University of Texas; Professor Thomas Searles, University of Illinois at Chicago; Professor Stephon Alexander, Brown University; Dr. Kenneth Evans-Lutterodt, Brookhaven National Laboratories; Dr. Donnell Walton, Corning Corporation; Professor Trevor David Rhone, Rensselaer Polytechnic Institute; Professor Jacob Gayles, University of Southern Florida; Professor Boubacar Kante, University of California; and Dr. Kayla Lee, IBM Corporation. The program was highlighted by a welcome from 2023 Noble Prize winner Prof. Moungi Bawendi, MIT. Moreover, Professors Misha Lukin, Harvard University, and Pablo Jarillo-Herrero, MIT gave spectacular talks on Rydberg Atom Quantum Logic and Moiré Quantum Materials respectively.

Importantly, we used Quantum Noir 2024 to connect researchers not only to each other and the community, but also to the available tools, technology, and resources of the trade. We chose to have the first meeting in Cambridge because the Harvard/MIT research community has been heavily engaged as international leaders in Quantum Materials and Device development. The Quantum Materials Science (QMS), Quantum Networking, and Quantum Information Science (QIS) thrusts supported by the Harvard University Center for Nanoscale Systems (CNS) has driven technology advances in nanophotonics, nanoelectronics, and nanobio engineering, not only leading to cutting edge discoveries but also several efforts that have moved on to commercialization. Driven by work at the NSF funded Center for Integrated Quantum Materials (CIQM), this community has contributed transformational work in quantum materials and device research and is poised to help connect and train the next generation of quantum researchers.



Harvard CNS and the Harvard Physics Department hosted the meeting, and this first Quantum Noir we took full advantage of the local expertise and this technology base as is evident in the schedule. Innovative faculty from Harvard, MIT, and others helped make the first meeting a spectacular success.

The broader impacts were essentially defined by the basic goals of Quantum Noir and were all on display.

Quantum Noir Goals:

- Creation of a community building event for folks in Quantum/NanoScience and Engineering broadly cast.
- Create an opportunity for grad students and post-doctoral researchers to get a full flavor of the frontiers of Quantum/NanoScience by exposing them to the leaders of relevant fields. (a bit of recruiting for this space)
- Offering a collaborative and networking opportunity for researchers and junior faculty of color in the Quantum/Nano Space, particularly those from small and/or minority serving intuitions. Here we can connect innovators to tools and materials enabling their contributions.
- Creating an opportunity for junior faculty to meet and network with federal funders (NSF/DOE/DOD) to help focus efforts on priorities for the nation.
- Creating an opportunity for Quantum and Nano researchers to meet and network with entrepreneurs and VCs focused on this branch of science.

Integrating, diversifying, expanding, and optimizing the Quantum research community is key; we are leaving no one behind as we marshal and educate our nation's human technical resources to take on the Quantum Challenge.

Research Triangle Nanotechnology Network (RTNN)

RTNN sustains its commitment to inclusion and promoting diversity in all activities including staffing, participants in programs and outreach, and representation in programs. Many education and outreach activities target diverse communities with high representation of women or girls in STEM, under-represented minorities (URM), underprivileged youth (e.g., Title-1 Schools), or in rural areas – including indigenous communities on tribal land. ~50% of Year 9 outreach events had >50% participation by under-represented groups including URM, indigenous, and/or women/girl participants. To date, REU participants have included >35% Under-Represented and >50% women. 4/4 community college interns to date are women seeking careers in science and engineering. The Coursera course gives an overview of nanotechnology tools and techniques and shows demonstrations within RTNN facilities by students, with an emphasis on the demographic diversity of the instructors and student lab demonstrators.

Students from the Future Successors program for underprivileged youth spend a day learning about nanotechnology via activities, tours, and trying on a cleanroom suit.

Cornell NanoScale Facility (CNF)

Since 1977, the Cornell NanoScale Science & Technology Facility (CNF) has engaged in efforts to broaden participation in nanoscience, taking a broad view of the many research fields reflected within the science and non-science communities. We take pride in providing access to any person interested in any application of nanofabrication.

For thirty-four years, CNF has hosted a NSF-funded Research Experiences for Undergraduates (REU) program. The CNF REU program is a hands-on, immersive ten-week summer research program for exceptional undergraduates selected from a diverse, highly talented pool of applicants. To date over 335 students have participated in the REU program.

This past year, CNF supported six undergraduates for the CNF REU program and specifically worked with the Cornell College of Engineering to support a Morgan State University CNF REU student. In addition, we incorporated four undergraduates hired via Prof. H. Grace Xing's Army Educational Outreach Program (AEOP). To assist several smaller summer programs on campus, we managed the logistics for five additional students including two hosted by our new Associated Director, Prof. Allison Godwin. Additionally, seven students from the 2023 NNCI REU class and 4 students from the NNCI Global Quantum Leap program traveled to Japan to work with our partners at the National Institute for Materials Science (NIMS) in Tsukuba. These competitive programs provided unique learning opportunities for all who participated (see photo).

2024 CNF REU summer program cohort

CNF supports diverse education and outreach efforts spanning K-12, post-secondary, professional, and public audiences (see photos below). In 2024, CNF reached over 9,000 individuals through 140 events, including national meetings and K-12 classroom visits.

This year, CNF hosted four summer interns supported by NORDTECH workforce development funds and one intern through an NSF FuSe proposal, focusing on hands-on training, cleanroom operations, and advanced research. CNF staff members played key mentoring roles, ensuring the interns gained valuable skills and experience to support their career development.

CNF continues to offer the Technology and Characterization at the Nanoscale (TCN) short course and its annual outreach events, including Tompkins County Expanding Your Horizons-a weekend of on-campus STEM activities for middle school girls, 4-H Career Explorations - two days of STEAM activities on campus (Cornell serves as the land grant school for New York State and is therefore the headquarters for NYS 4-H), New York State Fair, alumni reunion tours, Kangaroo Math, and various science classroom visits. The CNF continued hosting the FIRST LEGO Expo, where 200 middle-school students showed off their "Masterpiece" LEGO creations. The CNF staff, CNF ambassadors and Cornell's Society of Women Engineers volunteered to judge the LEGO creations and hand out group awards. The annual CNF Nanoday event, which welcomed 500 attendees for a public, nano-focused STEM experience, was the year's largest and most successful event. 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 100,000 copies have been distributed this year. The focus of all Nanooze issues is to excite and recruit a diverse community of students to the nanoscience field.

Education and Outreach: High purity welding program, Micron Chip camps, FIRST LEGO Expo, Microelectronics and nanofabrication Veterans program.

CNF partners with Tompkins Cortland Community College (TC3) to provide workforce development opportunities for veterans, Native Americans, un/underemployed and underrepresented workers, and economically and academically disadvantaged students. Our partnership with TC3 supports curriculum development, microcredential programs, and new equipment for semiconductor education. Collaborating with TC3 and Penn State, we hosted our first microelectronics and nanofabrication cohort for veterans and their dependents. CNF continues its work with NYS BOCES, including the successful CNF ATLAS program for high school seniors, which has led to summer REU placements and paid internships at the CNF. To meet workforce needs, we launched an ultrahigh-purity welding program with TST BOCES and Swagelok, certifying nine BOCES instructors in orbital welding. A two-year CTE program with OCM BOCES and TC3, combining electronics, mechatronics, and nanofabrication training, began in fall 2024.

Our most innovative initiative is digital and VR education, developed with e-Cornell and the Cornell Center for Teaching Innovation. These tools teach semiconductor processing and workforce readiness nationwide. With NORDTECH funding, we've completed seven VR modules (Youth Outreach, Gowning, Cleanroom Safety, and photolithography). Future plans include public engagement and industry-specific guided fabrication modules.

Annually, CNF presents the Whetten Memorial Award in recognition of women scientists whose work and professional lives exemplify a commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and enthusiasm for life. The 2024 award was presented to Kathleen Smith from Applied and Engineering Physics, Cornell University.

Over the years, CNF has been an active member of the NNCI Diversity Subcommittee, bringing concerns to the CNF staff for discernment. In addition, we collaborate with Cornell Diversity Programs in Engineering to recruit students to Cornell and to studies in nanoscience and engineering. Finally, CNF takes part in Cornell-required annual training activities that provide staff with the opportunity to learn and develop practical skills for cultivating a diverse, equitable, and inclusive workplace that fosters a culture of belonging.

Univ. of Washington and Oregon State Univ. (NNI)

NNI faculties have implemented comprehensive diversity and inclusion efforts to create a more equitable and supportive environment for users, staff, and faculty. These initiatives include several areas, including inclusive recruiting and hiring processes, training opportunities, research opportunities for underrepresented groups in STEM, and support programs for high-risk first-year students.

UW and OSU offer a variety of diversity seminars and initiatives at the university and college levels for staff, faculty, and graduate students. Anti-bias training is mandated for all faculty and senior staff, and a semester-long DEI seminar is required for all incoming graduate students. This seminar helps build a collaborative learning environment that validates diverse life experiences and promotes understanding across different cultural backgrounds and perspectives.

Search advocates training teaching faculty to look for biases in the hiring process. Every search committee at OSU has a search advocate from a different unit trained to identify and mitigate potential unconscious biases during recruitment. At each step (phone interviews, onsite interviews, etc.), a neutral party reviews the interview list.

Outreach to underrepresented students (high school and undergraduates) has returned to the pre-pandemic levels. During the weeklong Summer Experience in Science and Engineering for Youth program, OSU hosted 10 high school students from underrepresented groups for nanotechnology-related research projects. NNI welcomed 8,000 students from 4^{th} to 8^{th} grades to campus, in collaboration with the UW College of Engineering, for two days of hands-on projects and interactive exhibits demonstrating nanotechnology and nanomedicine.

NNI continues to support UW Engineering's Dean's Scholars Program, a year-long college transition program focused on supporting high-risk first-year students with preparatory coursework in chemistry, physics, and math, dedicated advising, scholarships, and cohort-building.

NNI facilities provide undergraduate assistants with hands-on experience immediately relevant to industry employment needs. In this the past year, the WNF employed 12 student lab assistants in the cleanroom, including 6 women and 2 students from the Pathways for Inclusive Excellence (PIE) program. Funding and mentoring by Intel and WNF staff was provided for three 6–9-month undergraduate research projects. The MAF employed 3 student assistants, including one Native/Pacific Islander, and OSU employed 7 undergraduates within NNI-supported facilities.

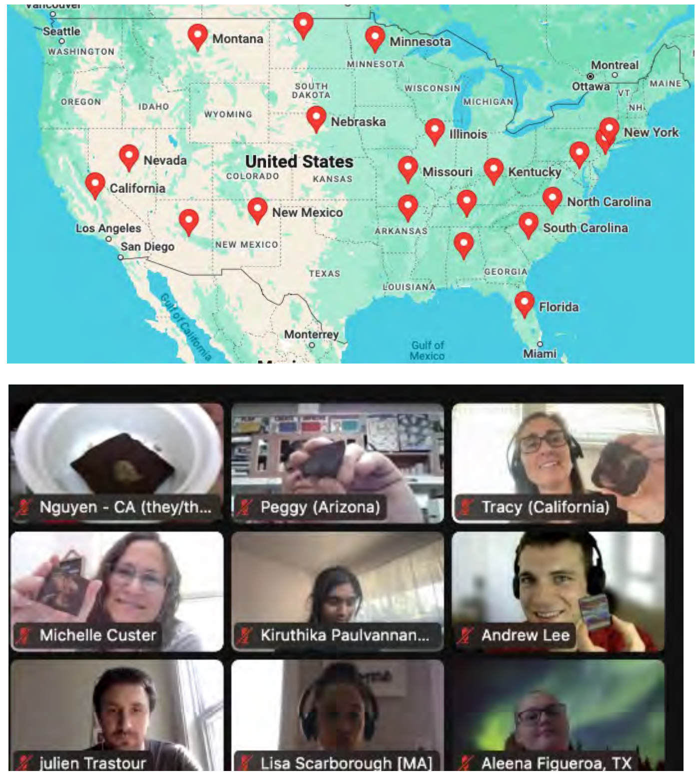
nano@stanford

The diversity, equity, and inclusion initiatives at nano@stanford in year 9 have been integrated into: (i) our community college internship program, (ii) the middle school teacher program, (iii) outreach activities, and (iv) the development of learning content.

nano@stanford interns presented their lab support project to an executive from Intel.

Our year-round, community college internship program is a hands-on, paid experience in nanotechnology for students from ~11 local colleges. While the interns learn transferable technical and professional/durable skills, the lab benefits from extra staff and user support. We trained 25 students in year 9, thanks to additional funding from Microelectronics Commons and Intel which helped support the higher number of interns as well as a 0.5 FTE intern coordinator. We intentionally target minority serving institutions (MSI) during recruitment and 76% of our interns have been from underrepresented groups and 60% have been female. Out of the 35 interns since 2018, 19 transferred to 4-year institutions, 2 accepted full-time jobs at startups, 1 interned at Intel, 1 was a summer research assistant in a Stanford professor's lab, 1 was hired as full-time staff at SNF,1 is now an MSE Masters student at Stanford, and 1 is a Ph.D. candidate at MIT.

The Nanoscience Summer Institute for Middle School Teachers (NanoSIMST) is a professional development workshop during which participants learn about nanoscience and develop classroom lessons. Since 2017, NanoSIMST has expanded into a network-wide initiative, led by nano@stanford. In year 9, 52 teachers were trained nationwide with 12 NNCI sites participating by either running an in-person program or sponsoring virtual teachers from their areas. Based on historical NanoSIMST implementation data, we estimate that these teachers will reach 3,900 students with nanoscience lessons in year 9, bringing the total number of students impacted since 2017 to over 13,800. Program growth this year was further supported by the Microelectronics Commons NW-AI-Hub, which supported the stipends of 11 virtual teachers and an additional teacher facilitator. We strategically select diverse teacher cohorts based on subject expertise and the demographics of their schools. The introduction of the virtual version of the workshop in 2020 has enabled us to reach a higher number of teachers from Title 1 schools. In year 9, 71% of participants taught at a Title 1 school. For the 2nd year in a row, we hosted a field trip for 150 eighth graders from a Title 1 school, where a NanoSIMST alumna teaches.



(top) Geographic distribution of year 9 NanoSIMST participants. (bottom) Teachers experiencing a chocolate lithography activity during the virtual NanoSIMST workshop.

nano@stanford continues to serve our greater community with numerous outreach events that prioritize experiential learning and reached 7000 participants in year 9. By specifically hosting groups from MSIs and Title 1 schools, we are confident that at least 1475 of these participants were underserved students. In year 9 we have continued to create content for our edX courses, reaching ~12K learners from 143 countries since 2019.

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, UPenn), Yu-Hwa Lo (UCSD), Sherine Obare (SENIC, UNCG and JSNN), 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 2024 subcommittee report summarizes the exchange of thoughts among committee members. Communication between subcommittee members took place via e-mail and in-person, e.g., at the NNCI annual conference hosted by the University of Louisville and organized by KY Multiscale in October 2024.

Closing the M&A Subcommittee's Work

The subcommittee has reached consensus that the necessary metrics for assessing NNCI have been identified. This conclusion manifests through a now static state in the requested metrics. This year's report entreaties the same metrics as last year's, sustaining — but not increasing — the high level of data collection effort previously required from the centers. By achieving this asymptotic saturation of requested information, consistency and comparability across reports are promoted, establishing a standard for a post-NNCI network.

Concluding Suggestions of the M&A Subcommittee

The M&A subcommittee recommends that centers explore alternative approaches for measuring and communicating site interactions in addition to quantitative metrics. The subcommittee fosters the collection of anecdotal evidence in addition to the existing metrics. Such narratives will play a prominent role in the final report and involve emphasizing the diversity in size, expertise, and strengths across NNCI sites. The approach helps achieve a core objective of NNCI: communicating how leveraging diversity among the various sites generates measurable synergies that drive the nationwide advancement of nanotechnology.

One of the primary assets driving NNCI's synergies are its research communities, which include Nanotechnology Convergence, Nanoscience in the Earth and Environmental Sciences, Nano-Enabled Internet-of-Things, Transform Quantum, Understanding the Rules of Life, and Microelectronics/Semiconductors. These communities organize workshops that are open to the broader public, helping to expand the user base of NNCI sites and raise awareness of NNCI. The impact of NNCI's research communities goes well beyond the NNCI sites and even beyond the nation but includes international impact as well. For instance, Professor Jacob Jones, leader of the Nanotechnology Convergence research community, delivered a keynote address at the 2024 conference "Nanotechnology Convergence for Sustainable Energy, Environment, Climate Change, and Health: A US-Africa Conference" in Casablanca, Morocco. His presentation, titled "Leveraging Nanotechnology Applications to Address Climate Change," highlighted the role of nanotechnology in tackling climate challenges and reflected work of the research community he leads. Additionally, the group published an article on this topic in the journal *Environment Systems and Decisions* (https://doi.org/10.1007/s10669-024-09991-w). Similarly, NNCI Director David Gottfried, in collaboration with colleagues in Australia and the EU, is initiating the establishment of a global nanofabrication network of networks. NNCI will send a delegation to the European Symposium on Nanofabrication Research Infrastructure to meet with NNCI counterparts from EuroNanoLab and the Australian National Fabrication Facility. Similarly, the research community Transform Quantum is a part of the Global Quantum Leap, an international network of networks that connects key nodes within NNCI and complementary networks in the US and worldwide, all focused on advancing quantum technologies.

Much like the research communities, NNCI's working groups have their own success stories. These groups bring together facility staff as well as specialists in SEI, education/outreach, and entrepreneurship to exchange best practices, experiences, and resources. They include network support, technical, and education/outreach working groups. Unlike the research communities, new working groups continue to be formed, even in this later phase of NNCI, including a new working group exploring mutual support of research projects by NNCI and DOE NSRC facilities, based on discussions begun at the October 2024 Annual Conference. The concepts of research communities and working groups will stand out as best practices for any post-NNCI nanotechnology network.

Members: Christian Binek (NNF/Nebraska), Trevor Thornton (NCI-SW/Arizona State University), 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 core objectives of the Global and Regional Interactions (GRI) subcommittee are to:

1. Engage and leverage NNCI node activities with regional programs and local institutions.
2. Explore plans to connect the NNCI network with analogous programs worldwide.
3. Encourage individual NNCI sites to identify local partners and regional collaborators.

In 2024, the GRI subcommittee convened regularly, fostering discussions and sharing experiences among members. Below are highlights of activities and initiatives that exemplify the regional and global impact of the NNCI network. The details of individual site programs and initiatives are listed in individual site reports. Herein is the summary of actions and activities.

Regional Collaborations: Metropolitan hubs actively collaborate with academic and research institutions to strengthen workforce development, facilitate outreach, and enhance regional partnerships. Key efforts include:

- Leading collaborative programs to provide research experiences for undergraduates and teachers.
- Hosting annual regional events to promote nanotechnology initiatives.
- Engaging in outreach activities targeting high schools, community colleges, and museums.
- Strengthening ties with diverse educational institutions to advance workforce development and inclusion.

Workforce Development and Economic Growth: Several NNCI sites have implemented impactful workforce development initiatives, such as:

- Offering training programs for veterans and underrepresented groups to prepare them for roles in the semiconductor industry and technical fields.
- Collaborating with local agencies to create high-paying job opportunities and address regional economic needs.
- Participating in CHIPS Act-related activities to foster innovation and expand educational initiatives.

Global and National Engagement

NNCI sites contribute significantly to global and national nanotechnology advancements by:

- Hosting student showcases, career fairs, and international research experiences to bridge academia and industry.
- Leading international collaborations and exchange programs to share expertise and foster innovation.
- Developing training programs and cleanroom education initiatives to support emerging technologies.

The subcommittee acknowledges various innovative approaches NNCI sites employ to expand their regional and global impact. Moving forward, the GRI subcommittee may prioritize initiatives like staff exchanges and AI/ML integration across networks to strengthen collaboration and elevate the NNCI's global presence.

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

5.4. Nanotechnology Infrastructure of the Future

At the end of year 8, the NNCI Nanotechnology Infrastructure of the Future Subcommittee hosted "The Workshop on Nanotechnology Infrastructure of the Future", a two-day interactive workshop to gather feedback and identify opportunities for future national nanotechnology infrastructure resources. The workshop organizing committee was comprised of Futures Subcommittee members, as well as other NNCI volunteers (e.g., Shyam Aravamudhan (SENIC), Matthew Hull (NanoEarth), Mikkel Thomas (SENIC), Jameson Wetmore (NCI-SW)).

Report to the National Science Foundation on

THE WORKSHOP ON NANOTECHNOLOGY INFRASTRUCTURE OF THE FUTURE

HELD SEPTEMBER 12-13, 2023, AT THE NATIONAL ACADEMY OF SCIENCES, IN WASHINGTON DC AND ONLINE

Chair: Debbie G. Senesky (Stanford University)

Co-chairs: David Gottfried (Georgia Institute of Technology), Sara Ostrowski (Stanford University), and Yuhwa Lo (University of California-San Diego)

Committee: Shyam Aravamudhan (NC A&T State University), David Dickensheets (Montana State University), Maria Huffman (University of Washington), Matthew Hull (Virginia Tech), Nan Jokerst (Duke University), Steven Koester (University of Minnesota), Mary Tang (Stanford University), Mikkel Thomas (Georgia Institute of Technology), Robert Westervelt (Harvard University), Jameson Wetmore (Arizona State University)

Invited Guest Speakers/Panelists: Debbie G. Senesky (Stanford University), David Gottfried (Georgia Institute of Technology), Mihail Roco (NSf), Mary Tang (Stanford University), Branden Brough, (NNCO), James Moore (NSF Directorate For EHR), Melissa Cowan (Intel), Jeffrey Miller (Kavli Foundation), Victor Zhirnov (Semiconductor Research Corporation), Cherie Kagan (University Of Pennsylvania), Nadia Carlsten (SandboxAQ), Jared Ashcroft (Micro-Nano Technology Education Center), Rae Ostman (National Informal Stem Education Network), Tavarez Holston (Georgia Piedmont Technical College), Holly Leddy (Duke University), Landon Loeber (Micron Technology), Lora Weiss (Chips R&D Program Office), Barry Johnson (NSF-TIP), Richard Schneider (Google), Ira Bennett (Arizona State University), Vijay Narasimhan (EMD Electronics), Raymond Samuel (NC A&T State University), Philip Hockberger (Waymaker Group), Christopher Gourlay (Australian National Fabrication Facility), Michael Spencer (Morgan State University).

Workshop Facilitator: Nexight Group, LLC

National Nanotechnology Coordinated Infrastructure

Early during Year 9, the organizing committee continued to meet weekly to review the output from the workshop and write a public-facing white paper. The white paper was officially published online on December 8, 2023. More details about the major takeaways and recommendations from the workshop can be found in the full white paper, which is available on the NNCI website.

Debbie Senesky presented on behalf of the subcommittee at the Shared Infrastructure Network Collaboration (SINC) meeting held in conjunction with the NNCI Annual Conference in Louisville, KY in October 2024. During the

SINC meeting, and during the NNCI conference itself, NNCI and NSRC directors and federal government leaders explored opportunities to increase collaboration across nanotechnology infrastructure programs, including collaborative pilot projects, government trends, and the incorporation of regional ecosystems.

In Year 10, the subcommittee will remain on standby to serve as the central NNCI team to respond to any NSF requests for additional information or recommendations related to the next call for proposals.

Members: Debbie G. Senesky (nano@stanford), David Dickensheets (MONT), David Gottfried (SENIC), Maria Huffman (NNI), Nan Jokerst (RTNN), Steven Koester (MiNIC), Shamus McNamara (KY Multiscale), Christopher Ober (CNF), Sara Ostrowski (nano@stanford), Mary Tang (nano@stanford), Andrea Tao (SDNI), Robert Westervelt (CNS)

6. Working Groups

One of the greatest strengths of the NNCI network is the combined staff expertise of 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 7) 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 of the working groups was examined, and some changes implemented, and all working groups were opened to new members from NNCI staff. During 2023, a new working group on Regional Networks was added.

Table 7: NNCI Working Groups (2023)

Working Group Topic	Working Group Lead(s)
Network Support Working Groups	
Equipment Maintenance	Jeremy Clark (Cornell)
Vendor Relations - inactive	Charles Veith (Univ. Pennsylvania)
Environmental Health & Safety	Andrew Lingley (Montana State Univ.)
Regional Networks	Ron Olson (Cornell)
Technical Working Groups	
E-Beam Lithography	Devin Brown (Georgia Tech) Stanley Lin (Stanford)
Etch Processing	Ling Xie (Harvard)
Photolithography	Pat Watson (Univ. Pennsylvania)
Atomic Layer Deposition	Mac Hathaway (Harvard)
Imaging and Analysis	David Bell (Harvard)

Education and Outreach	
K-12 and Community	
Workforce Development and Community Colleges	Andrew Lingley (Montana State Univ.)
Evaluation and Assessment	Jessica Hauer (Arizona State)
Technical Content Development	Daniella Duran (Stanford) Eric Johnston (Univ. Pennsylvania)
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 9, 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. When travel is an option, the Coordinating Office provides financial support (up to $1000 travel funding each for 5 attendees) to encourage staff participation. Recent events included:

- NNCI Education Symposium, Nov. 11, 2023 (UC San Diego)
- NNCI Etch Symposium, April 24-26, 2024 (Georgia Tech)

Received reports of current working groups, as provided by the leads, are presented below. 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 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 primarily vacuum and RF process equipment, as well as chemical sources. Most of this information continues to be unavailable directly from vendors and is often difficult to relay in public forums. We have assisted with vendor selection by smaller, newer labs, and made productive suggestions to several vendors.

We will continue to create opportunities to share our tribal knowledge with each other, particularly notes on alternative sourcing of OEM parts, the pros and cons of software upgrades, as well as critical reviews of newer vendors.

Members: Jeremy Clark (Cornell), Mary Tang (Stanford), Bob Geil (UNC-Chapel Hill), Jesse James (UT-Austin), Kyle Keenan (UPenn), 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. Environmental Health & Safety

The NNCI EH&S Group met in May 2024 and had a productive discussion covering a variety of topics. First, we disseminated literature and information that Grant Shao of Stanford had collected from a working group on tetramethyl ammonium hydroxide (TMAH) that was started from the MIT LabNetwork listserv. We also included Mary Tang's presentation from UGIM 2022 on TMAH safety.

Next, we discussed calcium gluconate expiration dates and prices and found a few less expensive options for purchasing this necessary antidote to hydrofluoric acid exposure.

We also discussed ALD exhaust safety, and the differences in academic versus industrial settings with respect to the CVD exhaust and the volumes involved. One solution is to use a mist eliminator or similar device before the pump to increase the surface area and react out the excess precursor. Another is to use a fluorinated oil pump, although several attendees said they had better pump lifetimes with dry pumps. Several attendees were locked into using Ebara pumps and some used Edwards exclusively, and we discussed the merits of and tradeoffs of using N2 purges. We also briefly talked about how ALD/chopping valves and other components can get contaminated and need replacement. An anecdote was shared about an LPCVD wet pump running dichlorosilane that seized up and caused an exhaust duct clog. The clogged duct created a fire in the stainless duct when there was an attempt to clean it out.

Then we moved into a discussion about toxic gas monitoring systems (TGMS). This was initiated in part by a discussion of GaN/GaAs etching in chlorine systems (CMP is a more common EH&S topic regarding these materials.). We discussed the Midas units and PS7s, and some of the failure modes, like cartridges failing or having dead cells, or filters or pumps failing. We talked about contracting companies to do maintenance, including Honeywell, and EERC (https://undeerc.org/). For some facilities, this type of maintenance comes out of the building maintenance funds and not core facility budgets.

This led to a discussion about how university risk assessments through companies like FM Global can prompt the university to pay for upgrades (e.g. safety shower curtains, first aid kits, wet benches, hydrogen tanks, gas cabinets, etc.).

Members:

Name	Affiliation	Name	Affiliation
Andrew Lingley	MONT (Montana State)	Mary Tang	nano@stanford (Stanford)
Nasir Basit	SHyNE (Northwestern)	Hang Chen	SENIC (Georgia Tech)
Brian Olmsted	MiNiC (Univ. Minnesota)	Grant Shao	nano@stanford (Stanford)
Philip Infante	CNF (Cornell)	Darick Baker	NNI (Univ. Washington)
Mark Walters	RTNN (Duke)	Philip Barletta	RTNN (NCSU)

6.3. Regional Networks

We held our regional network working group meeting on June 17, 2024. The following NNCI regional networks were present: Northern Nano Lab Alliance (NNLA), Southeastern Nano Facility Networks (SENFN), Mid-Atlantic Nanofab Managers Meeting (MANTH), Northwest Nanotechnology Laboratory Alliance (NWNLA), Ohio Valley Nano+AM Regional Network, RTNN Affiliates Network, and the NY State Nanotechnology Network (NNN).

Several questions for discussion were proposed:

1. Have the goals and missions of the regional networks changed?
2. Tell us about upcoming events and their objectives.
3. How can we measure the success of these regional networks?
4. How can regional networks be leveraged in the next NNCI?

<u>NY State Nanotechnology Network (NNN)</u>

Ron Olson shared updates on the NNN activities and goals. The focus remained on workforce development and regional collaboration, particularly within the New York State region. The NNN has emphasized efforts in education, outreach, and creating opportunities like internships and co-ops for students. The next NNN event is scheduled for September 27, 2024 at Rochester Institute of Technology. This event aims to showcase local talent to industry partners, fostering collaboration and highlighting research projects. In terms of measuring success, the NNN currently tracks attendance numbers but are exploring methods to assess more impactful outcomes like job placements or internship connections.

<u>Northern Nano Lab Alliance (NNLA)</u>

James Marti from University of Minnesota described their regional group's focus since 2016, emphasizing logistical support, tool sharing, and best practices. Their primary mission has been to assist facilities managers, especially at smaller institutions lacking extensive resources, or comprehensive support teams. While their historical focus has been on logistical support, recently they have begun considering education and workforce development, particularly engaging community and technical colleges. They aim to support these institutions in graduating students interested in emerging technologies. James mentioned upcoming events, including efforts to organize another in-person meeting to foster collaboration and engagement among members. MiNIC measures success by the level of participation and engagement within their regional network, particularly in taking on new initiatives and sustaining them over time.

<u>Mid-Atlantic Nanofab Managers Meeting</u>

Pat Watson and Eric Johnston discussed their regional group's efforts to connect various institutions like Princeton and University of Delaware, within their region, emphasizing collaboration and resource sharing. They highlighted the evolution of their twice-yearly meetings, initially spearheaded by Noah Clay and Meredith Metzler, focusing on topics of interest. They noted the abundance of nano fabs in the region and their intention to leverage these resources more effectively. Recent meetings have included topics like safety and reservation systems, with plans for future sessions at NYU and discussions on standardizing onboarding processes and safety training.

<u>Southeastern Nano Facility Networks (SENFN)</u>

Walter Henderson and Gary Spinner discussed the revival of their regional network, focusing on sharing best practices and coordinating meetings among universities in the southeastern states. They highlighted the initial show-and-tell format, transition to virtual meetings during the pandemic, and plans for an upcoming in-person meeting in early 2025. The group currently includes a core of about a dozen participants from 10 universities, with broader engagement during planned events. They emphasized the value of regular monthly meetings (3rd Friday of every month) for maintaining momentum and knowledge sharing among members. measuring success by increasing participation across universities and potentially tracking job outcomes through platforms like LinkedIn.

Ohio Valley Nano+AM Regional Network

Ana Galiano from the University of Louisville discussed upcoming events such as the NNCI Nano and Manufacturing Summit in July and the NNCI conference in October. She highlighted their approach to measuring success through participant feedback via surveys, evaluating attendee satisfaction, and tracking metrics like registrations, sponsorships, and abstract submissions. Ana emphasized the importance of outreach beyond their immediate area and noted their efforts in workforce development, including new teachers' educational programs and the renewal of their Research Experiences for Undergraduates (REU) program. She stressed the significance of long-term impact assessment by tracking alumni via LinkedIn to monitor career progression and professional achievements.

Northwest Nanotechnology Laboratory Alliance (NWNLA)

Andrew Lingley provided an update on the Northwest Nanolab Alliance's recent activities. They held two meetings, one virtual in 2021 with around 100 attendees and another in-person in 2023 with approximately 60 participants. The alliance focuses on regional collaboration and uses subgroup conversations and polls to determine meeting topics, ensuring broad participation and relevance. Andrew mentioned ongoing efforts to gather feedback through surveys to assess both qualitative and quantitative aspects of attendee satisfaction. Looking ahead, they aim to enhance interaction with other networks like UGIM, exploring synergies in topics such as staffing and facilities management. The NWNLA tracks attendance numbers and conducts surveys to gather qualitative feedback, focusing on participant satisfaction and preferences. The regional aspect of the alliance is valuable, especially for smaller institutions and facility managers who found networking and shared problem-solving beneficial.

RTNN Affiliates Network

Phillip Strader discussed the role and challenges of regional networks affiliated with the NNCI. These networks, though not directly funded by NNCI grants, offer specialized equipment and capabilities not always available in core facilities. Phillip emphasized the importance of not overburdening these affiliates. The RTNN network measures success by the number of users and facilities utilized. Looking forward, there's consideration of restructuring to include topical networks alongside regional ones, accommodating facilities like nano fibers that may not fit into traditional regional definitions. Future plans also include evaluating the role and criteria for inclusion in these networks and balancing geographical proximity.

General discussion around lab management software

Brian K. Olmsted later discussed the alliance's consideration of lab management software, specifically Book It Labs, emphasizing the potential benefits of a unified platform across regional labs for scheduling, communication, and resource sharing. They are in the process of transitioning to Book It Labs despite initial plans for NEMO, driven by the software's functionality.

Ana Galiano discussed the use of Facility Online Management software (FOM) at the University of Louisville. The software integrates core facilities across universities in Kentucky, including the University of Kentucky. It enables equipment visibility between institutions, facilitates data capture for NNCI reports, and offers features like online calendars for remote equipment booking and billing options. However, there's a current push to potentially replace FOM with another software, causing concern due to established multi-scale functionalities. Discussions explored the idea of standardizing lab management software regionally to streamline operations and collaboration across universities.

Ron Olson mentioned the potential of regional networks to streamline access to equipment across universities, facilitating faster project execution. He suggests expanding this concept nationally, envisioning a centralized platform—possibly enhanced with AI—that dynamically updates tool availability. This would enable researchers to quickly locate and utilize needed resources listed on the NNCI website, promoting efficiency in collaborative research efforts.

How can these regional networks be leveraged?

The participants discussed leveraging regional networks for future initiatives within the context of the NNCI. Key points included:

1. Efficiency in Access to Tools: Emphasizing the role of regional networks in facilitating access to shared equipment and tools across universities, potentially expanding this model nationally. This could involve integrating AI or smarter systems to streamline tool availability updates.
2. Staff Exchange Programs: Highlighting the value of staff exchanges between institutions to enhance collaboration and skill development. This initiative has shown significant impact within the NNCI network and could be expanded regionally to foster closer ties and resource sharing.
3. Workforce Development: Recognizing the potential of regional networks in supporting workforce development, especially in partnership with community colleges and technical institutes. This includes training technicians and potentially bachelor-level engineers, thereby creating a feeder system for skilled labor in advanced technology fields.
4. Industry Engagement: Advocating for increased involvement of industry partners in regional networks, not only to support workforce training but also to potentially share costs and enhance facility utilization. This aligns with broader goals of sustainability and efficiency in resource allocation.
5. Financial Considerations: Addressing concerns about funding limitations and the need to maximize the impact of existing resources within the regional networks. Strategies include exploring partnerships with state-level alliances and seeking additional funding opportunities to sustain and expand initiatives.

Overall, the discussion emphasized leveraging regional networks as a strategic approach to strengthen collaboration, support workforce needs, and optimize resource utilization within the framework of the NNCI and beyond.

Members:

Regional Network	NNCI Site	Contacts
Northern Nano Lab Alliance	MiNIC	Jim Marti, Brian Olmstead
Southeastern Nano Facility Network	SENIC	Gary Spinner, Walter Henderson
Mid-Atlantic Nanofab Managers Meeting	MANTH	Eric Johnston, Pat Watson
Northwest Nanotechnology Laboratory Alliance	NNI/MONT	Darrick Baker, Andrew Lingley
Southwest Nano Lab Alliance	NCI-SW	Trevor Thornton
Ohio Valley Nano+AM Regional Network	KY Multiscale	Ana Sanchez-Galiano
RTNN Affiliates Network	RTNN	Philip Strader
NY State Nanotechnology Network	CNF	Ron Olson

6.4. E-Beam Lithography

We are an active working group that aims to meet online as needed and provide support to email questions to the group for various issues. We held one meeting this year on April 18, 2024. Each member in attendance covered roles and responsibilities for their organization. Some members support many different types of tools (typically with fewer overall users and overall facility equipment) while some members primarily support EBL only (typically with more users). We had a useful and supportive discussion on different approaches and wisdom in handling varied needs in multi-user facilities.

Besides our online meeting, there were a few requests throughout the year for support by email to the user group email distribution list.

- One request was from Cornell University on advice to give a user who needed to minimize heating while applying a bilayer PMMA film (required no baking at ~180 C). The user ideally wanted to use a vacuum oven at minimal temperature. Devin from Georgia Tech was able to provide a previously successful recipe in an oven at atmospheric pressure for PMMA to minimize heating. Additionally, Stanley from Stanford was able to supply a journal paper that used PMMA hotplate bake at 80C.
- Another email request was from Georgia Tech on experiences with shipping HSQ resist coated samples by mail at various process steps and conditions and results. Various sites (U Penn, MIT, Harvard, and Stanford) weighed in on their experiences and suggestions.
- A third email request was from Stanford to Georgia Tech for a sales contact for ESpacer, a water-soluble anti-charging coating layer used for insulating samples.

The group welcomed a new member, Eric Carlson from Virginia Tech. Virginia Tech received a new JEOL JBX-8100FS G2 with installation finished at the beginning of the year. They are operational, but still trying to get the surrounding parts of the facility running – training, rates, website, etc. The tool has been installed in Virginia Tech's Nanoscale Characterization and Fabrication Laboratory (NCFL) located in the VT Corporate Research Center adjacent to the VT campus. The group also welcomed Andrew Lingley from Montana State University. Their site was looking to acquire a Raith Voyager with which the Stanford group has had experience for several years. Andrew was able to connect with Stanley at Stanford in order to get advice and insight on the Raith Voyager system.

Overall, our EBL working group had a successful year with one meeting and fruitful discussions with a bright outlook on EBL research and support that each NNCI site has to offer. We anticipate the network's growing capabilities as newer state-of-the-art equipment becomes available within our facilities.

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 Barth David Jones
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	Andrei Sokolov Ather Mahmood
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	Doc Daugherty
NanoEarth	Virginia Tech	Eric Carlson
MONT	Montana State Univ.	Andrew Lingley

6.5. Etch Processing

The Etch Working Group provides a forum for etch personnel from all participating NNCI sites to share information on a range of topics, including etch capabilities, established etch processes, processes under development, equipment maintenance issues, preventative maintenance, baselining efforts, equipment modification, and the acquisition of new etch tools/technologies. We hold virtual and in-person meetings within and beyond the network and collaborate with national etch experts to address the increasing challenges of plasma etching at the nanoscale.

There were two major activities this past year. First, successfully organizing the 2024 NNCI Etch symposium at the Georgia Institute of Technology April 24-26, 2024, and second, planning the 2025 NNCI Etch Symposium, to be held at the Massachusetts Institute of Technology.

The Working Group has been organizing the Etch Symposium since 2018, connecting etching experts to exchange experiences and share knowledge. These symposia contribute to the national nanotechnology development and the education of the next generation of scientists and engineers in nano and quantum technologies. The 2024 organizing committee included Durga Gajula (Georgia Tech), Ling Xie (Harvard University), Lavendra Mandyam (Stanford University), and Vince Genova (independent consultant). We spent more than a year preparing and planning for the 2024 Symposium – inviting speakers, fundraising, developing programs, and arranging vendor exhibitions. The 2024 Symposium was the largest event we had ever organized. We increased fundraising by more than 50%, expanded the program from 2 days to 2.5 days, and added two more sessions to the program – student posters and panel discussions. This event was well attended, with ~120 people in-person and ~65 online, 13 vendor booths and 11 student posters.

General Presentation Session

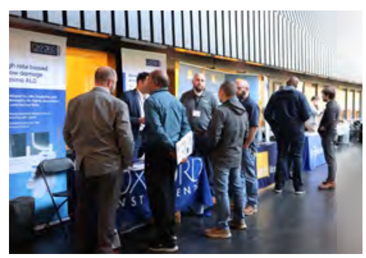
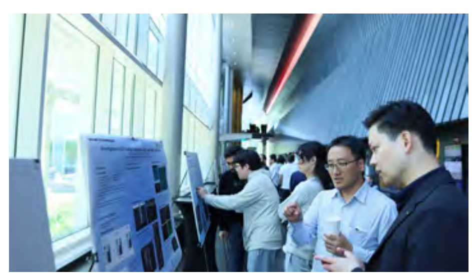


Exhibit and Sponsors

Lunch Social Hour



Poster Session

In September 2024, the NNCI Etch Working Group approached MIT.Nano and both parties agreed that Harvard CNS and MIT.Nano will co-host the 2025 Etch Symposium on the MIT campus in June 2025. Dr. Joerg Scholvin, the associate director of MIT.Nano Fab, joined the organizing committee. Since then, we have been holding bi-weekly virtual meetings to prepare. The 2025 symposium will focus on topics including:

- Device driven plasma etch challenges
- Advances in Atomic Scale Processing
- Advances in Cryogenic Etching
- Plasma characterization, diagnostics, and manipulation
- Modeling/Artificial intelligence/Machine Learning for Plasma Etching
- Sustainability in plasma etching

Members:

Cornell University (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, 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. Heath)
University of Washington (M. Morgan, M. Brunson)
Arizona State University (S. Ageno, S. Myhajlenko)
UC San Diego (X. Lu, David Prescott)
Montana State, (J. Heinemann)
Virginia Tech (D. Leber, M. Hollingsworth)
University of Chicago (P. Duda, S. Kaehler)

6.6. Atomic Layer Deposition

The ALD Working group has been staying in contact via email group discussions this past year. The forum has been a valuable place for group members to exchange ideas and solutions for safe operations and training specifically around ALD as well as lab operations in general.

One of the current projects of the Working Group is to organize another conference in the upcoming year. The group has tentatively settled on Georgia Tech as the location for the next ALD Working Group Symposium and details are currently under discussion.

Members:

Anil Dhote	Northwestern
Bangzhi LIiu	Penn State
Bill Mitchell	UC Santa Barbara

Darick Baker	University of Washington
Don Leber	Virginia Tech
Fred Newman	University of Washington
Bob Geil	University of North Carolina
Hang Chen	Georgia Tech
Jeremy Clark	Cornell
Kyle Keenan	University of Pennsylvania
Lucas Barreto	University of Pennsylvania
Mac Hathaway	Harvard
Matthew Oonk	University of Michigan
Michael Martin	University of Louisville
Mahendra Sunkara	University of Louisville
Paul Kimani	University of Minnesota
Robert Amundson	University of Minnesota
Gary Spinner	Georgia Tech
Stefan Myhajlenko	Arizona State University
Tony Whipple	University of Minnesota

6.7. Workforce Development and Community Colleges

The Workforce Development and Community Colleges group met virtually in August 2024. First, we had a short discussion on the overlap between E&O and WFD and spent time trying to find ways to effectively differentiate the two types of activities. We decided that for each site, it may be useful to categorize WFD activities into several different categories: K-12, associates, bachelors, and graduate activities. Next, we had a discussion on how to develop activities from a dedicated workforce position through the NNCI when there is not a dedicated group of students to work with. Here are some ideas we discussed:

- Encourage your students to start a campus organization. Montana State University undergraduate employees of the Montana Microfabrication Facility started the NanoCats, an official student organization dedicated to nanofabrication and semiconductors. They do outreach and coordinate with industry, and considered developing a network of groups that could compete on design of fabrication tasks (i.e., NanoCats vs NanoDawgs vs NanoBears).
- Reach out and advertise to 100-level engineering and science classes to get a group of students to help with outreach, volunteer for workforce activities, or start a group.
- Employ student staff in nano-related core facilities on campus. Student employees are great at advertising and growing excitement.

We also had a discussion on engaging industrial partners in WFD activities:

- Coordinate explicitly with university career fair planners, bi-directionally. Figure what relevant companies are coming and encourage planners to contact local companies who might be working in nano-related fields.
- Work with startups that use core facilities.

Next, Tom Pennell of Cornell CNF showed a video of their extremely compelling VR educational program. We talked about having each site contribute a technique or activity to a VR series. Finally, we discussed how we could create a concise list of effective ideas comprised of only the best ideas and programs we have for each level of workforce development and to try to implement them at different sites.

Members:

Name	**Affiliation**	**Name**	**Affiliation**
Andrew Lingley	MONT (MSU)	Dan Ratner	NNI (UW)
Maude Cuchiara	RTNN (NCSU)	Trevor Thornton	NCI-SW (ASU)
Jenna Huttenmaier	NNF (Nebraska)	Daniella Duran	nano@stanford
Sylvianne Velasquez	NanoEarth (VA Tech)	Tom Pennell	CNF (Cornell)
Tonya Pruitt	NanoEarth (VA Tech)	Steven Wignall	NNF (Nebrasksa)
Allison Weavil	SENIC (JSNN)	Phillip Strader	RTNN (NCSU)
Julia Aebersold	KY Multiscale (UofL)		

6.8. Evaluation and Assessment

In Year 10, the E&A WG convened to advance our primary goal: to gather and consolidate the various program assessments and evaluations conducted during the 10-year grant period of the NNCI. These discussions focused on identifying, organizing, and analyzing the diverse evaluation tools and methodologies used across programs to ensure a future collaborative would have a history of NNCI assessment tools. This effort lays the foundation for informed decision-making and continuous improvement within future nanotechnology initiatives. Survey and evaluation tools that we have currently identified to place within the NNCI website as an archive include:

- NNCI Education Office Research Experience for Undergraduates (REU) Participant Post Survey (2016) - This is part of a longitudinal study of a long-running REU program begun under the National Nanotechnology Infrastructure Network (NNIN).
- NNCI Research Experience for Undergraduates (REU) Faculty PI and Mentor Survey
- KY Multiscale REU Program Evaluation Template
- KY Multiscale University of Louisville REU Alumni Survey
- Nanotechnology Collaborative Infrastructure - Southwest (NCI-SW) REU Graduate Student and Faculty Survey
- NNIN Research Experience for Teachers (RET) Program Survey (2011)

- Georgia Tech NNIN Nanotechnology Workshop for Educators Workshop Survey (2013)
- Stanford Nanoscience Summer Institute of Middle School Teachers Postsurvey (2017)
- Solar Cells Summer Program for Teachers: End of Program Survey
- SENIC Georgia Tech Introduction to Nanotechnology Post Survey
- Nanotechnology Collaborative Infrastructure - Southwest (NCI-SW) Outreach Event & Activity Survey
- Arizona State University Remote Access to Instrumentation Instructor Survey (2021)
- Arizona State University Remote Access to Instrumentation Student Survey (2021)
- Arizona State University Outreach Program (Science is Fun) Student Participant Post Survey (2016)
- Arizona State University Outreach Program (Science is Fun) Teacher Participant Post Survey (2016)
- Follow-up User Satisfaction Survey for Montana Nanotechnology Facility (MONT) at Montana State University
- Follow-up Web Survey for MONT Military Workshop Participants
- MONT Survey for Montana Nanotechnology Facility Workshop Participants
- MANTH NanoDay - Teacher/Chaperone Survey (2018)
- MANTH NanoDay - High School Tour Student Survey (2018)

Members: Jessica Hauer (NCI-SW), Tonya Pruitt (NanoEarth), Carolyn Plumb (MONT), Dan Ratner (NNI), Ana Sanchez Galiano (KY Multiscale), Mikkel Thomas (SENIC)

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 the NSF's "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 8 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 2023 NNCI Annual Conference, and these can be viewed along with other resources on the Research Community page of the NNCI website.

Table 8: 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), Christian Binek (NNF)
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, and Kentucky Multiscale sites. Major individual contributors in 2024 included: Jacob Jones (RTNN), David Berube (RTNN), Maude Cuchiara (RTNN), Kevin Walsh (KY Multiscale), Ana Sanchez Galiano (KY Multiscale), Phillip Strader (RTNN), Yves Theriault (SDNI), Ross Sozzani (RTNN), Khara Grieger (RTNN), Sarah J. Kariko (Harvard), and Elaine Hubal (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 that are of great societal significance. Historical examples of disciplinary convergence can be found, for example, in bioinformatics, bioengineering, and nanotechnology. It is important to note that the concept of Convergence Research extends beyond the converging of disciplines to include, for example, 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 highly 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, 2021, 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 manuscript was under review as of the writing of this report.

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 through, for example, bootcamps. A major activity was the NSF NNCI Nano+Additive Manufacturing Summit held on August 9-10, 2022, 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 renowned speakers, at least three of which pushed the boundaries of convergence, for example, through topics on neural interfaces, entrepreneurship, and additive manufacturing for the medical field. The Summit was hosted jointly with the annual 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 <u>discipline</u>, 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 2023-2024 topic of the Research Community was **Convergence in Nanotechnology for Addressing Climate Change**. To accelerate our resilience against climate change, we must leverage the full force of society's knowledge base, science, and technology to advance both sustained mitigation strategies as well as implementing adaptation measures. Nanotechnology, developed as an interdisciplinary research area over the past several decades, is one of those major past investments that can offer opportunities to address key climate change mitigation and adaptation challenges, helping to reduce significant losses and damages in the future. Especially over the past 20 years, the U.S. invested in nanotechnology through a concerted, multi-agency National Nanotechnology Initiative (NNI). In 2000, the genesis of the NNI catalyzed organizations and individuals from academia, industry, and government to develop new foundational knowledge of nanoscale phenomenon and materials and develop novel and economic applications for nanotechnology. Moreover, an important goal from the outset of the NNI was to support the responsible development of nanotechnology, e.g. by considering the environmental, health, and societal implications of the technologies themselves and their applications. Since that time, over $40B USD has been invested to advance our fundamental understanding of and ability to control matter at the nanoscale [7] and we now have nationally-supported nanotechnology infrastructure centers sponsored by many federal agencies including the Department of Energy (e.g., Nanoscale Science Research Centers, or NSRCs) and the National Science Foundation (e.g., the National Nanotechnology Coordinated Infrastructure Sites, or NNCI Sites). The time, investment, and successes were so substantial that Roco said nanotechnology is now for "general-purpose and mass use"[8].

More recently, nanotechnology and its associated disciplines have been more strongly connected to climate change at national and global levels. In early 2021, President Biden elevated climate change in the U.S. national agenda at the beginning of his term [9]. Later, in 2022, the U.S. White House Office of Science and Technology Policy (OSTP) released 37 “Net-Zero Game Changer Opportunities," physical science and engineering challenges that could help transform our energy system and infrastructure, seeking to motivate and direct the full potential of the U.S. public and private innovation ecosystems [10]. Soon thereafter, the Engineering Research Visioning Alliance (ERVA), a project sponsored by the U.S. National Science Foundation (NSF), published a workshop report that identified specific opportunities in science, engineering, and technology that are necessary to advance solutions to addressing climate change [11]. These opportunities became grouped topically into four natural categories: i) energy storage, transmission, and critical materials, ii) greenhouse gas (GHG) capture and elimination, iii) resilient, energy-efficient, and healthful infrastructure, and iv) water, ecosystems, and geoengineering assessment. The ERVA report emphasized the importance of engineering tools that require significant and sustained investment, some of which are the tools and facilities supported under the NNI, e.g. currently available NSRCs and NNCI Sites. Nanotechnology, now poised as a general-purpose and mass use technology within these open-access facilities, presents opportunities to address challenges in all four of these research categories.

The identification of nanotechnology as an opportunity to address climate change mitigation and adaptation challenges was further solidified in 2023, when the National Nanotechnology Coordination Office (NNCO) issued a “Nano4EARTH Challenge.” Nano4EARTH was motivated by a need to act quickly, with matured science and technologies, to advance compelling nanotechnology commercialization opportunities for climate change mitigation and adaptation [12]. In an inaugural convening event for Nano4EARTH, the NNCO brought together hundreds of stakeholders in a hybrid event to identify the most impactful research opportunities for nanotechnology to help address climate change and to identify technologies that were ripe for translation into the market. Common themes that emerged involved immediate opportunities in battery technologies, catalysts and advanced materials and sorbents for addressing greenhouse gas emission and capture, and coatings and other material innovations for increased efficiency in industrial processes [13].

While these efforts address certain immediate commercialization opportunities of mature technologies, there remain other relevant questions around how the nation's basic research activities and infrastructure in nanotechnology, which was built up and maintained through decades of national investments, could evolve to help support both commercialization and basic research underpinning nanotechnology for addressing climate change and to do so in a way that is inclusive and provides equitable solutions. To fill this information gap, the Research Community identified and reported key needs in research, the research process, and infrastructure to advance climate change solutions in the longer term [14].

In 2023, the Research Community convened a range of stakeholders from research, industry, and government and from disciplines across the physical, life, social, and economic sciences throughout the year to discuss key questions about the future needs and opportunities at the intersection of nanotechnology and climate change. An initial event was an open, online workshop in February 2023, which was followed by synthesis meetings of a working group and select participants to further elaborate and prioritize key needs. An emphasis was placed in the project on the underlying infrastructure that supports nanotechnology research such as NNCI Sites, although insights related to infrastructure could be related to other shared user facilities supported by universities, the Department of Energy, federally funded research and development centers (FFRDCs), or government laboratories. In fact, the most inclusive definition of infrastructure used in the context of this project includes nanotechnology and microelectronics cleanrooms, materials characterization facilities, environmental engineering laboratories, field research test sites, greenhouses, pilot plants, shared computational resources, etc. The working group synthesized the input and discussions and published a manuscript on the topic in 2024 [14].

From the activities emerged five high-level characteristics of future research, published in the manuscript, that can most effectively advance nanotechnology solutions to address climate change:

1. Long-term basic research in nanotechnology needs use-inspiration, i.e. connection to specific solution spaces in climate change needs.
2. Systems-level thinking is needed to create new discoveries and effective nanoscale innovations that can ultimately be adopted by society as solutions.
3. The research process needs to converge diverse disciplines physically and intellectually on specific and compelling topics of appropriate scope.
4. Stakeholders must be involved in guiding the prioritization of nanotechnology research effort and the design of research projects.
5. Nanotechnology infrastructure, e.g., equipment, personnel, and facilities, needs to be designed or adapted to a different and evolving user base which is increasingly interdisciplinary and is composed of individuals working on increasingly complex systems.

The five characteristics themselves are distinct yet also highly complementary. For example, higher level constructs such as Convergence Research can capture most, if not all, of these characteristics.

As the fifth characteristic, which is related to infrastructure, may be the most interesting to the NNCI audience, we quote a few key recommendations from this section of the manuscript:

5.1 An important observation from this project is that nanotechnology infrastructure facilities and programs may need to reconsider how the value proposition of existing nanotechnology infrastructure is framed to users and stakeholders from disciplines or sectors who do not traditionally use these facilities. For example, one cannot expect that highly application-oriented researchers working on, for example, climate change, will be able to navigate and identify the right resources, opportunities, or technical expertise inside specialized nanotechnology facilities.

5.2 There may also be opportunities in evaluating and realigning the breadth of technical expertise throughout a nanotechnology user facility, for example, in its technical staff and leadership. As convergence research brings a broader set of users and knowledge bases that present both more opportunities and demands, facilities can consider recruiting technical experts with expertise in specific application spaces, for example, biological sciences or ecology, or individuals who have experience in conducting convergence research. In some cases, existing staff may desire new professional development opportunities that would be able to address some of this diversification.

5.3 When working with an increasingly diverse user base, there will be increasing requirements to pivot across diverse applications, which may require increased adaptability in available equipment or daily process flows, or even the complete redesign of spaces within infrastructure facilities. Here, we reemphasize the reward systems, and specifically for technical staff in nanotechnology facilities; these reward systems may need to be reevaluated such that staff are encouraged to assume and be rewarded for any additional burden or complexity associated with supporting convergence research.

5.4 Finally, a major challenge in advancing nanotechnology to address climate change is the need to scale technologies from the bench to the environmental scale, which is not only much larger in size scale, but often contains much more diversity in conditions. In fact, some see scaling as the primary challenge underpinning deployment of nanotechnology applications to address climate change. Current capabilities at nanotechnology user facilities typically support small-scale bench/prototyping research with predictable conditions, although deploying nanotechnology-based solutions in the environment will require both significant scale-up (e.g., prototype manufacturing) and testing and performance at scale (e.g., for validation). Recently, the Department of Defense created the Microelectronics (ME) Commons through the CHIPS and Science Act [15], which consists of Hubs that provide access to U.S.-based semiconductor prototyping, an example of major investments in scaling infrastructure. In the ME Commons, many industrial partners are involved, which reinforces the need for academic-industrial partnerships in scaling technologies.

Future Plans: One effort that is continuing into 2025 involves hosting an in-person Convergence Workshop. A Center program associated with the RTNN and NNCI received supplemental funding to host a workshop that brings together practitioners, theorists, trainers, evaluators, and leaders of boundary-spanning integration and knowledge synthesis work across a broad range of large convergence research efforts, including NSF STCs, NNCI, BIIs, and GCR awards. The objective is to create maximum visibility and transferability of approaches and to study the process of practicing convergence, which often intersects with the world of nanotechnology. To support this workshop, supplemental funding was made available from NSF OIA through the Science and Technologies for Phosphorus Sustainability (STEPS) Center, an NSF-supported Science and Technology Center (STC). The workshop will be held in picturesque Boone, North Carolina, in the Appalachian Mountains, October 6-8, 2025. The Research Community for Nanotechnology Convergence has representation on the advisory committee for the workshop, one mechanism to enable connectivity to the NNCI community. A conference website is not yet available online.

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7.2. Nanoscience in the Earth and Environmental Sciences

The Nanoscience in the Earth and Environmental Sciences Research Community (Nano EES RC) facilitated the first staff exchange during Year 9. NanoEarth Lab Manager and Instrument Specialist Weinan Leng and NanoEarth Postdoctoral Associate Bipin Lade visited Montana State University (MONT) and Arizona State University (NCI-SW) for a week in April 2024. They toured facilities, met with other staff scientists and engineers in roles similar to theirs, and explored the unique expertise and instrumentation available at each site. They introduced MONT and NCI-SW staff to NanoEarth and discussed potential for further collaboration. The trip was funded in part by the NNCI Coordinating Office's staff exchange program. In return, NanoEarth will host visitors from the other Nano EES-RC sites in Year 10. We expect they may be most interested in visiting after the Virginia Tecg central facility's instrumentation upgrade, including new JEOL JEM-ARM200F TEM, will be completed in mid-Feb. 2025. It is worth noting that NanoEarth's budget includes funds designated to support Nano EES-RC staff exchange travel to our site.

For year 10, three research communities, Nano Convergence, Earth Sciences, and Rules of Life, are continuing discussions to implement a joint virtual or in-person event around methods, application and development for plant matter preparation and EM imaging at participating NNCI sites. We also aim to summarize our 5-year experience and best practices.

7.3. Nano-Enabled Internet-of-Things

During this reporting period, the Nano-IoT Research Community did not have a formal meeting. This was due in part to the desire to plan for maintaining the Research Community beyond the current phase of NNCI, which was discussed at the Annual Meeting in October 2024. In lieu of a formal meeting, individual participating sites within the Research Community continued to carry out their own research missions in this space. Selected examples include the "Internet of Things for Precision Agriculture" at MANTH and the "Center for Research on Programmable Plant Systems" at CNF.

7.4. TransformQuantum

The TransformQuantum Research Community was established in 2020 to organize and systematize considerations of how the NSF-supported National Nanofabrication 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 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.

Annual Update:

Over the past year, most of the activities have been organized through the Global Quantum Leap (GQL) program, led by the University of Minnesota (PI: Steven Koester). GQL is funded through the NSF AccelNet program and creates a network-of-networks in the fields of **nano-fabrication** and **quantum computing & information sciences**, aligning well with TransformQuantum. GQL's main goal is to train nano- and quantum scientists to work in diverse, international environments.

Partners in the GQL network-of-networks include:

- The National Nanotechnology Coordinated Infrastructure (NNCI) network
- The Matter and Light for Quantum Computing (ML4Q), a Cluster of Excellence funded within the Excellence Strategy by the German Research Foundation.
- The Chicago Quantum Exchange (CQE), based at the University of Chicago, comprising Argonne National Laboratory, Fermilab, the University of Illinois-Urbana Champaign, Northwestern University, and the University of Wisconsin-Madison.
- Advanced Research Infrastructure for Materials Nanotechnology Japan (ARIM), comprising 22 universities and institutes across Japan and is managed by the National Institute for Materials Science (NIMS).
- OpenSuperQPlus, a reformulated version of previous partner OpenSuperQ, a European multi-university and industry network focused on the development of an open-source superconducting quantum computer.
- EuroNanoLab, a recently-formed research infrastructure across Europe consisting of over 40 state-of-the-art academic nanofabrication facilities.

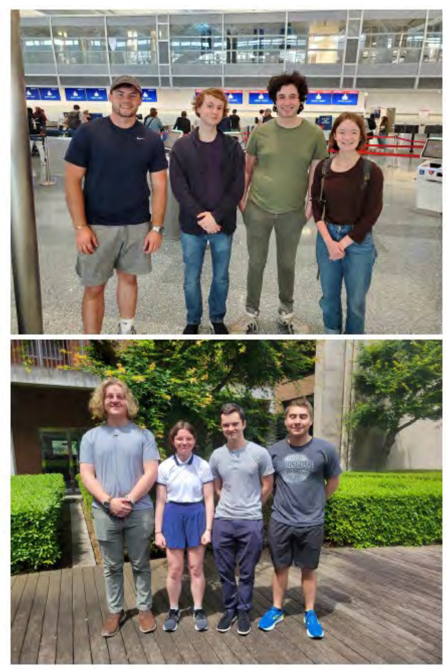
- The QCS Hub is a collaboration of leading research teams, across 17 universities, within the United Kingdom (UK), working in partnership with over 25 commercial, governmental, and academic organizations.
- The Challenge Institute for Quantum Computation (CIQC), spanning quantum information science researchers at eight U.S. research universities, where the University of California, Berkeley, is the lead institution.

The three main activities in 2024 comprised:

- Student/faculty exchanges coordinated and funded through the GQL
- Bootcamps, short courses for K-12, undergrads, teachers and professionals
- A second workshop on Quantum Engineering Infrastructure (WQEI2)

Exchange Program - IRTE with NIMS/ARIM and ML4Q*:* In the summer of 2024, GQL continued our successful International Research and Training Experience (IRTE) program in collaboration with our partners at NIMS/ARIM and ML4Q. In our IRTE program, undergraduate students from US institutions travel to one of our international partners in a structured program where the students work in the research labs of a mentor for roughly 10-12 weeks. The NIMS/ARIM IRTE was coordinated by Dr. Lynn Rathbun at Cornell University, performed in conjunction with an existing IRTE program run through the Cornell Nanoscale Facility (CNF) as part of their NNCI education and outreach program.

For this year, 7 students were selected: 4 for Japan and 3 for Germany. The summer experience dates for the Japan IRTE students were May 21 to August 6, 2024, and all the students traveled to Japan together and were accompanied by Dr. Rathbun for the first week. For the German program, the students traveled with program administrator Jordan Schwed on May 22, returning on August 14. As in previous years, GQL covered travel and housing costs as well as providing a stipend payment dependent on the length of the individual experience. After all students returned from abroad, they filed a written report on their research and also answered a detailed questionnaire about their experiences.



Top: Austin Shoemaker, Sergey Blinov Jordan Schwed, and Piper Eriksson, preparing to depart for Germany. Bottom: Nicholas Richardson, Amelie Deshazer, Keyes Eames, and Cedric Silva at NIMS in Tsukuba, Japan.

Workshop - WQEI2: Instead of perusing a Quantum Technology Infrastructure Roadmap (QTIR), we decided this year that the best role that the GQL can play in mapping the future of quantum infrastructure is to continue to host workshops to drive understanding of how research facilities can support quantum fabrication.

This year we successfully fulfilled our goal to hold a second workshop, WQEI2, held on March 3, 2024, which was the Sunday prior to the 2024 APS March Meeting in Minneapolis. The goals of WQEI2 were (1) to assess the outcomes from WQEI in 2021 and evaluate progress toward recommendations from that workshop; (2) to understand how new developments in quantum computing have altered the needs and best practices for quantum fabrication infrastructure since 2021, and (3) to provide a vision for the future of quantum fabrication infrastructure in the United States so that shared national resources meet the needs of quantum engineered systems.

The workshop was a hybrid event with roughly 120 registered attendees in total, with most from US universities, but with other attendees from government, industry, national labs and foreign universities. Approximately 60 people attended in person. The workshop had 4 sessions, with an overview talk at the beginning of each session, followed by a panel session. All speakers and panelists were selected by invitation of the organizing committee. The invited speakers were chosen by topical area, so that as many relevant aspects of solid-state quantum information science and engineering can be covered as possible. The main topical areas covered were superconducting qubits, spin qubits, color centers, and emerging quantum platforms. At the beginning of each session, a speaker provided an overview of the field and then was followed by a panel session where curated questions were asked of the 10 panelists. The organizing committee members acted as session chairs and breakout moderators. A photograph of the workshop during one of the breaks is shown to the left.

Participants of WQEI2 during the lunch break.

A series of conclusions and recommendations were formulated, and while these will not be summarized in this report, the executive summary will be posted in the future on the NNCI website. The main recommendations fell into the following categories: processing/tooling infrastructure, shared characterization facilities, partnerships/collaborations, funding avenues, process staffing, and miscellaneous concerns.

Quantum+Chips Bootcamp: For the second year in a row, UMN hosted the Quantum+Chips bootcamp. The workshop was organized by Prof. Tony Low at UMN, and was co-sponsored by GQL, among other funding sources. Once again, the program was structured as a two-week-long summer school for early-stage undergraduate students to immerse them in the physics and technology of cutting-edge computing technologies, spanning quantum computing, spintronics, and semiconductor chips. A total of 48 students from the US and Korea participated.

In addition, the NSF-supported Quantum Leap Challenge Institute HQAN, partnering with the CQE at UChicago, offered a course in “Quantum Science, Networking, and Communications,” comprising an 8-week course in quantum technology that targets early and mid-career engineers with bachelor’s degrees in science, covering quantum information processing, quantum networks and quantum communication, with the course including technical demonstrations and simulations. CQE also supported a more intensive program in Quantum Engineering and Technology, comprising a 4-day course in quantum engineering that targets current professionals in transition to quantum careers, where participants are recommended to already have a master's or higher degree.

For 2025, we will continue the IRTE program, hopefully with an even larger cohort than in 2024. GQL also plans to perform more research-specific exchanges to help strengthen ties with international partners who have been less engaged in our program. Finally, we plan to continue our workshops and bootcamps, including Quantum+Chips, as well as make plans for the WQEI to become a regular conference with student presentations and contributed papers.

7.5. Understanding the Rules of Life

The Understanding the Rules of Life (RoL) initiative, a significant focus of the National Science Foundation, represents a strategic challenge and target of opportunity for the NNCI network. The RoL theme spans molecular intricacies to ecological impacts, fostering interdisciplinary opportunities. The NNCI Research Community (RoL-RC) has been instrumental in defining and advancing RoL themes, leveraging the network's strengths in metrology, collaboration, and infrastructure development. Regular meetings have guided this effort, ensuring alignment with NNCI's mission and fostering impactful research.

Activities and Outcomes: Over the past year, the RoL-RC has convened quarterly to strategically identify and refine opportunities within the RoL framework. These meetings have focused on defining themes, fostering collaboration, and prioritizing education and workforce development. Key outcomes include:

1. **Core Themes Defined:**
    - Synthetic Biology (SynBio): Infrastructure needs for SynBio were mapped, emphasizing metrology as a critical enabler for future advancements.
    - Seeing & Sensing the Invisible: Efforts focused on imaging and diagnostic technologies across scales, firmly aligning with NNCI objectives.
    - Outreach and Workforce Development: Educational and professional development programs were prioritized to expand societal impact and global collaboration.
2. **Collaborative Efforts:**
    - Webinars and workshops facilitated knowledge sharing. For example, the webinar "Polymer Vehicles for CRISPR Gene Editing" showcased cutting-edge research and inspired cross-network collaborations.
    - NNCI sites such as SHyNE and CNF (Cornell) spearheaded initiatives like rapid diagnostics development and SynBio infrastructure. These sites also enhanced educational outreach through REU and RET programs, nurturing future researchers.
    - Regional engagements, including the M3S meeting in Chicago and collaborations with the Chan Zuckerberg Biohub, extended RoL-RC's reach to industry and academic stakeholders.
3. **Educational Contributions:**
    - RTNN's efforts in K-12 education and the Kickstarter Program have broadened access to nanotechnology, ensuring an inclusive approach to workforce development. Immersive lab experiences and nano-themed lesson plans further enriched student engagement.

Regular assessments during quarterly meetings have allowed the committee to track progress effectively, ensuring alignment with NNCI's broader mission. These discussions have also provided a platform to address emerging challenges, such as ensuring equitable access to resources and fostering collaborations across geographically diverse sites. The emphasis on metrology as a unifying framework has proven particularly beneficial, enabling consistent development of tools and methodologies applicable across the RoL themes.

Furthermore, the RoL-RC has played a pivotal role in integrating industry and academic partnerships. For instance, collaborations with organizations such as the Chicago Biomedical Consortium and national centers like the Chan Zuckerberg Biohub have facilitated advancements in diagnostic tools and imaging technologies. These partnerships underscore the network's ability to adapt and evolve in response to interdisciplinary research demands.

Future Plans: Looking ahead, the RoL-RC will build on its foundational work by:

- **Strengthening Collaboration:** Quarterly meetings will continue to drive strategic discussions and identify new opportunities for interdisciplinary research.
- **Advancing Infrastructure:** Research tools and infrastructure supporting RoL themes will be developed to address critical questions in life sciences and engineering.
- **Expanding Outreach:** Additional initiatives, including vendor/webinar events, workforce training, and community engagement, will enhance the network's impact.

The committee also plans to expand its educational offerings, leveraging successful programs like REU and RET while exploring novel approaches to engage underrepresented groups. By fostering a diverse pipeline of researchers and professionals, the RoL-RC aims to strengthen the workforce's ability to address complex scientific challenges. Similarly, regional initiatives will continue to integrate local resources and expertise, ensuring a robust and dynamic approach to achieving RoL objectives.

The RoL-RC remains committed to fostering innovation and collaboration across the NNCI network, ensuring sustained progress in understanding the complex interplay between life and physical sciences. By maintaining a clear focus on interdisciplinary engagement and infrastructure development, the network is well-positioned to make significant contributions to the broader scientific community.

7.6. Microelectronics and Semiconductors

The Microelectronics and Semiconductors Research Community serves as a conduit to the broader semiconductor manufacturing community beyond the NNCI. In Sept 2022 we held a virtual workshop that resulted in a White Paper to inform government thinking vis-à-vis forthcoming funding from the CHIPS and Science Act. During NNCI Year 8 the Microelectronics Commons was established by the DoD with NNCI sites represented at all eight regional hubs. Since the announcement of the ME Commons, the initial funding has been used to establish research capabilities with infrastructure investments that, in a number of cases, have upgraded equipment in multi-user core facilities at NNCI sites during Year 9. We anticipate that the Microelectronics and Semiconductors RC will continue to serve as an interface between the ME Commons Hubs and the current NNCI, as well as any future network supported by the NSF.

8. NNCI Network Promotion

8.1. Marketing and User Recruitment

Marketing and user recruitment strategies vary widely across the NNCI network, based on a range of local and regional factors unique to each site. During the January 2017 NNCI Conference, a breakout session on marketing and user recruitment identified a number of strategies 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 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 attend 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. David Gottfried, Trevor Thornton, and Mary Tang all attended and presented at the 2023 ENRIS Conference (bi-annual meeting of the Euro Nano Lab network).

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 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

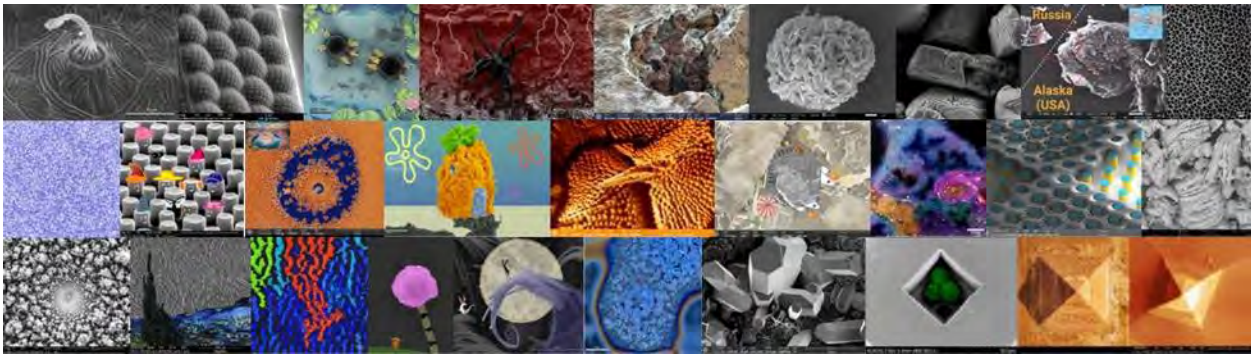
During the first year of the NNCI Coordinating Office, one of the main activities was the creation of a web portal (www.nnci.net) to provide a comprehensive list of tools and experts available within the network for both user recruitment and support. The design of a new, comprehensive website was predicated 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, 2024, the video had been viewed more than 2,500 times. During 2021, the NNCI YouTube channel was added to the home page, and more details on this are provided later in this report (Section 10.4).

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

1. News items on the blog (4 news items in 2024)
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

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 Sept. 20-27, 2024, 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 2024 there were more than 44,000 visitors to the website, a 3% increase over the prior year but a 26% decrease from the peak in 2021. As in previous years, a large spike in visitors was observed in October, primarily to participate in the image contest voting. For the year, 99% were new visitors with 53% from the United States (up from 51% the previous year). There were more than 87,000 pageviews, which is also a 3% increase from the prior year. The average session duration was slightly less than 1 minute, comparable to previous years. During this time period, the top ten pages visited are shown in Table 9 below. These ten pages account for 53% of all pageviews. Significant differences this year include a large increase in views of the REU and Image Contest pages. 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. A decrease in pageviews for the site page while an increase for the tools page can be seen in 2024.

Table 9: NNCI Website Page Visits (2024)

Page	# Pageviews in 2024	%Change from 2023	% Pageviews in 2024
/	11,869	+3.1%	13.6%
/careers-nanotechnology	7,149	+4.0%	8.2%
/research-experience-undergraduates	4,803	+37.6%	5.5%
/how-small-nano	4,739	+29.5%	5.4%
/what-nano	4,477	-22.3%	5.1%
/plenty-beauty-bottom	3,334	+26.9%	3.8%
/sites/view-all	2,809	-19.7%	3.2%
/search/tools	2,673	+8.0%	3.1%
/nnci-image-contest-2024-unique	2,243		2.6%
/about-nnci	2,109	-5.0%	2.4%

Since the NNCI website's debut in late 2016, the growth in annual visitors and pageviews is shown in Figure 10 below. A maximum in annual visitors was reached in 2021 followed by decreasing numbers of visitors in 2022-2023, but this appears to have stabilized over the past year.

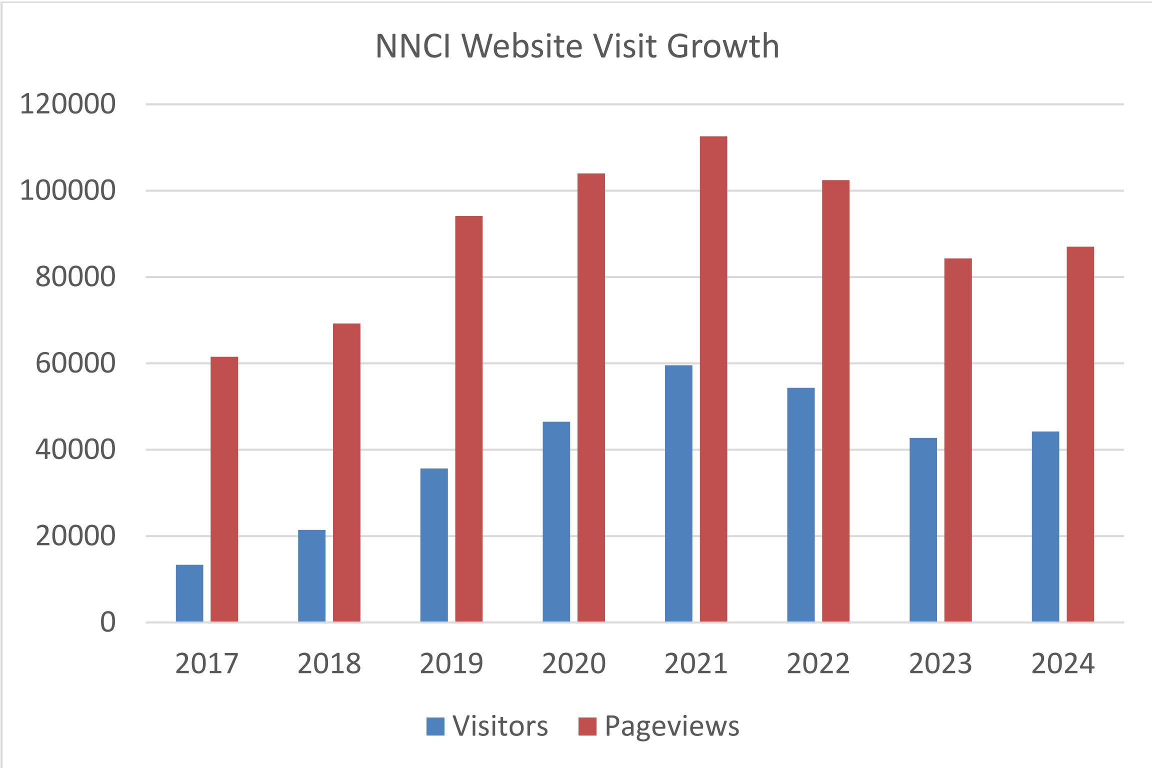


Figure 10: Growth in Annual NNCI Website Usage

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 11). The organic search rate of 60% is similar to the previous year but a decrease from a peak of 67% (2020). Direct acquisition remained the same at 32%. Referral and Social routes increased slightly from 2023, but these remain a relatively minor route for visitors.

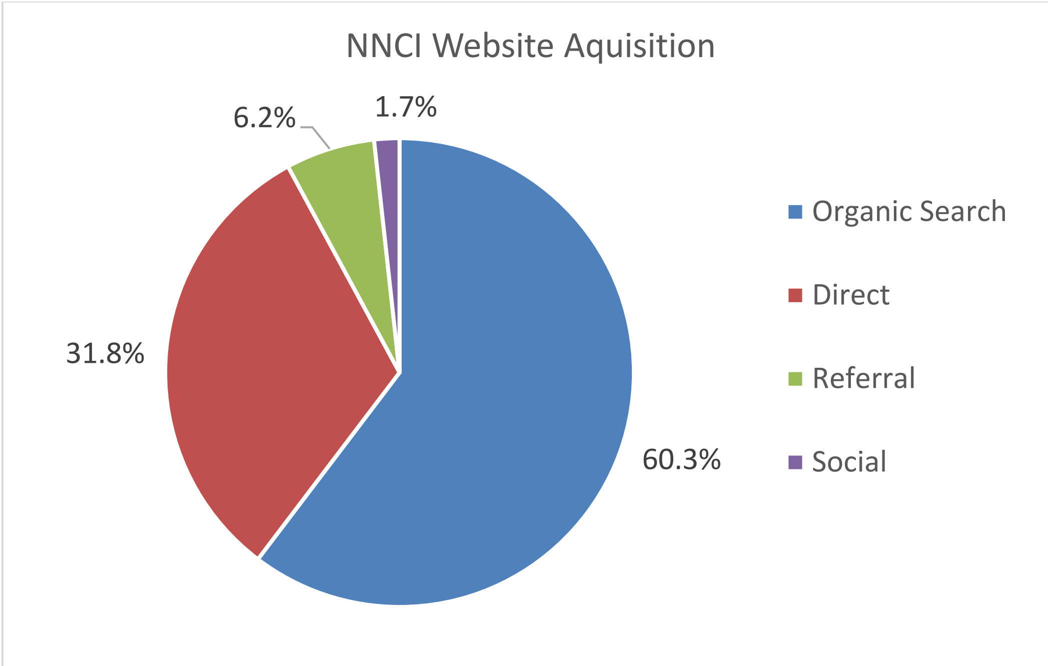


Figure 11: Site Acquisition (how visitors get to the website) for www.nnci.net (2024)

The geographic distribution of visitors to the website is illustrated by the map in Figure 12 below indicating the nearly complete global reach. The top ten locations of visitors are shown in Table 10 and these account for 82% of all visitors to the website.

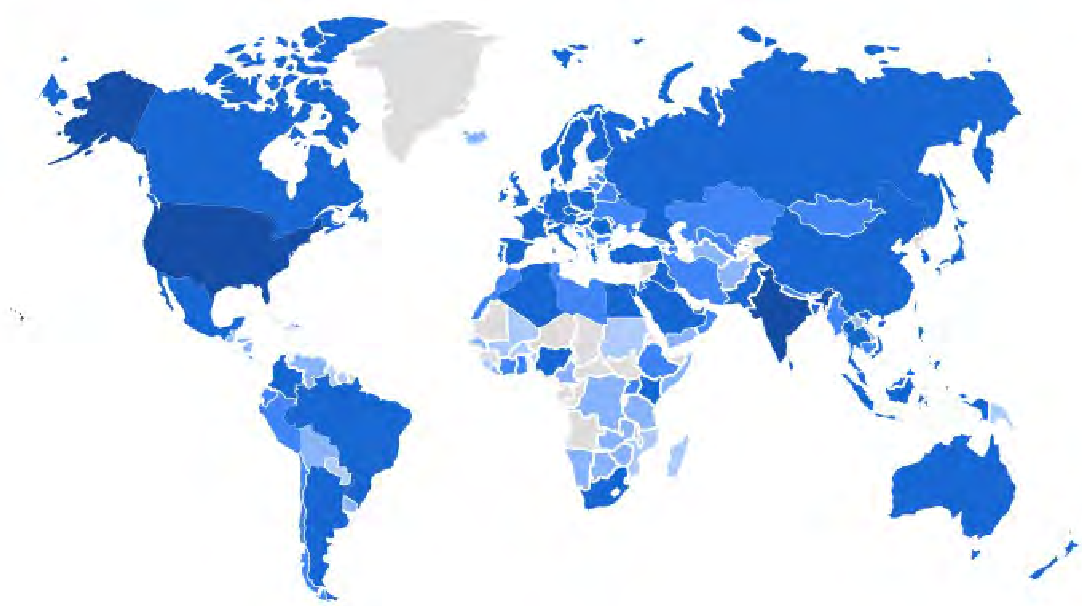


Figure 12: Geographic Distribution of Visitors to www.nnci.net (2024)

Table 10: NNCI Website Visitors by Location (2024)

Country	# Visitors	% Visitors
United States	23,062	51.2%
India	5,237	11.9%
China	2,622	5.9%
Philippines	1,468	3.3%
Canada	919	2.1%
United Kingdom	893	2.0%
Germany	601	1.4%
Indonesia	563	1.3%
Australia	562	1.3%
South Korea	531	1.2%

A further examination of the US locations of website visitors not surprisingly reveals that the highest densities are in states with NNCI facilities (California, Virginia, New York, Texas, and Georgia are the top 5, the same as 2023) although all 50 states are represented.

8.3. User Satisfaction Survey

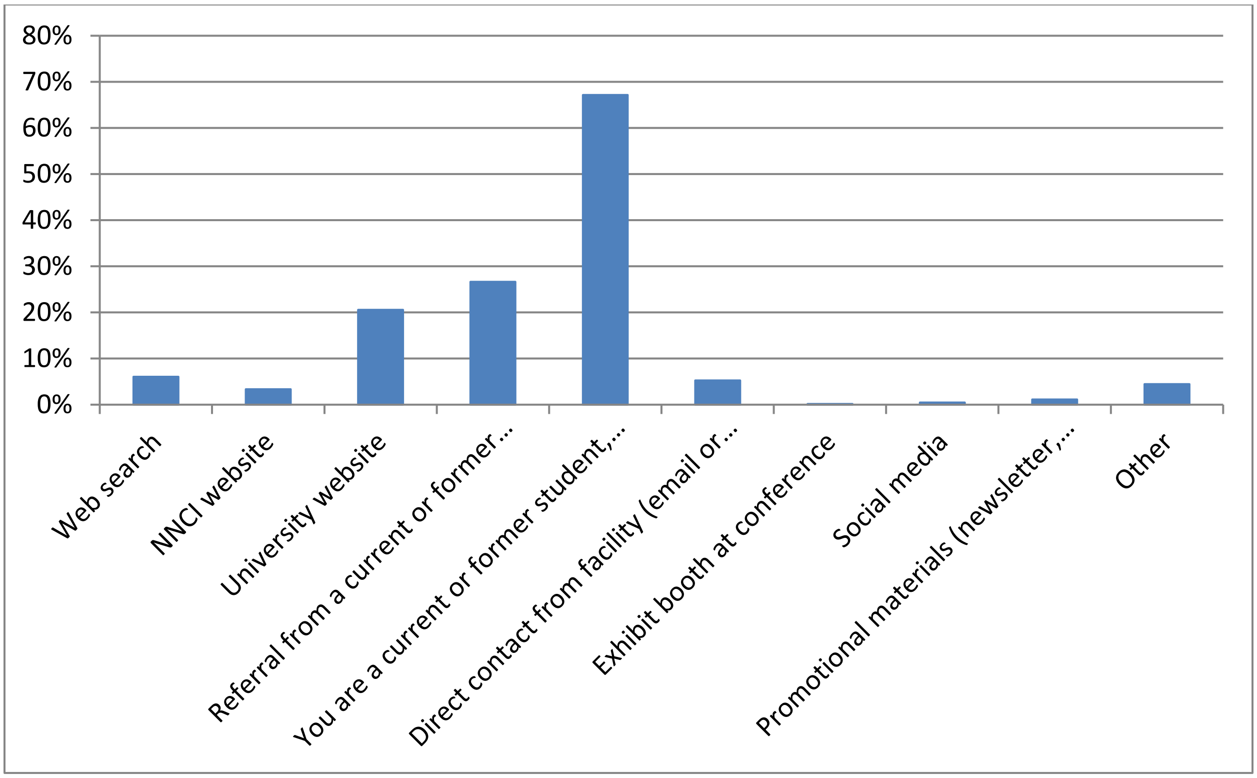
As a result of site director discussions, as well as recommendations from the Advisory Board, the Coordinating Office created a User Satisfaction Survey for implementation throughout the NNCI network. Using a *Survey Monkey* platform, the survey was first made available to sites for forwarding to their 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 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. The 2024 survey, shown below, was not changed from 2022. 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 on some questions (N=949). The site-specific filtered results, with comments, were provided to individual sites for identification of action as needed.

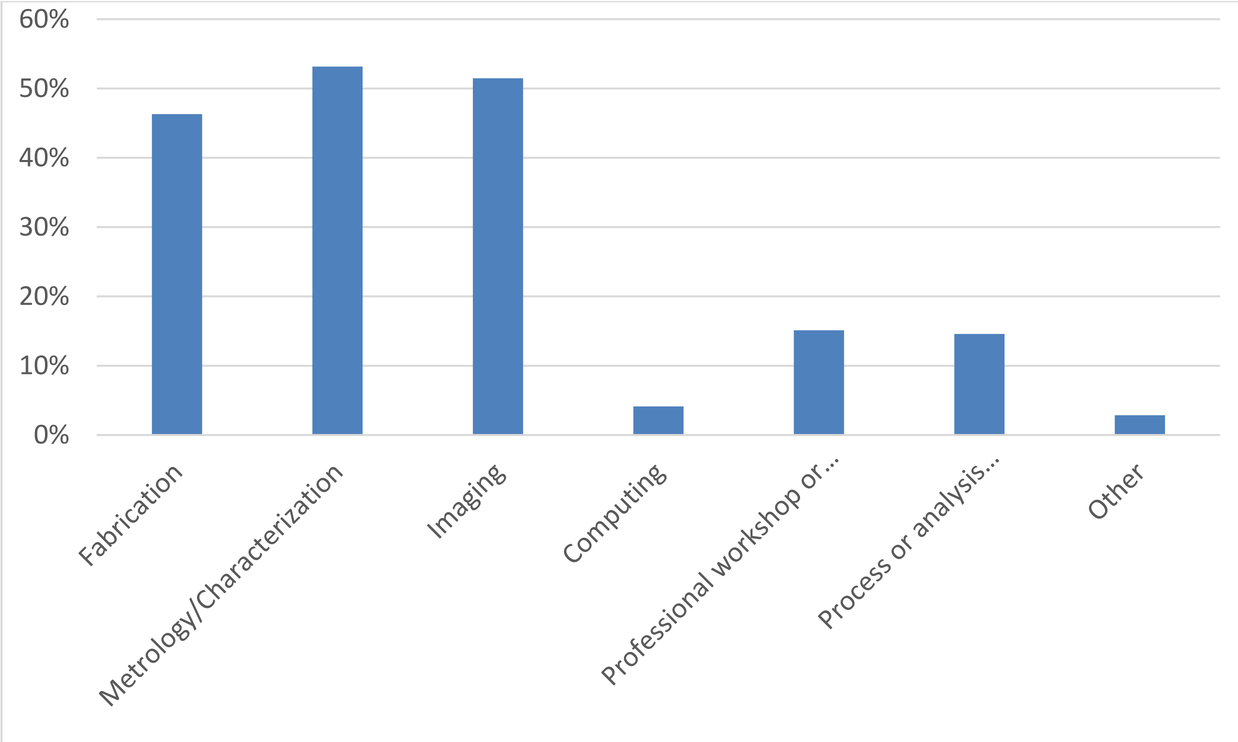
The NNCI facility that was primarily used during the previous 12 months.

The number of responses from each site varies from 12 to 295 (mean=59.3). 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 <5% of users. In addition, users were not asked to identify specific universities or facilities within the NNCI site which were accessed.

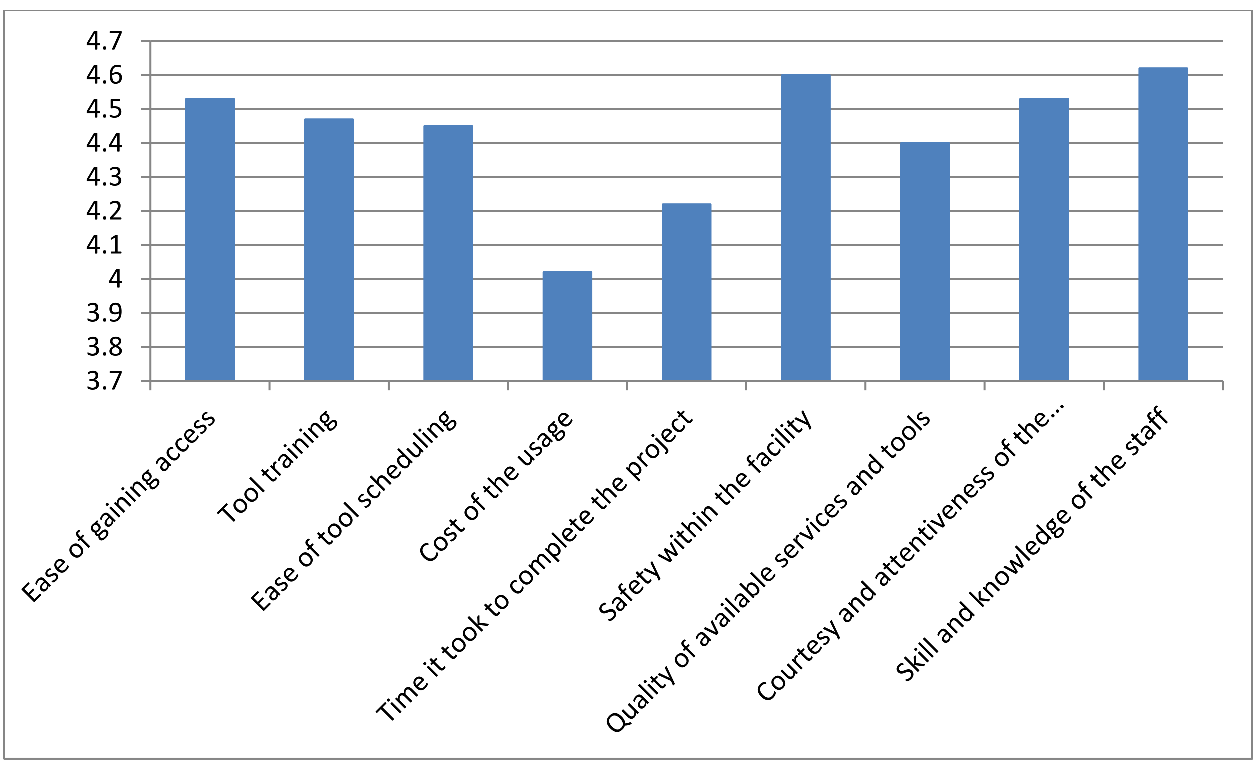
How did the user find out about the NNCI facility? (N=627)



Which services were used at the NNCI facility? (N=946)

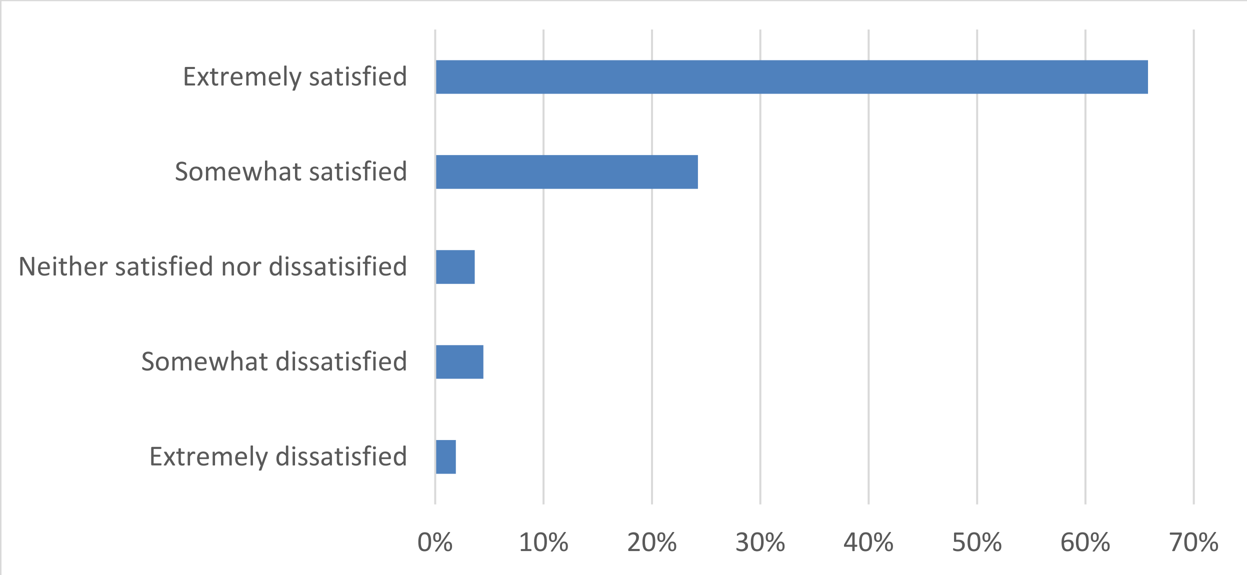


Regarding this NNCI facility, rate your satisfaction with the following (N=627; Scale=1-5, 1=extremely dissatisfied, 5=extremely satisfied)



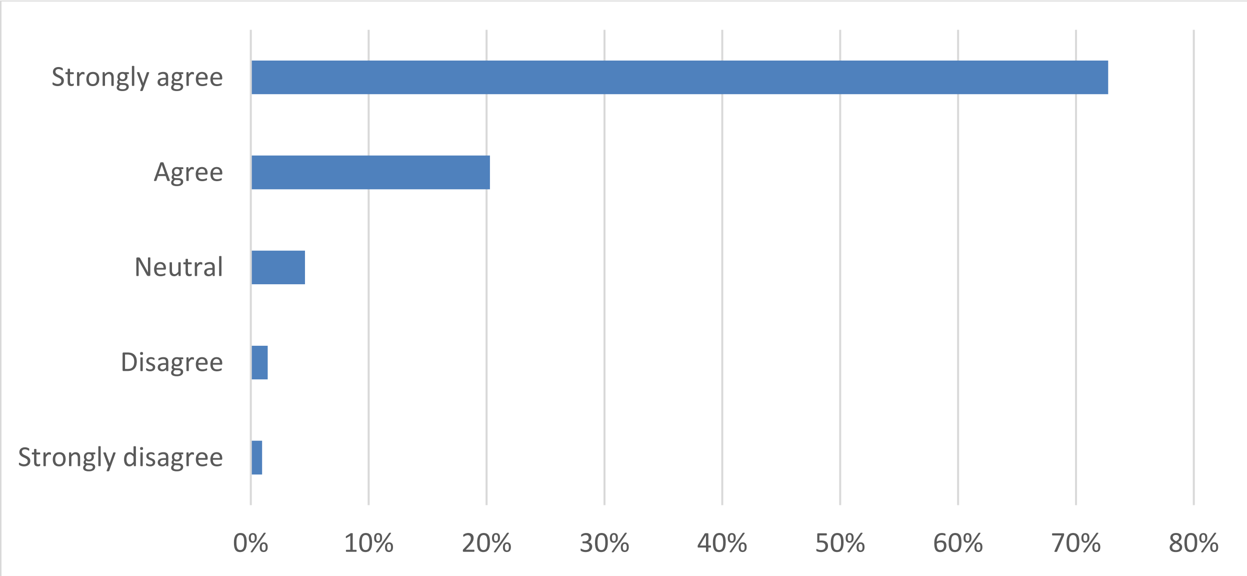
Rate your overall satisfaction with this NNCI facility (N=949)

For all NNCI sites, the average overall satisfaction rating is 4.48/5. For the common survey (N=631), the detailed ratings are as indicated below, with 90.0% of respondents indicating either somewhat or extremely satisfied.



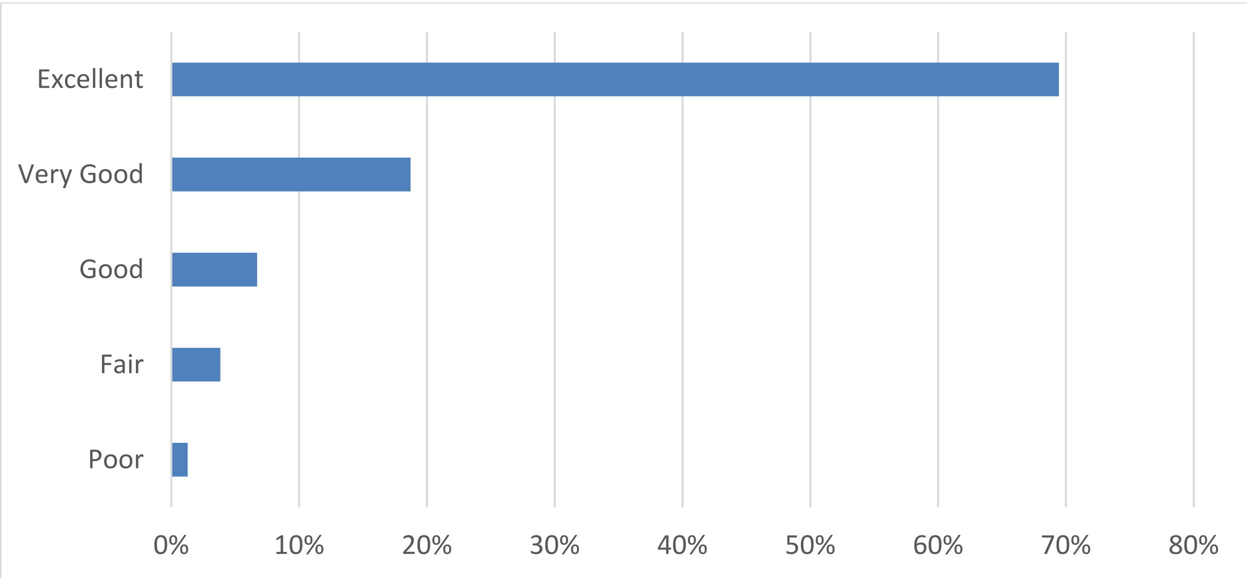
Rate your agreement with this statement: This NNCI facility has had a positive impact on my project goals or research activities (N=631)

This question was first asked in 2021, with 94.5% of respondents agreeing or strongly agreeing with the statement. In 2024, the percentage that agreed or strongly agreed has decreased slightly to 93.0%



How would you describe the level of civility (professional engagement and mutual respect) in your interactions at this NNCI facility? (N=625)

This question was 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. The percentage of respondents that rated the level of civility as Fair or Poor continues to remain low at 5.1%, although this has increased slightly from 2022. More than 130 comments were also provided so sites would be aware of any specific issues that might exist.



Would you recommend this NNCI facility to a colleague? (N=905)

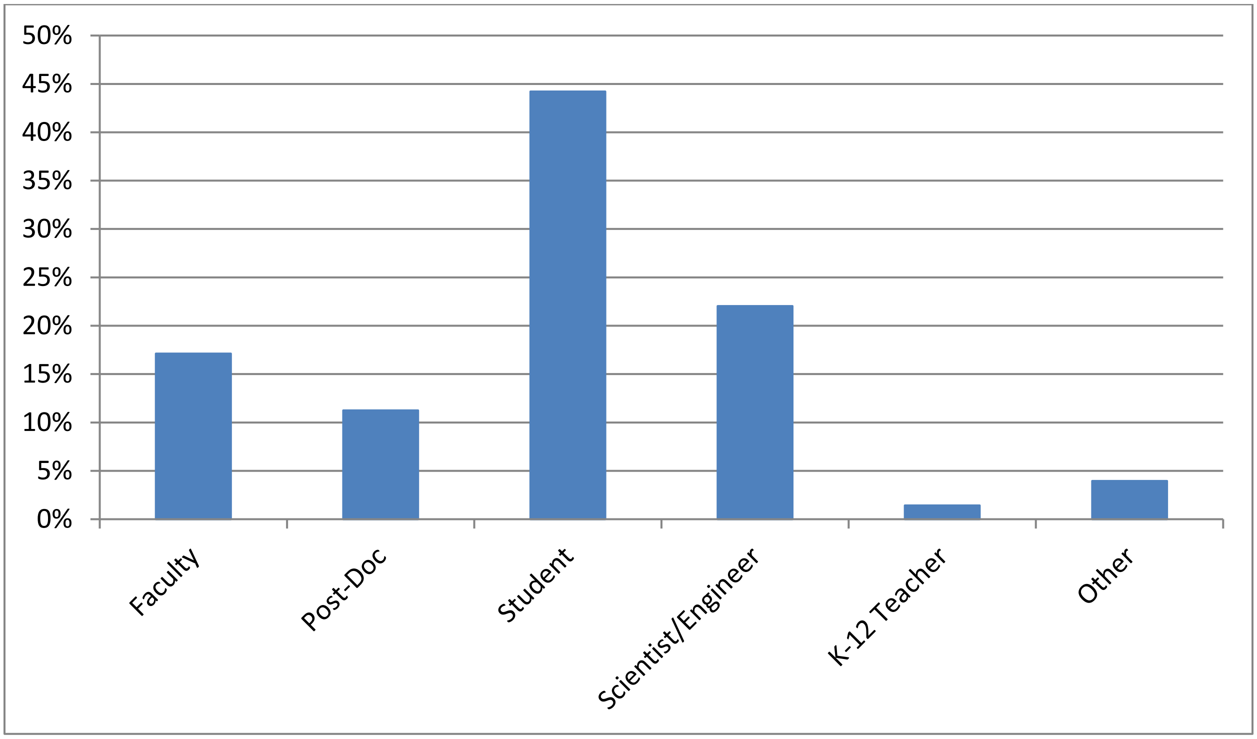
Yes: 96.1% (this is similar to 2023)

No: 3.9%

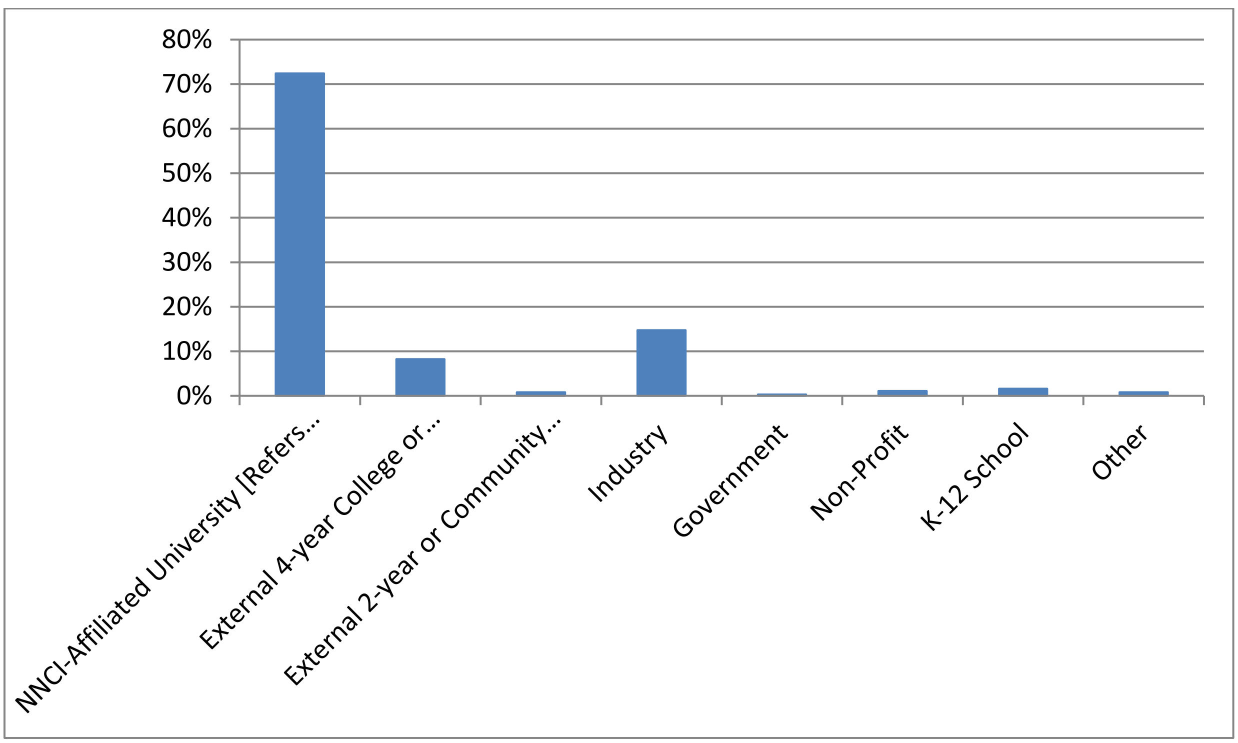
If you have any recommendations for specific new tools or services at this NNCI facility, please indicate them.

More than 140 suggestions were received and provided to the sites. Examples include characterization tools like FIB-SEM, XPS, XRF, XRD, SIMS, ICP-MS, photothermal IR imaging, fluorescence and Raman microscopy, micro CT, cryo-EM, nanoparticle characterization, and other chemical or mechanical analysis, as well as fabrication improvements such as additional maskless lithography tools, upgraded Nanoscribe systems, laser ablation/dicing, ALD, and ion implantation. In addition, replacing old and outdated tools, as well as additional standard tools (light microscopy, hot plates, oven), were also suggested. Finally, survey responses suggested changes to tool scheduling and real-time status, additional training options, better safety monitoring, improved tool maintenance, and additional staff.

User Position (N=631, this question was only asked on the common survey)



User Affiliation (N=631, 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 24) suggesting that the survey is probing a statistically similar cross-section of NNCI users.

In addition to responses to the survey questions noted above, 66 individual free-text comments were provided, both positive and negative, and a selection of these is provided here (specific facility names removed):

As a small startup (fewer than 10 employees), we depend on both … and … for our fabrication processes. Both are doing a great job …

The tools that I would like to use (usually in lithography fabrication) are often heavily booked, and I find it difficult to obtain time on the equipment that I need to perform experiments essential to my PhD work.

Thanks to everyone for helping me while I learn some new materials and processes!

Overall, very happy to have … in the community it's a great resource! However, we'd like to see more training & monitoring specifically for high-risk processes like acid/base work. Ultimately, it's a teaching cleanroom and people will make mistakes, but the rate of incidents lately is concerning.

… has a great facility with tremendous capabilities. Some equipment is beginning to age, so don't forget to plan for maintenance / upgrades / replacement at some point in the future.

The staff has helped with anything that I needed while working with the instruments they have. When they didn't know how to do what I needed, they spent lots of time with the manufacturer and I to implement a process to get the measurements I needed. I've had nothing but a positive experience working with ..

We are using … because a tool at our university broke, and because of tools they have that we do not. So, we are grateful for NNCI (even if we're also a little envious).

I've been affiliated with … for more than a decade and have seen a strong decline. For the most part, the cleanroom staff have been great, but clearly management has been unresponsive to their (or us as users) needs. It is an utter tragedy to observe the current state of the facility.

I have used … as a student, then faculty, and more recently as an industry engineer. The facility does an amazing job of facilitating industrial engagement, in the interest of doing good science with meaningful outcomes. Fantastic place with fantastic people!

9. NNCI Annual Conference

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 returning to in-person (hybrid) meetings in 2022, this past year's conference was held in-person (with limited virtual options) at University of Louisville on October 28-30, 2024. The 2.5-day event had a registration of 106, including senior representation from every site (13/16 site directors); 5 of 7 advisory board members; NSF officials including NNCI Program Officer Dr. Richard Nash and ECCS Division Director Dr. Tony Maciejewski; NNCO Director Dr. Branden Brough and Deputy Director Dr. Quinn Spadola; as well as invited speakers.

This year's program included a ½-day special topic program on "Partnerships and Synergies between NNCI and DOE NSRCs", with invited guest speakers from all five DOE NSRC facilities, panel discussion moderated by Dr. Brough, and breakout sessions with NNCI and NSRC participation (photo at right).

Invited NSRC representatives included:

- Charles Black (Director, Center for Functional Nanomaterials, Brookhaven National Laboratory)
- Jim Ciston (Deputy Director, Molecular Foundry, Lawrence Berkeley National Laboratory)
- Neus Domingo Marimon (Group Leader, Center for Nanophase Materials Sciences, Oak Ridge National Laboratory)

- Jeffrey Nelson (Director, Center for Integrated Nanotechnologies, Sandia National Laboratories)
- Gary Wiederrecht (Deputy Division Director, Center for Nanoscale Materials, Argonne National Laboratory)

Breakout session topics, co-lead by an NSRC and NNCI team, were:

- Reciprocal user access and support
- National research capabilities database
- Annual nano infrastructure conference
- Joint webinars/seminars and other outreach activity

The conference agenda also featured:

1. Separate meetings for those interested in Education/Outreach, SEI, and Innovation/Entrepreneurship were held during the afternoon before the main conference.
2. The Shared Infrastructure Network Collaboration (SINC) Convening, organized by the National Nanotechnology Coordination Office, was held as a follow-up to the initial meeting held in 2023.
3. Remarks from Dr. Richard Nash (NSF Program Manager for NNCI) and Dr. Quinn Spadola (Deputy Director of the National Nanotechnology Coordination Office, NNCO).
4. 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.
5. Short site reports from each of the 16 NNCI sites. Each site was requested to address the question: "What are examples of programs and activities developed under NNCI that will be sustainable, independent of any continued NSF renewal funding, and what strategies or sources will be used to support them?"

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.

6. Site presentations were grouped into 4 topical areas, with panel discussions featuring the site directors and attendees.

- "What are you doing now and how can a future infrastructure better reach out to underserved communities (for example, rural areas, underrepresented groups, or low research activity institutions)?"
- "For NNCI Research Communities, what worked, what didn't, and what are suggestions for what a future network might implement to support national priority research topics?"
- "What role do community/technical colleges play in your education and workforce development strategy and what role should they play in a future infrastructure network?"

- "How does your NNCI site support translation of research to the commercial sector and what more could be done?"

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 10 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-2024.

The next/final NNCI Annual Conference is scheduled to be held at Georgia Institute of Technology in October 2025.

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.

<u>Network-Wide Activities</u>

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. Twelve NNCI sites submitted 32 entries for the "Plenty of Beauty at the Bottom" image contest in 2024.
6. Participation in the NNI 20th Anniversary Celebration (March 2024).
7. Student attendance at the CHIPS-related programming at TechConnect (June 2024), with travel supported by the NNCI Coordinating Office.
8. Attending NSF Nanoscale Science and Engineering Grantees Conference. The December 2024 conference was held in person and virtually, and included organizing committee members Dan Herr, UNC-Greensboro (SENIC), Bill Wilson, Harvard (CNS), and Mary Tang, Stanford (nano@stanford).
9. Attending NNCI Annual Conference (October 2024)
10. Participating in NNCI REU Convocation (Hosted in Aug. 2024 by NNF)
11. 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
12. Participating in the NNCI Nanotechnology Entrepreneurship Challenge (NTEC) competition and showcase event
13. Providing content for the NNCI website
14. Participation in the NNCI Outstanding Staff Awards program
15. Discussions between site staff on equipment repair and maintenance issues
16. Dissemination and promotion of NNCI, network events, and opportunities (webinars, workshops, job postings, etc.) through electronic communications and other marketing
17. User referrals to other sites, via NNCI email list or responses to NNCI website contact form
18. Leadership of and participation in the NNCI Research Communities

19. Participation in the NNCO Shared Infrastructure Network Collaboration (SINC) (convened October 2024)
20. Many NNCI site directors participated in the National Academies Quadrennial Review of the National Nanotechnology Initiative during the summer/fall of 2024. This quadrennial review of the NNI is focusing on the US nanotechnology research and development infrastructure and will identify barriers to use for communities who are not fully engaging with this infrastructure.

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. Workshop on Quantum Engineering Infrastructure II (Univ. Minnesota), held March 3, 2024, the Sunday prior to the 2024 APS March Meeting in Minneapolis. The goals of WQEI2 were (1) to assess the outcomes from WQEI in 2021 and evaluate progress toward recommendations from that workshop; (2) to understand how new developments in quantum computing have altered the needs and best practices for quantum fabrication infrastructure since 2021, and (3) to provide a vision for the future of quantum fabrication infrastructure in the United States so that shared national resources meet the needs of quantum engineered systems. The workshop was a hybrid event with roughly 120 registered attendees in total, with most from US universities, but with other attendees from government, industry, national labs and foreign universities, and approximately 60 people attended in person.
    b. Quantum Noir: A Quantum/Nano Meeting, directed at networking, supporting and recruiting researchers and students of color (+) into the Quantum/Nano Condensed Matter Sciences, was organized by Diversity Subcommittee chair Bill Wilson (Harvard). A workshop grant for this meeting was awarded by NSF CMP. CNS hosted the first meeting June 11-14, 2024, and a number of NNCI sites sent meeting participants.
    c. NNCI Nano+Additive Manufacturing Summit, July 30-31, 2024 (University of Louisville/KY Multiscale). 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.
    d. NNCI Etch Symposium, April 24-26, 2024 (Georgia Tech) with a theme of “Advances in Micro- & Nanoscale Patterning of Strategic and Emerging Materials for Electronic, Photonic, Quantum, & MEMS Devices.” The program was organized by SENIC staff member Durga Gajula, with help from colleagues at Harvard, Stanford, and Cornell, and had 141 in-person attendees from 42 organizations including representation from 10 NNCI sites. In addition, there were 67 virtual attendees (37 organizations from 9 countries).
    e. NNCI Education Symposium, November 11, 2023 (SDNI) with the theme “K-12, Community College, and Universities: Building the Next Generation of US Nanotechnology Workforce.” The meeting included presenters from NNCI sites (SDNI, nano@stanford, NanoEarth, CNF), NNCO, MNT-EC, Penn State/NACK

network, UCSD MRSEC, SEMI Foundation, and local middle and high schools. In the 1-day virtual event, people exchanged ideas and collaboration plans to promote STEM in K-12 and integrate nanotechnology into the current science curricula.

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. During Year 9, RTNN referred a user for die bonding to Georgia Tech.
    b. NNI's WNF has been involved in remote projects with Montana State University.
    c. MONT had user/technical interactions with MINiC, MANTH, NanoEarth, and CNF on user needs.
    d. CNF collaborates with other sites on project support, particularly nano@stanford, MANTH, and CNS.
3. Staff technical interactions:
    a. MONT and NNI are continuing to collaborate on managing the NorthWest Nano Lab Alliance.
    b. MONT hosted staff members from MANTH in a visit to their ICAL facility. ICAL director Recep Avci visited the CNS at Harvard, meeting with the facility director/manager and touring the facility
    c. CNF staff visited Stanford to benchmark the Heidelberg MLA150 operations.
    d. nano@stanford collaborated with NNI on technician training through the ME Commons, NW-AI-Hub's working group.
    e. Spurred by a conversation between Pat Watson (MANTH) and Walter Henderson (SENIC) at the 2023 NNCI Annual Conference at Stanford, MANTH & SENIC coordinated staff visits to each other's facilities at Univ. Pennsylvania and Georgia Tech in early 2024. Two staff members from Penn (one each from the fabrication and characterization facilities) visited their counterparts at Georgia Tech in Feb/March and four members of the Georgia Tech Materials Characterization Facility journeyed up to Penn in mid-March.
    f. The Nano Earth and Environmental Sciences Research Community initiated a staff exchange. NanoEarth Lab Manager and Instrument Specialist Weinan Leng and NanoEarth Postdoctoral Associate Bipin Lade visited Montana State University (MONT) and Arizona State University (NCI-SW) for a week in April 2024. They toured facilities, met with staff, and explored the unique expertise and instrumentation available at each site. They introduced MONT and NCI-SW staff to NanoEarth and discussed potential for further collaboration. The trip was funded in part by the NNCI

Coordinating Office staff exchange funding program. In return, NanoEarth has offered to host visitors from the other Nano EES-RC sites and expect they may be most interested in visiting after the new JEOL JEM-ARM200F TEM is installed later this year.

4. NSF-funded Research Experience for Teachers (RET) program (Georgia Tech, lead institution, with Northwestern, Univ. Minnesota, and Univ. Nebraska). During 2020-2023, these four universities from across the NNCI network supported 20 high school/community college faculty each year in a 6-week summer research experience, with follow-up support during the school semesters. A renewal RET proposal was submitted in January 2024 with Georgia Tech as the lead site and University of Minnesota and University of Nebraska as partners and this was funded for program activity during the summers of 2025-2027.
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. GQL supports a webpage (www.globalquantumleap.org), Twitter, and LinkedIn pages. GQL has two 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. GQL also sponsored research-specific student/postdoc exchanges coordinated between members of the US and international partner networks. The cohort was expanded this year to include 4 undergraduates who traveled to NIMS in Japan and 3 to RWTH Aachen in Germany. GQL also sponsored 2 one-on-one student/postdoc exchanges between international researchers and US-based institutions. GQL has also co-sponsored several events for the quantum community including the Summer 2024 Quantum + Chips Workshop and the Workshop on Quantum Engineering Infrastructure II (WQEI2), which was held in March 2024.
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, and RTNN took part in the Greensboro Science Center Extravaganza in partnership with JSNN. 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. JSNN is a collaborative partner in the DOD Microelectronics Commons Hub “Commercial Leap Ahead for Wide Bandgap Semiconductors (CLAWS),” led by NC State University and RTNN, in the NSF STC “Science and Technologies for Phosphorus Sustainability Center (STEPS)” led by NC State University, and in the Duke University-led NSF AccelNET program, “International Network for Researching, Advancing, and Assessing Materials for Environmental Sustainability (INFRAMES).”
7. Joint proposals:
    a. CNF and nano@stanford collaborated on a Mid-Scale RI-2 Consortium proposal.
    b. CNF and NNI collaborated on a NATCAST proposal.

c. nano@stanford partnered with NNI and NCI-SW on a proposal for the NSTC Workforce Partner Alliance 2024.

d. nano@stanford partnered with CNF, TNF, NCI-SW, and NanoEarth on a proposal for the Digital Twins Chips Manufacturing USA Institute.

8. Sharing of best practices:

   a. Regional facility networks have continued and expanded and a working group (led by Ron Olson, CNF) meets to enable sharing of ideas, challenges, and solutions.

   b. Nano Summer Institute for Middle School Teachers (NanoSIMST): This weeklong workshop, originally developed by Stanford, was implemented in 2024 at more than half of NNCI sites, virtually or in-person. Stanford continued to support the in-person programs at SENIC, NNF, and SDNI, and also lead the effort to coordinate a nationwide virtual NanoSIMST program, which extends the reach to more low resource communities where there is an increased diversity in the student population. Eleven NNCI sites (SHyNE, MANTH, MONT, CNS, RTNN, MiNIC, SDNI, NCI-SW, KY-Multiscale, and NanoEarth) sponsored teachers to attend.

   c. 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.

   d. Research and Entrepreneurship Experience for Undergraduates (REEU) seminars (led by Matt Hull), which offers traditional REU students a gentle introduction to technology translation and entrepreneurship.

   e. NNF continued to collaborate with Montana Nanotechnology Facility (MONT) and the Northwest Nanotechnology Infrastructure (NNI) by sharing synchronous lessons and activities and partner contact information, respectively.

9. Participation in SEI Programs:

   a. The SEI program hosted a half day workshop shortly before the NNCI annual conference in 2024 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 (ASU) 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.

10. 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.

11. Several sites (ASU, Georgia Tech, Cornell, and UC San Diego) collaborate with Penn State's Nanotechnology Applications and Career Knowledge (NACK) in the Microelectronics and Nanomanufacturing for Certificate Program. Designed specifically for US military personnel and veterans, this program is 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.

12. 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).
13. Activities in computation, modeling and simulation have been organized by Coordinating Office Associate Director Azad Naeemi (SENIC) in collaboration with faculty at NCI-SW, TNF, and other NNCI sites.

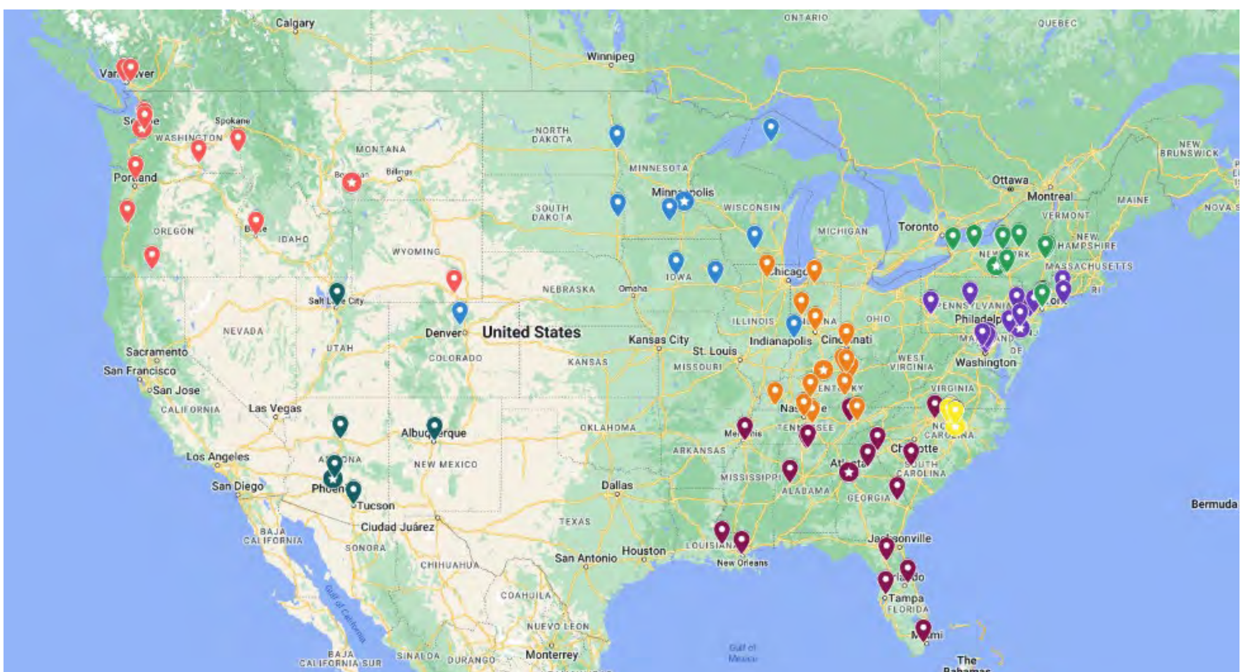
<u>Site Activity on Behalf of the NNCI</u>

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 continued its partnership with radio producer Jim Metzner who produced a NanoEarth-sponsored "Pulse of the Planet" long form podcast for the eighth year. To date, 62 NanoEarth-sponsored shows have been produced. These episodes are built for public consumption and highlight the most interesting projects from external users, impactful research at other NNCI sites, and local site researchers, with those individuals personally interviewed for each episode. A new episode "Secrets of Soil" featured Dr. Nikolla Qafoku of Pacific Northwest National Laboratory discussing numerous nanoscale aspects of his soil research including the potential use of soil for carbon sequestration was released in May 2024. "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 REU Convocation by NNF (August 2024). The 3-day event for 125 attendees (91 REU students) included oral presentations, poster sessions, keynote speakers, and social events.
7. Hosting of NNCI Annual Conference by KY Multiscale (October 2024). Planning activities included arranging logistics, soliciting sponsors, creating communications materials, and developing technical content. In addition, NNCI Director David Gottfried organized, with support from the NNCO, a special topic session on collaborations with DOE NSRC labs.
8. KY MMNIN hosts the UGIM website and several NNCI staff are members of the UGIM Steering Committee (Aebersold (KY Multiscale), Cibuzar (MINIC), and Tang (Stanford)).
9. Daniella Duran (nano@stanford) provided organization support for the NNCO-Nanoeducators Forum. She 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. Washington Nanofabrication Director Dr. Maria Huffman (NNI) is a member of the external advisory board of Myfab (www.myfab.se), the Swedish Research Infrastructure for micro and nanofabrication.
11. Mikkel Thomas (SENIC, CO) meets monthly with Jared Ashcroft, Director of the NSF-supported Micro Nanotechnology Education Center, to discuss mutual interests.
12. David Gottfried (SENIC, CO) has a monthly meeting with the Director and Associate Director of the National Nanotechnology Coordination Office.
13. David Gottfried (SENIC, CO) attended and presented at the nanoFabUK Symposium (Sept. 2024) and the International Conference on Research Infrastructure (Dec. 2024).

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 13) shows the updated geographic distribution and regional clustering of these networks, along with a brief description of each. During 2023, a new working group to communicate and share best practices among those sites which support regional networks was formed and has begun meeting (Section 6.3).



Northern Nano Lab Alliance (NNLA)
Southeastern Nano Facility Network (SENFN)
Southwest Nano Lab Alliance (SW-NLA)
Northwest Nanotechnology Laboratory Alliance (NWNLA)
Ohio Valley Regional Network
Mid-Atlantic Region Cleanroom Managers Workshop
RTNN Affiliates Network
New Yok State Nanotechnology Network (NNN)

Figure 13: 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 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 Multiscale: The **Ohio Valley Regional Network** is a coordination of universities, colleges, and community colleges in the Midwest region of the US with state-of-the-art research and educational facilities in the converging fields of micro/nanotechnology and additive manufacturing (AM). The purpose of the network is to exchange information on facilities operation and to highlight the exciting research occurring at each location. The signature event of the network is its annual NNCI Nano+Additive Manufacturing Summit which is held in Louisville in the summer.

CNF: The **New Yok State Nanotechnology Network (NNN)** is focused on bringing 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 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 2023 averaged around 37 (range:8-70). Video recordings are then posted on the NNCI YouTube channel (see below). The list of 2024 seminars is provided in Table 11.

Table 11: NNCI 2024 Webinars

Date (Topic*)	Speaker(s)	Affiliation	Title
March 11 (I)	Jacques Chirazi, Christine Liou, Yves Theriault	Univ. of California-San Diego	"How to Engage with Diverse Student Populations in Entrepreneurship"
May 9 (C)	Evan Michelson, Program Director	Energy and Environment Program at the Alfred P. Sloan Foundation	"Philanthropic Funding of Research"
	Ian Philp, Program Officer	Environment at the Bernard and Anne Spitzer Charitable Trust	
	Josh Greenberg, Program Director	Technology and New York City Programs at the Alfred P. Sloan Foundation	
Sept. 17 (I)	Yossi Feinberg, The Adams Distinguished Professor of Management and Professor of Economics	Stanford University	"From Lab to Launch: Stanford's Entrepreneurial Ecosystem"
	Jennifer Dionne, Professor of Materials Science and, by courtesy, of Radiology	Stanford University; Chan Zuckerberg Investigator; co-	

		founder of Pumpkinseed
	Keegan Cooke, Director	Stanford Ecopreneurship, Stanford University

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

10.4. NNCI YouTube Channel

The NNCI YouTube Channel was created in April 2018 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 348 current subscribers (nearly 100 new added in 2024) and 3,065 views during 2024, a 14% increase compared to 2023. Analytics of the top video content during 2024 is shown in Table 12 below, with newly-added videos in bold. Since the start of the channel, there have been more than 9,000 total views with the top 5 videos including those discussing careers, “What is the NNCI”, and computation videos from Shela Aboud (Synopsys) and Dragica Vasileska (ASU).

Table 12: NNCI YouTube Video Analytics (2024)

Video*	Views	Average View Duration
The Evolution of Process TCAD in Semiconductor R&D and Manufacturing (Shela Aboud, Synopsys)	605	6:25 (10.8%)
Careers in Nanotechnology: Opportunities for STEM Students (Jim Marti, MiNIC)	570	2:47 (20.4%)
Silvaco Technology CAD, Background, Overview & Future" (Eric Guichard, Silvaco)	353	4:46 (8.5%)
What is the NNCI?	251	1:39 (45.4%)
X/Nano: The Enabling Potential of a Career in Nanoscience (Matt Hull, NanoEarth)	181	4:18 (14.8%)
Evaporative Deposition	131	2:51 (51.7%)
Antiferromagnetic Tunnel Junctions for Spintronics" (Evgeny Tsymbal, Univ. Nebraska-Lincoln)	126	4.45 (7.4%)

Simulation Software Next Door (Dragica Vasileska, ASU)	124	4.33 (7.4%)
"From Lab to Launch: Stanford's Entrepreneurial Ecosystem"	**101**	**7:18 (12.1%)**
"Particle Based Simulation of Wide Bandgap Devices" (Stephen M. Goodnick, ASU)	101	3:40 (5.6%)

*Videos added in 2024 are bolded.

10.5. NNCI Outstanding Staff Awards

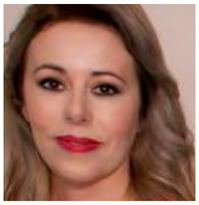
During 2024, the NNCI Coordinating Office organized the seventh year of the "Outstanding NNCI Staff Member" awards. This award acknowledges the significant efforts by NNCI site staff who endeavor to provide excellent service and support to all network users in three categories: Technical Staff, Education and Outreach, and User Support. In June 2024 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 their own site and the NNCI network. Each winner received an engraved desktop plaque and was recognized at the 2024 Annual Conference, with travel support provided to attend. Some awardees from 2020-2023 were also recognized at this event.

Education and Outreach

- Jessica Hauer (Education and Outreach Coordinator, Arizona State University, NCI-SW)

"… the glue that holds these programs together across three campuses separated by 150 miles...."

- Ana Sanchez Galiano (Education & Outreach and Logistics Coordinator, University of Louisville, KY Multiscale)



"… passionate about education and outreach and the opportunity to positively impact the lives of our current and future STEM students…"

Technical Staff

- Jeremy Clark (Research Support Specialist III/Senior Engineer, Cornell University, CNF)

"…commanding knowledge of modeling and simulation software, lab logistical software, programming, chemistry, plasma physics, and cleanroom tools and processes, provides users with a comprehensive, clear learning experience."

- Toby Tung (Instrumentation and IT Manager, North Carolina State University, RTNN)

"… consistently performing beyond expectations, allows for instruments to stay up and running for users to be trained and educated on, often without them knowing."

<u>User Support</u>

- Stacy Clementson (Program Assistant I, Cornell University, CNF)

"… an unsung hero who promotes cooperation and manages customer relationships, Stacy creates mutually beneficial and long-lasting relationships.…"

- Sara Ostrowski (Associate Director, Stanford University, nano@stanford)

"… a budding leader and has extended her impactful efforts to reach various K-12, community college, and public communities beyond our network."

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 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).

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 collected regularly. 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 for them by site staff. 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 site's 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, 2023 - Sept. 30, 2024)

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 13 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 13: Summary of NNCI Aggregate Usage Data (Year 9)

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users	14,732	921 (264 – 1,866)
Unique Internal Users	10,904	682 (201 – 1,602)
Unique External Users	3,828 26.0%	239 (63 – 618) 26.0% (14.2% – 50.2%)
External Academic	1,422	89 (12 – 331)
External Industry	2,094	131 (24 – 362)
External Government	272	17 (0 – 210)
External Foreign	40	3 (0 – 10)
Average Monthly Users	5,679	355 (79 – 858)
New Users Trained	5,676	355 (67 – 834)
Facility Hours*	1,159,953	72,497 (9,387 – 225,932)
Facility Hours – External Users	272,242 23.5%	17,015 (1,913 – 67,126) 22.9% (6.0% – 50.9%)
Hours/User*	78.8	72.4 (35.6 –128.7)
User Fees Internal Users External Users	 $29.4M $22.4M	 $1.84M ($216K – $6.34M) $1.40M ($58K – $4.63M)

*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 1-9 is shown in Table 14 below. As can be seen, all metrics show positive percentage increases from Year 8 to Year 9. In fact, many metrics have increased to the levels seen in Year 4, just prior to the pandemic and the previous peak year for NNCI. The exception to this recovery remains the level of external academic usage, with these users in Year 9 still approximately 7% below that seen during Year 4, even with the 9% increase in the past year. This trend is also reflected in the external user hours, which grew 6% during the past year yet remain 9% below the Year 4 level. We can speculate that the return to normal operations has been easier for internal users, which are at their highest level since the start of NNCI, who have the benefit of proximity to their home facilities that external users do not. Still, it is encouraging that external usage has continued to grow since Year 4, just not at the same pace as internal users. The changes in internal and external users and usage hours over the first nine years of NNCI are illustrated in Figures 14 and 15. These results further illustrate the improvements in Year 9 compared to Year 8, and the slower rate of usage growth since the pandemic recovery when compared to the first four years of NNCI. Finally, it should be noted that, with the start of the second 5-year funding period, i.e. in Year 6, a few facilities were dropped and others added to the network sites (see Section 1.2) so comparisons between Years 1-5 and Years 6-10 should take that into account.

Table 14: Comparison of Years 1-9 NNCI Aggregate Usage Data

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Δ Year 8-9
Unique Facility Users	10,909	12,452	13,110	13,355	10,501	11,242	13,348	13,722	14,732	+7.4%
Unique Internal Users	8,342	9,276	9,731	9,503	7,668	8,449	9,967	10,079	10,904	+8.2%
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%	3,643 26.6%	3,828 26.0%	+5.1%
External Industry Users	1,413	1,669	1,870	1,961	1,529	1,619	1,882	2,044	2,094	+2.4%
External Academic Users	1,060	1,295	1,365	1,531	1,064	964	1,238	1,300	1,422	+9.4%
Average Monthly Users	4,429	4,911	5,001	5,292	3,654	4,381	5,112	5,296	5,679	+7.2%
New Users Trained	4,116	4,563	4,981	5,194	2,813	4,414	5,151	5,115	5,676	+11.0%
Facility Hours	909, 151	939,230	1,006,764	1,149,788	767,255	967,297	1,072,332	1,095,931	1,159,953	+5.8%
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%	256,767 23.4%	272,242 23.5%	+6.0%
Hours/User	83	75	77	86	73	86	80	78	79	+1.3%
User Fees										
Internal	$20.6M	$23.0M	$23.6M	$23.2M	$16.3M	$21.9M	$24.4M	$26.0M	$29.4M	+13.1%
External	$13.5M	$14.5M	$16.9M	$20.5M	$13.1M	$17.8M	$20.1M	$19.7M	$22.4M	+13.7%

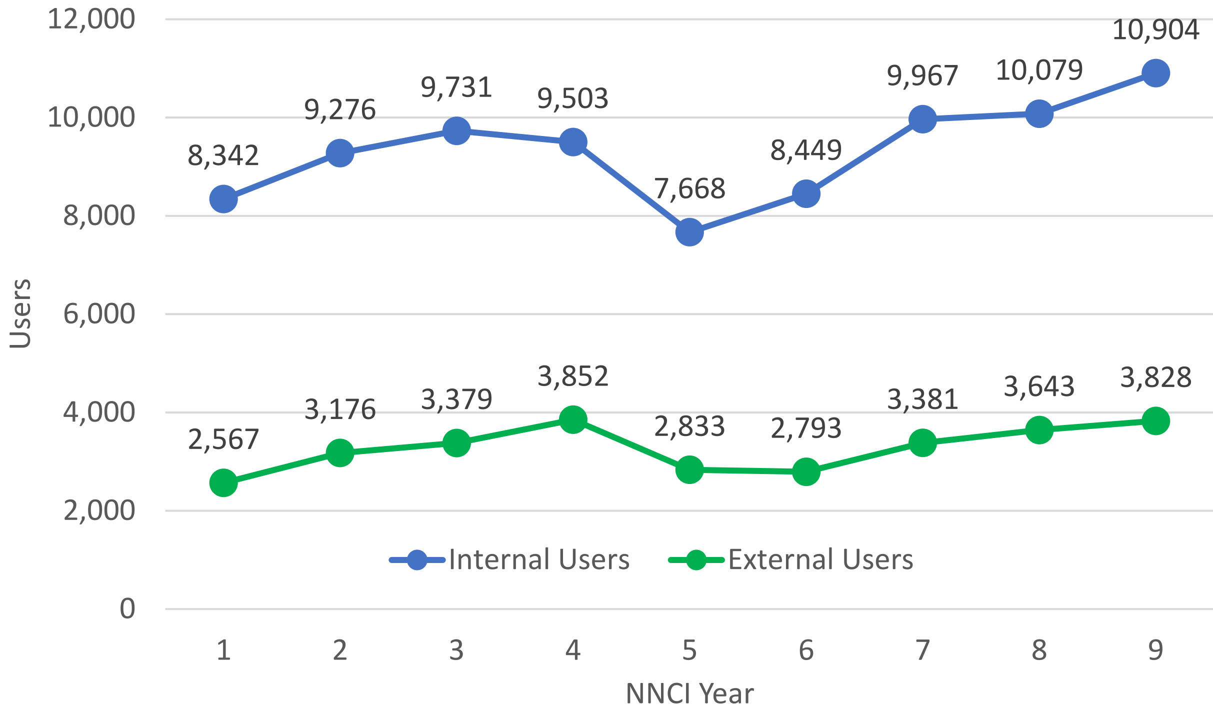


Figure 14: NNCI Users by Year

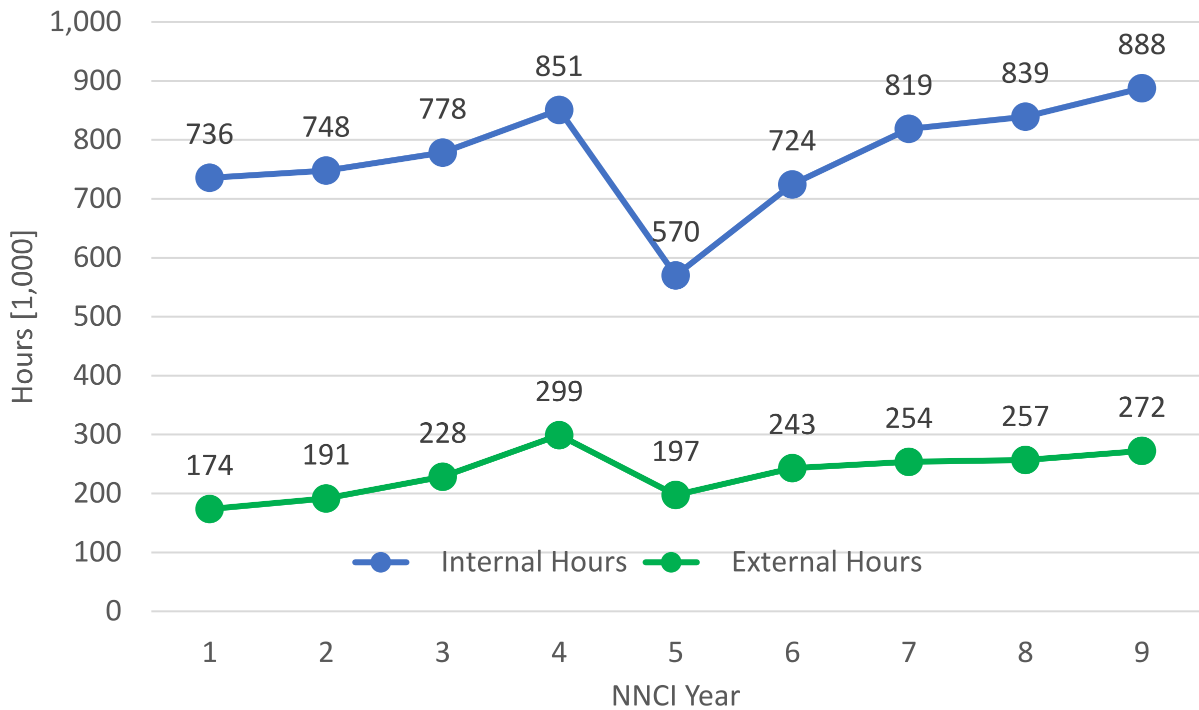


Figure 15: NNCI Usage Hours by Year

A deeper analysis of the annual usage growth, the effects of the pandemic closures, and recovery of usage is explored in the figures below. Figures 16 and 17 show the Years 4-9 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 and growth continued with a 3% increase in Year 8 and a 7% increase during Year 9. Recovery in lab time also appears robust, with a 6% increase over last year and a slight increase in Year 9 total hours compared to Year 4. The effect on cumulative external usage is further illustrated in Figure 18 which shows the percentage of cumulative external users by month for Years 4-9. This figure indicates 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 6-9. The overall fraction of external users in Years 8 and 9, 26.6% and 26.0%, respectively, is lower than Year 4 (28.8%) as the increase in internal users has outpaced that of external users.

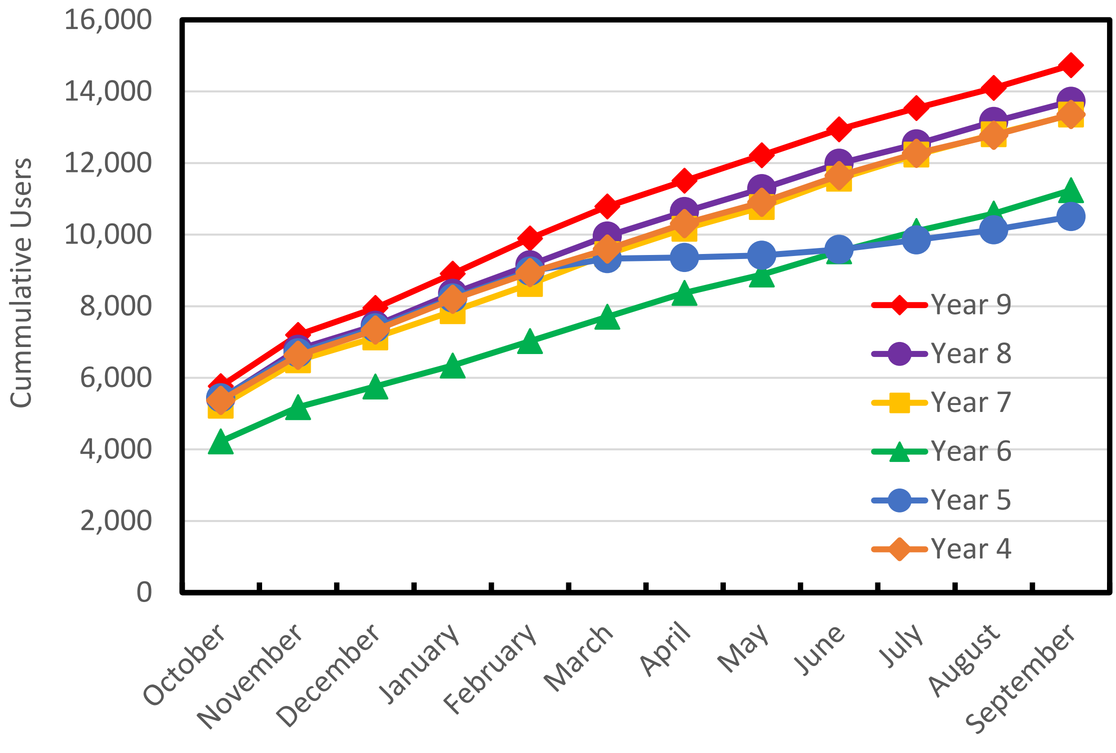


Figure 16: NNCI Cumulative Total Users by Month for Years 4-9

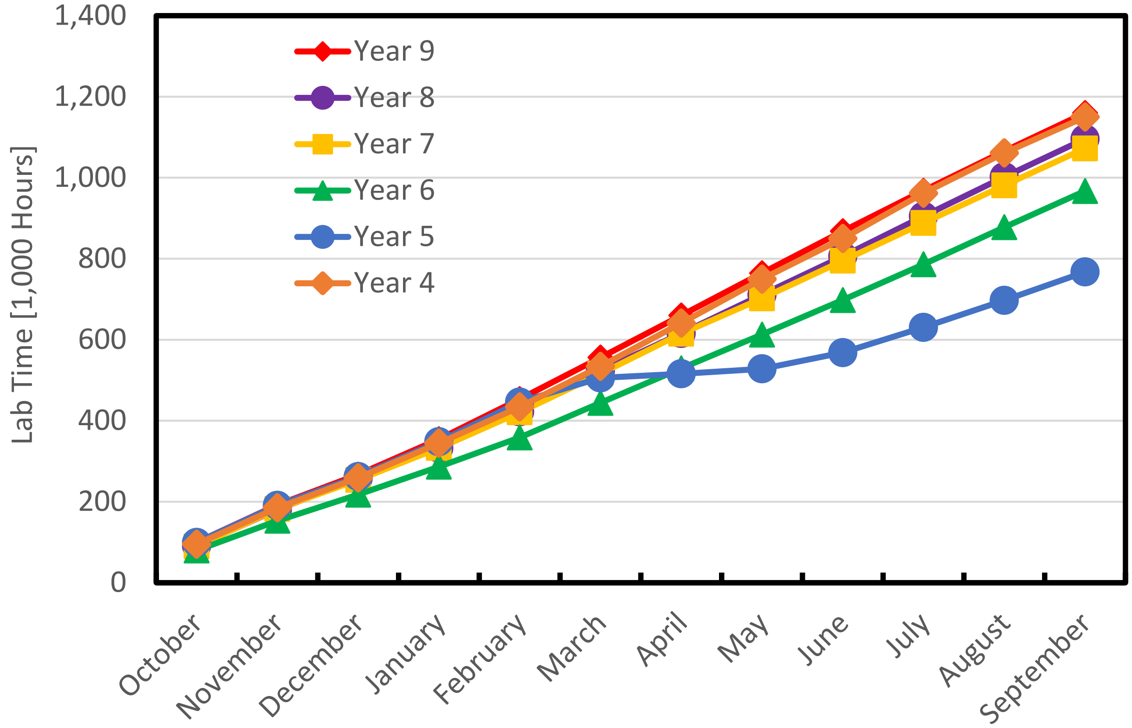


Figure 17: NNCI Lab Usage Time (1,000s of Hours) by Month for Years 4-9

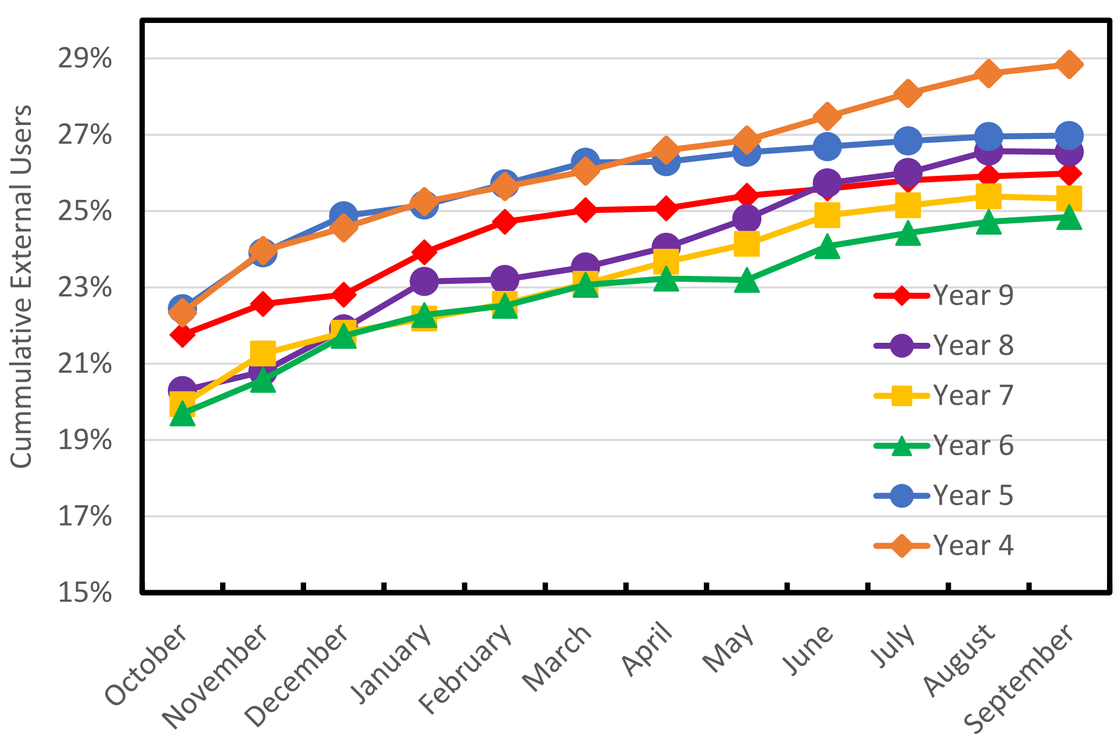


Figure 18: NNCI Cumulative External Users (%) by Month for Years 4-9

As can be seen in the figures above, Year 6's overall external usage started off lower than pre-pandemic levels and failed to recover fully even with robust month-over-month increases. While in Year 7 the total usage achieved near full recovery, external usage continued to be depressed, as was the case in Year 8. During Year 9 the number of external users reached its pre-pandemic level, although internal users rose at a faster rate. These differential pandemic effects on usage are amplified in Figures 19 and 20, which show the number of monthly internal and external users across the NNCI network. This indicates that during Years 7 and 8, monthly internal users reached values seen in Year 4 and the beginning of Year 5, while surpassing those levels during Year 9. Monthly external users at the end of Year 8 returned to 95% of pre-pandemic levels after starting the year at 9% below, reflecting improvement over the 12-month period, whereas all monthly external usage was improved during Year 9. Monthly internal users in Year 9 averaged 4,436 which is 8% better than the Year 4 average (4,102), while monthly external users in Year 9 averaged 1,243, which is 4% better than the Year 4 average (1,190) and 10% improved compared to last year.

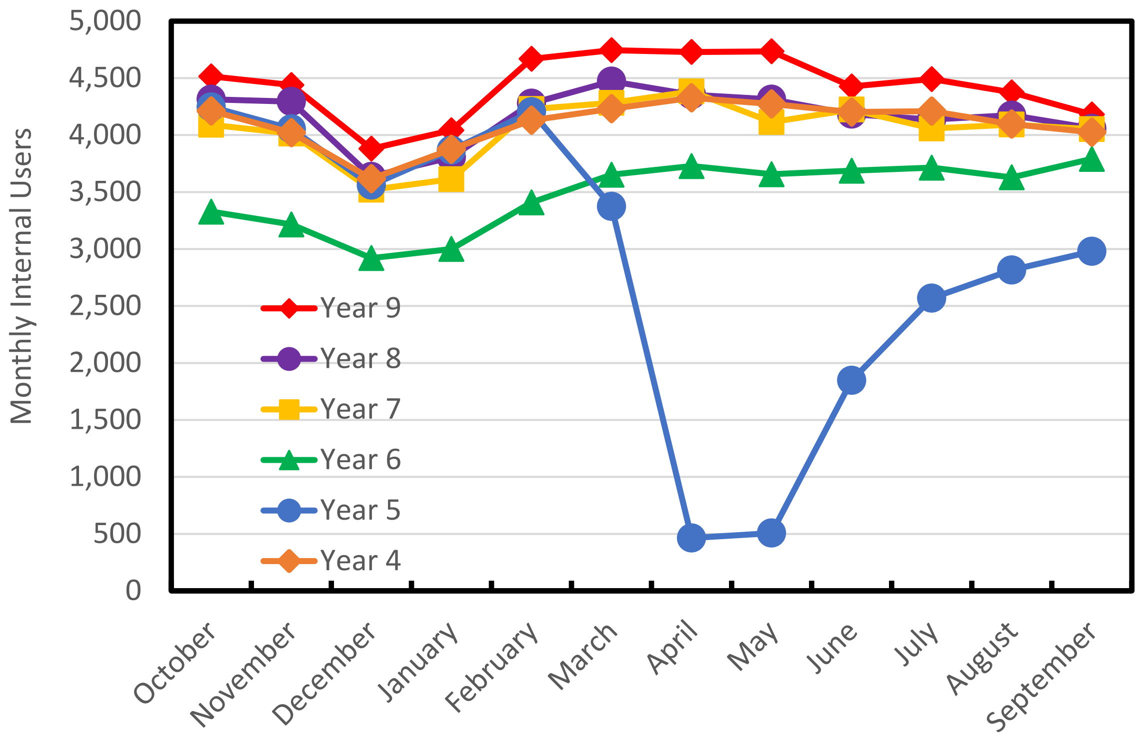


Figure 19: NNCI Monthly Internal Users for Years 4-9

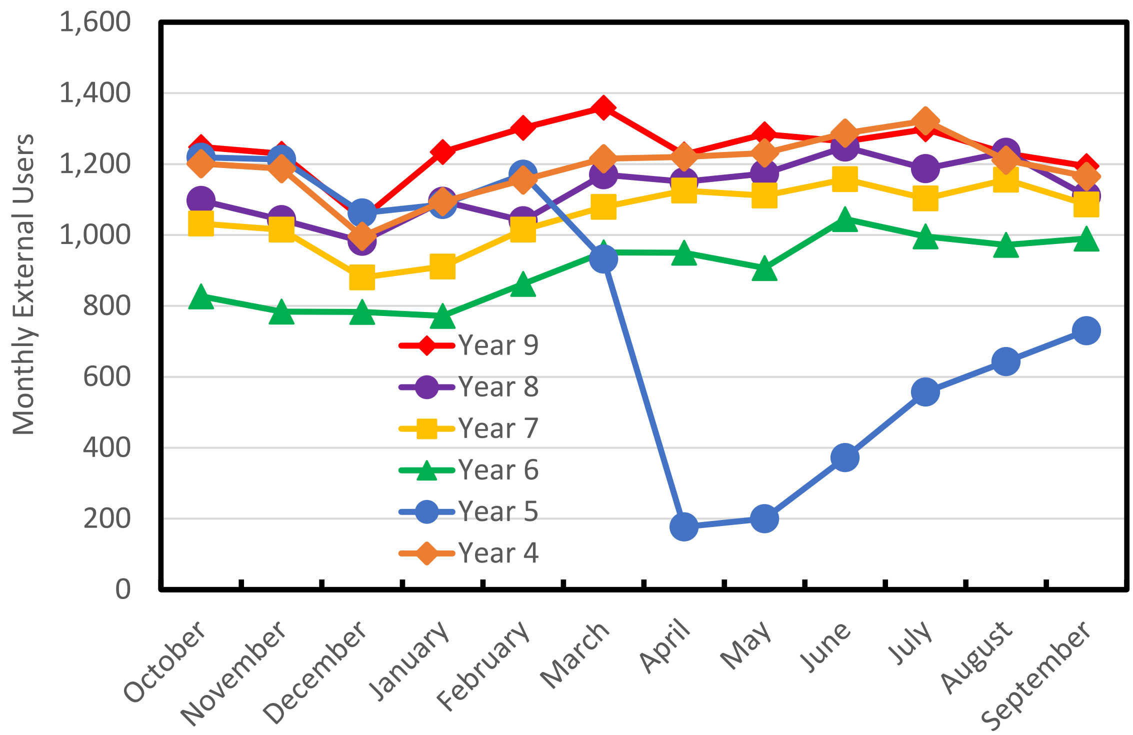


Figure 20: NNCI Monthly External Users for Years 4-9

Finally, the pandemic accelerated a shift to remote usage as can be seen in Figures 21 and 22 for remote users and hours, respectively, which began 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, avoided the hurdles associated with travel and training. What can now be seen is that the remote access modality decreased in Year 8, in terms of both users and hours. This trend accelerated during Year 9, especially for remote hours which was only 73% of that seen in Year 4 and 68% of the remote usage during Year 6.

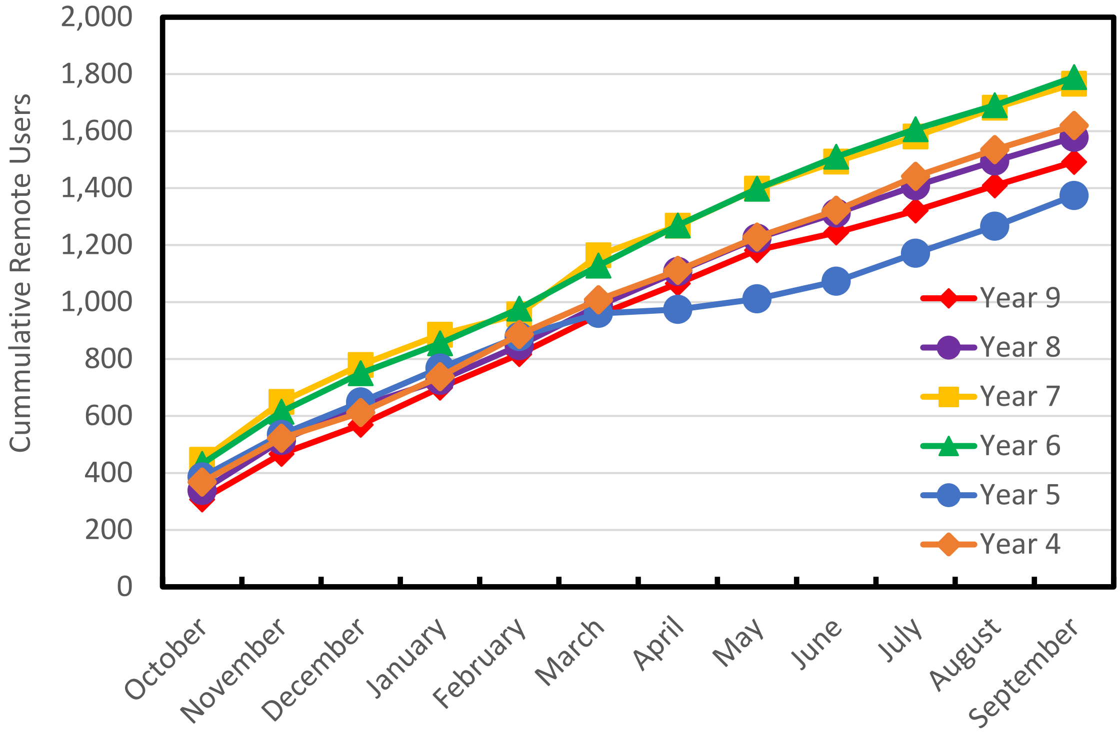


Figure 21: NNCI Cumulative Remote Users for Years 4-9

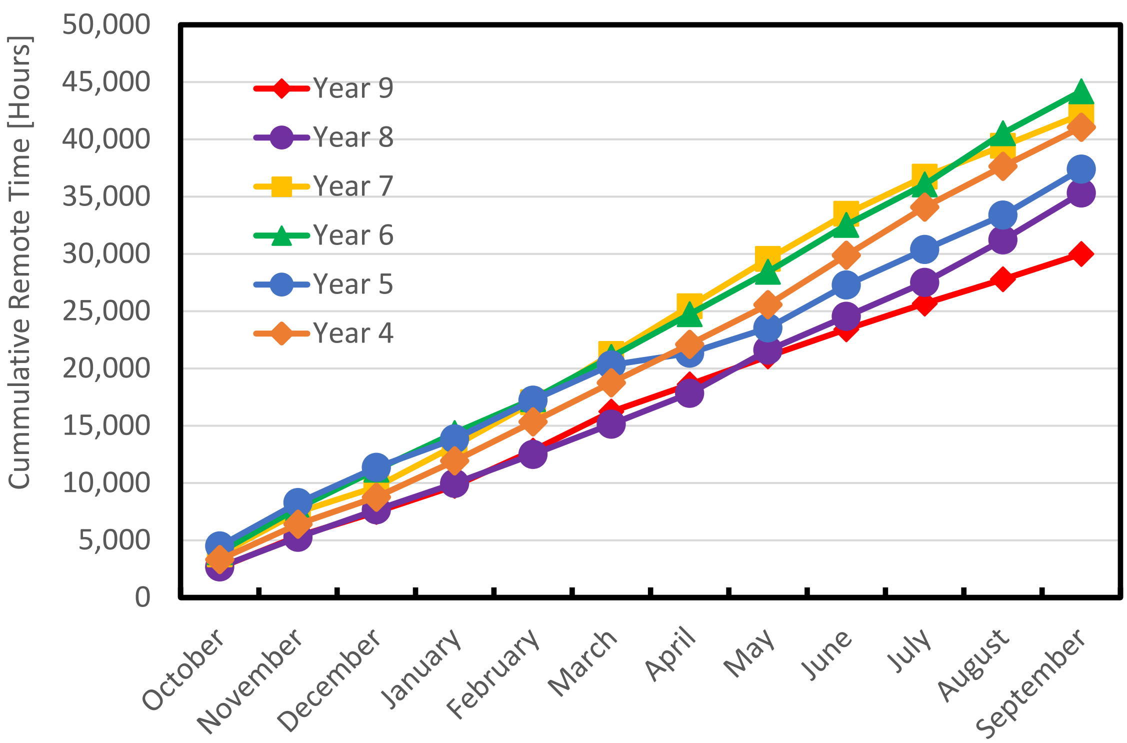


Figure 22: NNCI Cumulative Remote Hours for Years 4-9

The 3,800+ Year 9 external users come from more than 1,100 distinct external institutions (full list shown in Appendix 14.2), including 217 US academic institutions from 43 states (Figure 23), 619 small companies, 197 large companies, 17 US local/federal government organizations, 42 international institutions (from Europe, Asia, North America, South America, and Australia), and 25 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 100 companies that remain anonymous due to contractual requirements with an NNCI site and may or may not overlap with those listed in the appendix.

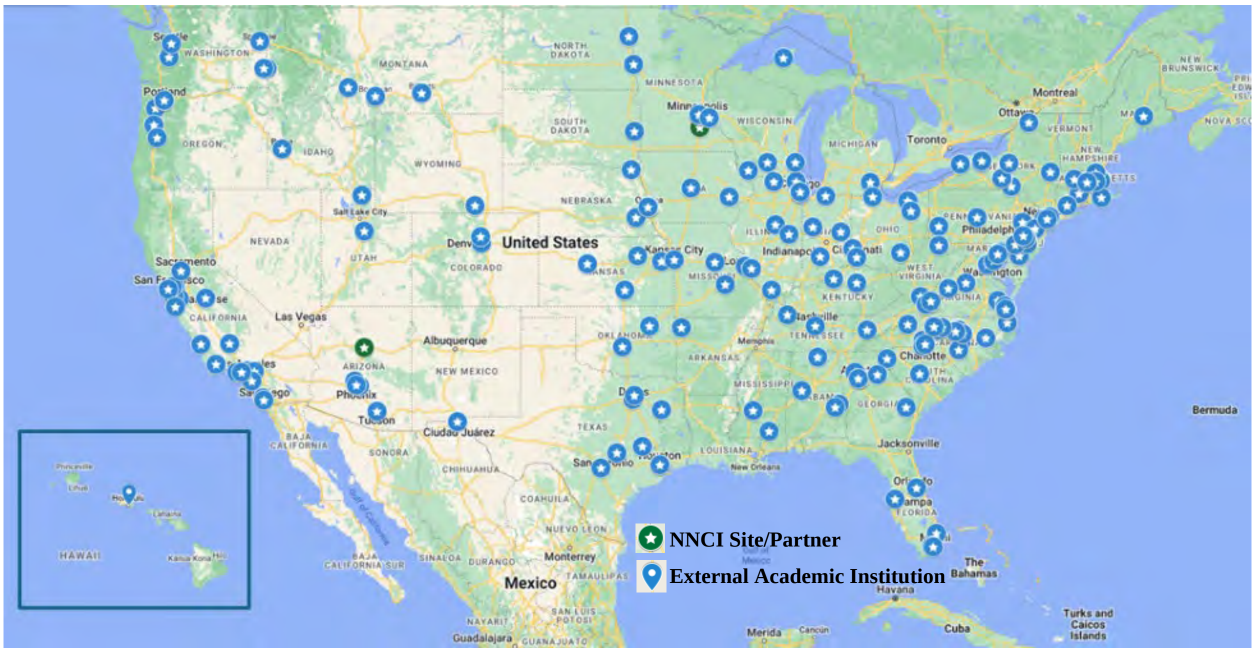
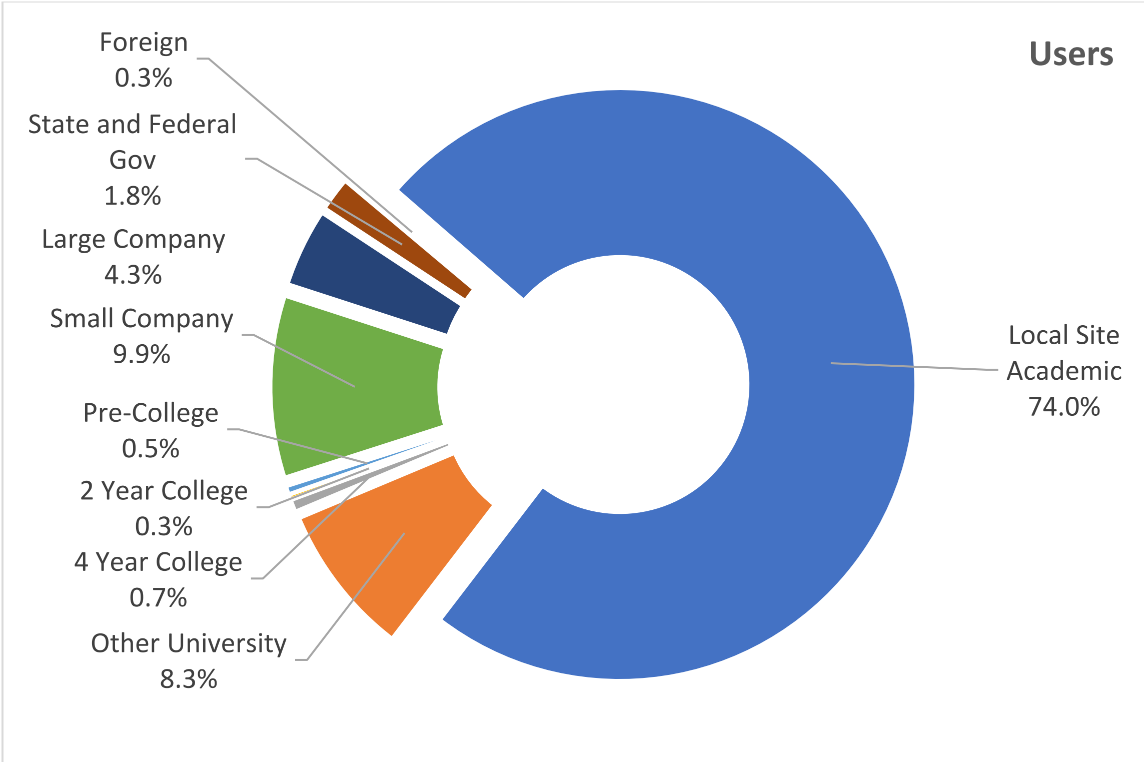


Figure 23: NNCI Year 9 US Academic Institutions (217 External)

Figure 24 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 26.0% of total users and external hours are 23.5% of total hours. This difference between external users and hours (2.5%) has decreased compared to last year and is another indicator of healthy operations. The slightly 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 the percentage of external users and external hours was trending downward since the start of NNCI (see Table 14 above), with the smallest difference observed during pandemic Year 6, and had been increasing in Years 7 and 8 before this year's decline.

External Academic Institution



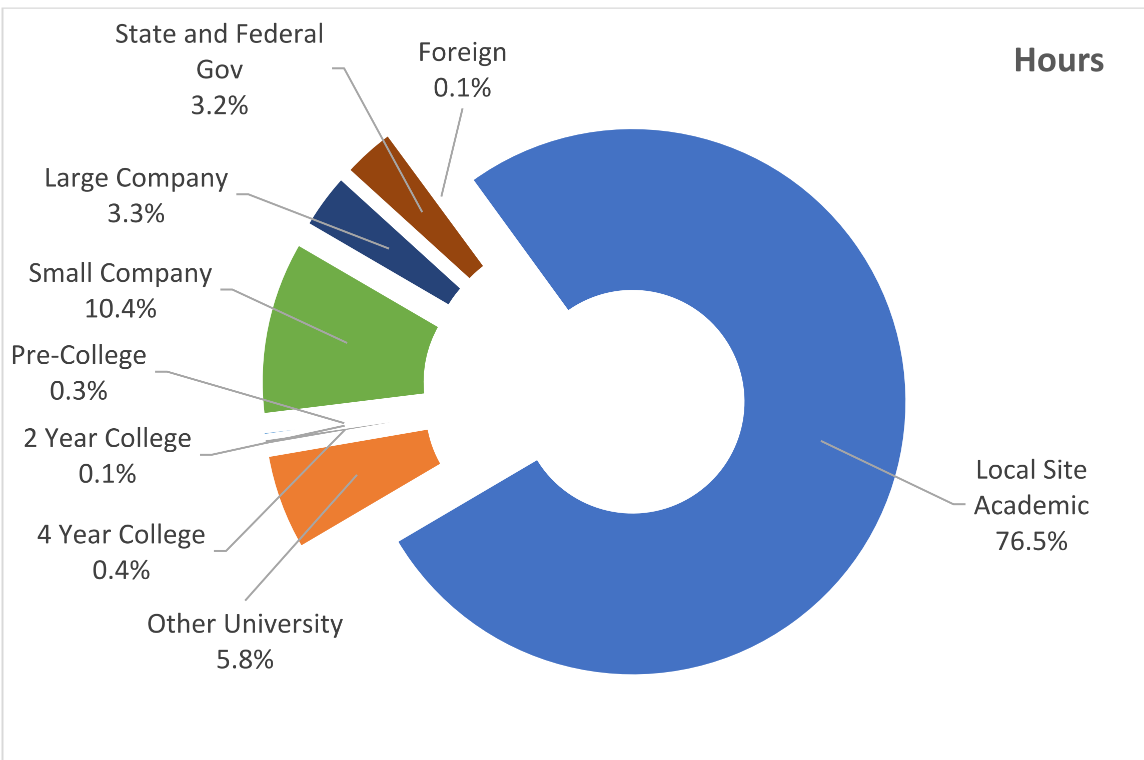


Figure 24: NNCI Users (top) and Usage Hours (bottom) by Affiliation (Year 9)

A comparison of Year 9 cumulative users (by affiliation) by site is provided in Figure 25 for all users and in Figure 26 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 whereas others are not; some serve a general NSE user base with a broad tool set while others have a particular research focus; some were part of the NNIN program while others have only been funded under NNCI; some have a large number of facilities, tools, and staff and others do not. Thus, it can be difficult to draw conclusions from a site-to-site statistical comparison. In fact, it is these unique qualities of the NNCI network sites and their geographical distribution that augments its impact.

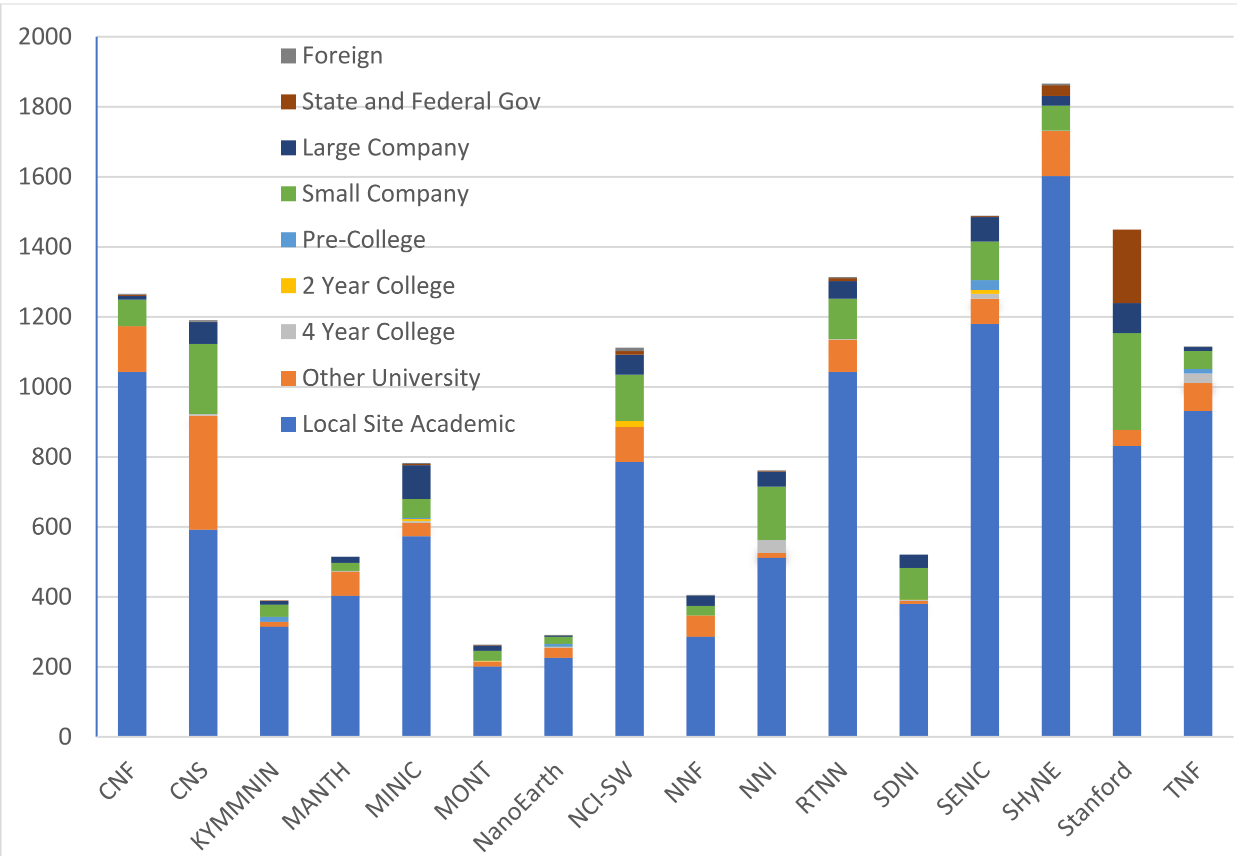


Figure 25: NNCI Cumulative Users by Site (Year 9)

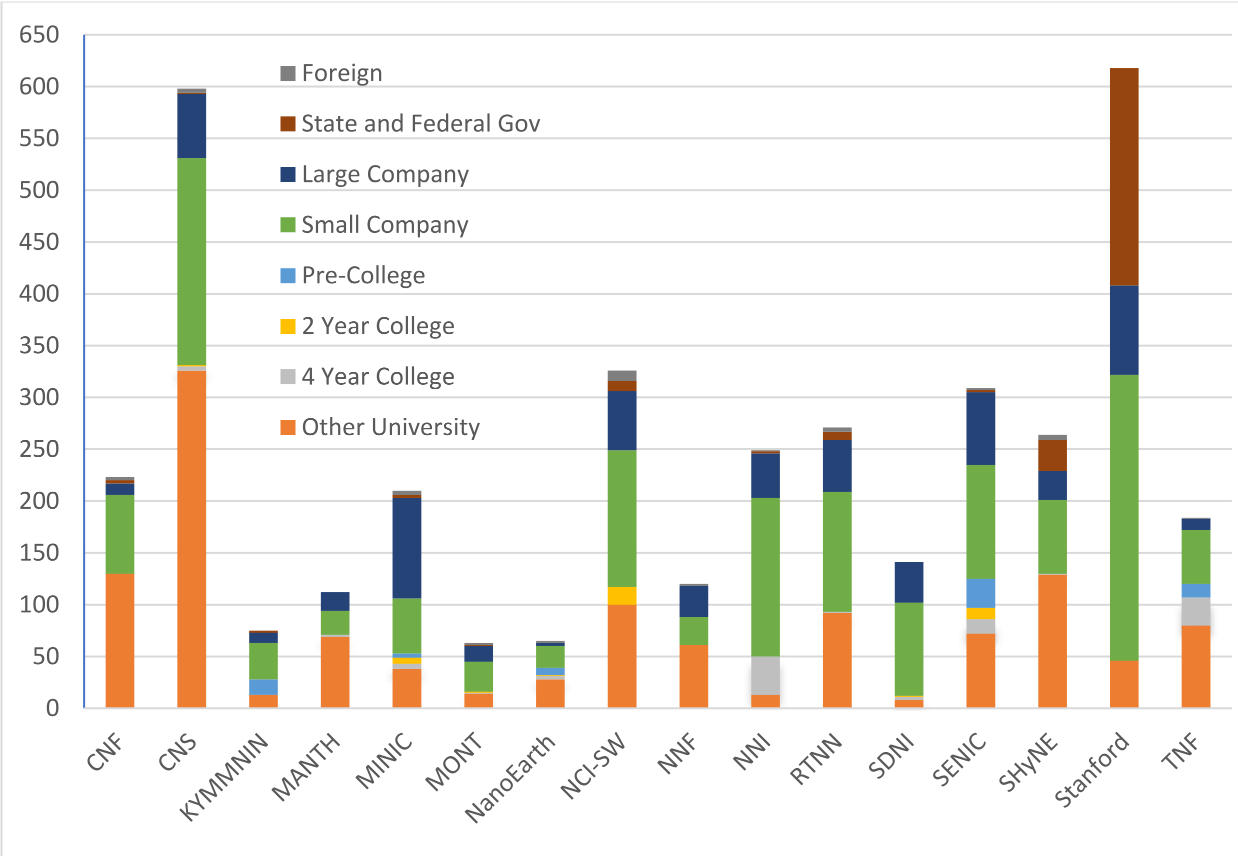


Figure 26: NNCI Cumulative External Users by Site (Year 9)

For academic institutions a network map showing the NNCI nodes and associated US colleges and universities (from 43 US states) is shown in Figure 27 below. The NNCI nodes are shown as blue circles connected to its user institutions; red dots are NNCI site universities while green dots are other US academic entities. Universities with connections to 3 or more NNCI sites are labeled in Figure 27; six universities had users at 4 different NNCI sites, while Virginia Tech had users at 5 sites, and UC-San Diego had users at 6 sites. In Year 1 there were 296 linkages between institutions, and this increased each year reaching 395 in Year 4. The number of linkages fell to 307 in Year 5 due to the pandemic-related decrease in usage and has risen to 349 in Year 9. In addition to the academic usage depicted by the figure, it was also observed that approximately 42 companies, government agencies, or other entities accessed facilities at multiple NNCI sites, although it cannot be determined if these resulted from the same or unique users or projects.

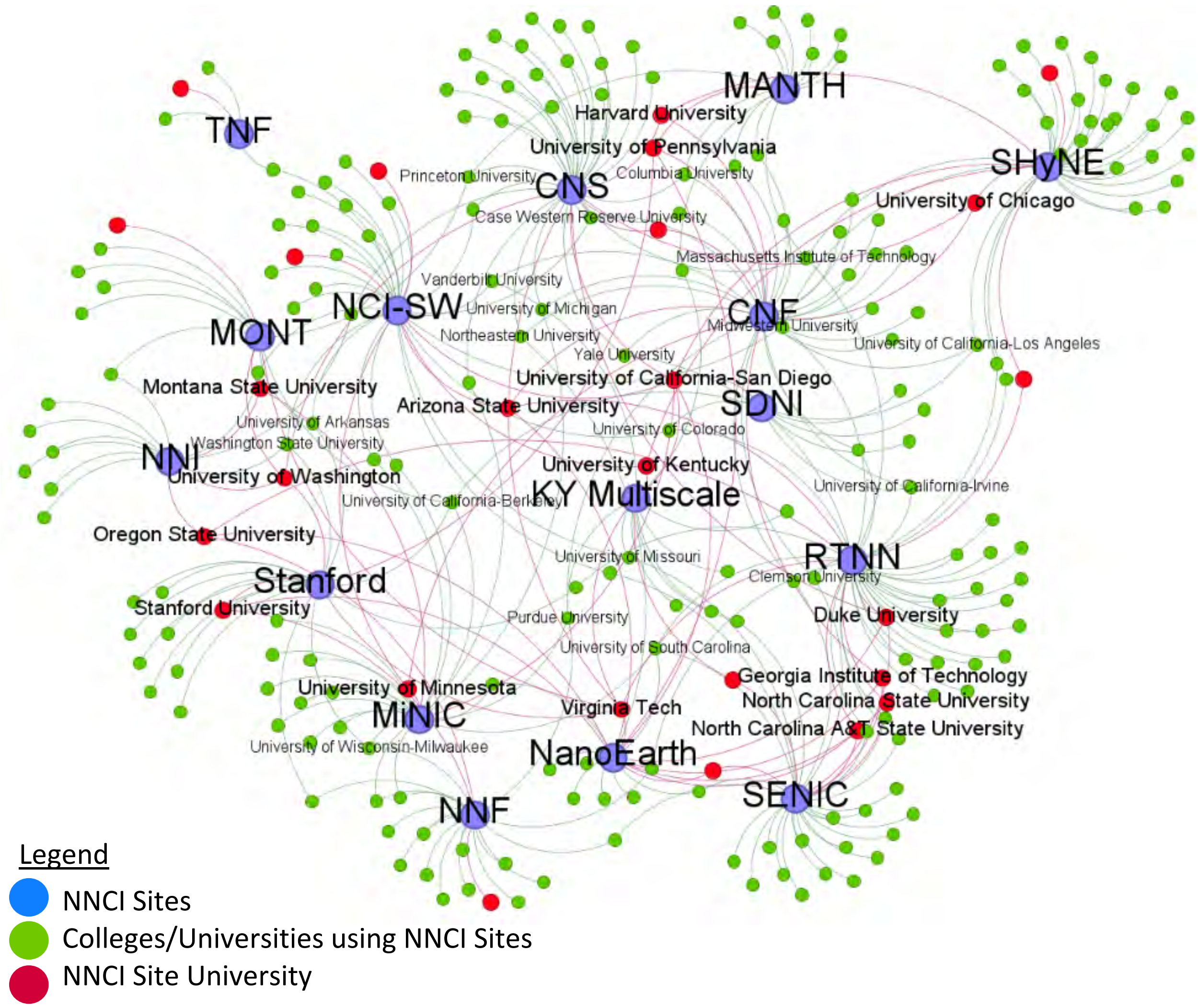


Figure 27: NNCI Academic User Network Map (Year 9)

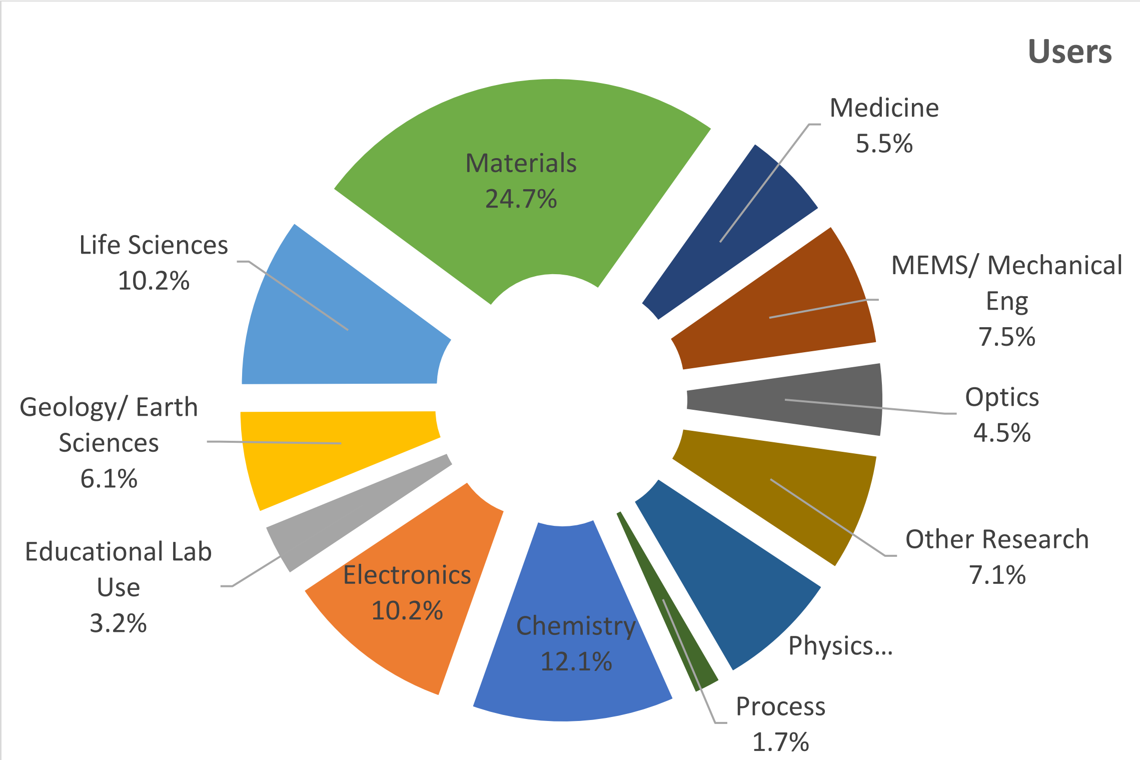
11.2. Non-Traditional Users

One important, though difficult to define, metric is how well NNCI reaches and assists non-traditional users. 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 1 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 28 illustrates the distribution by number of users and usage hours in specific disciplines. Furthermore, Figure 29 illustrates the average number of hours/user across the network based on the user's discipline, demonstrating that the fabrication-heavy disciplines of electronics, MEMS, optics, and physics, tend to require more lab usage by researchers. Geology/Earth Sciences (primarily characterization activities) now rank second among the hours/user leaders. The usage distributions by discipline are similar to those in previous years, continuing the rapid growth in Geology/Earth Sciences users (6.1% in Year 9 compared to 2.4% in Year 1) and usage hours (8.9% in Year 9 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 nearly 22% of all NNCI users. The annual changes in number of users in each discipline are graphically displayed in Figure 30 (with "Educational Lab Use", "Process", and "Other" removed for clarity). In Year 9, all disciplines showed an increase in the number of users, with the exception of Medicine, which had a slight decline.



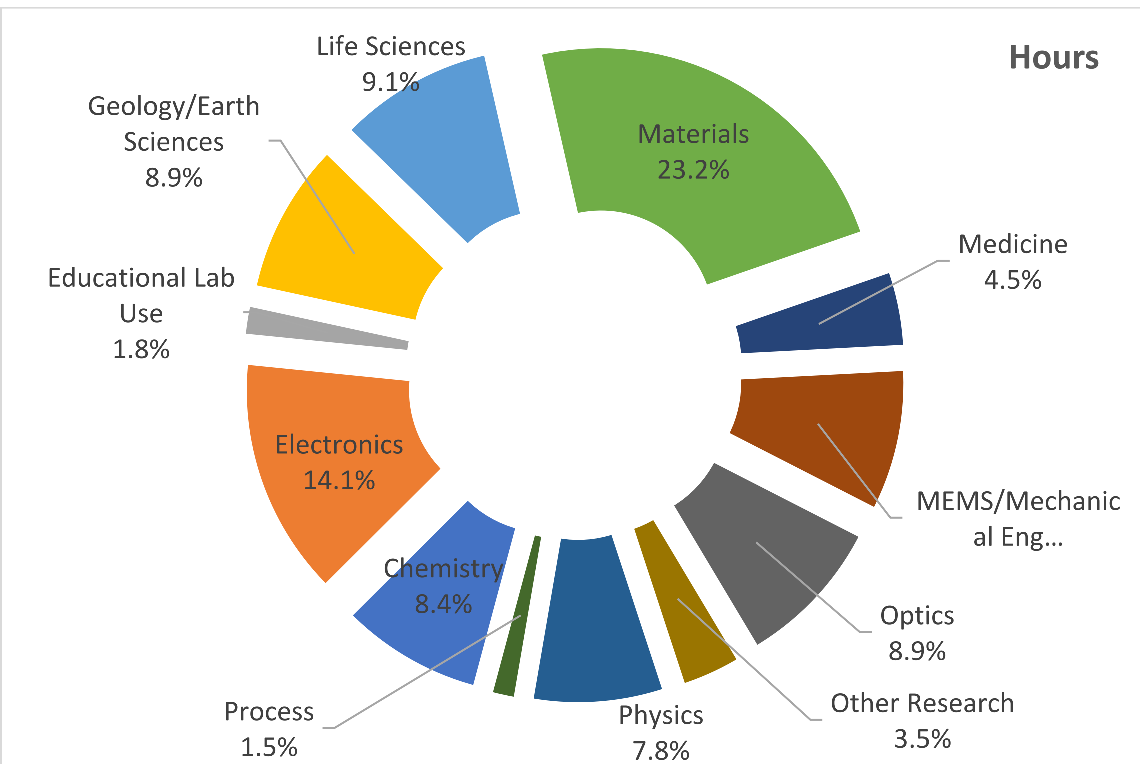


Figure 28: NNCI Users (top) and Usage Hours (bottom) by Discipline (Year 9)

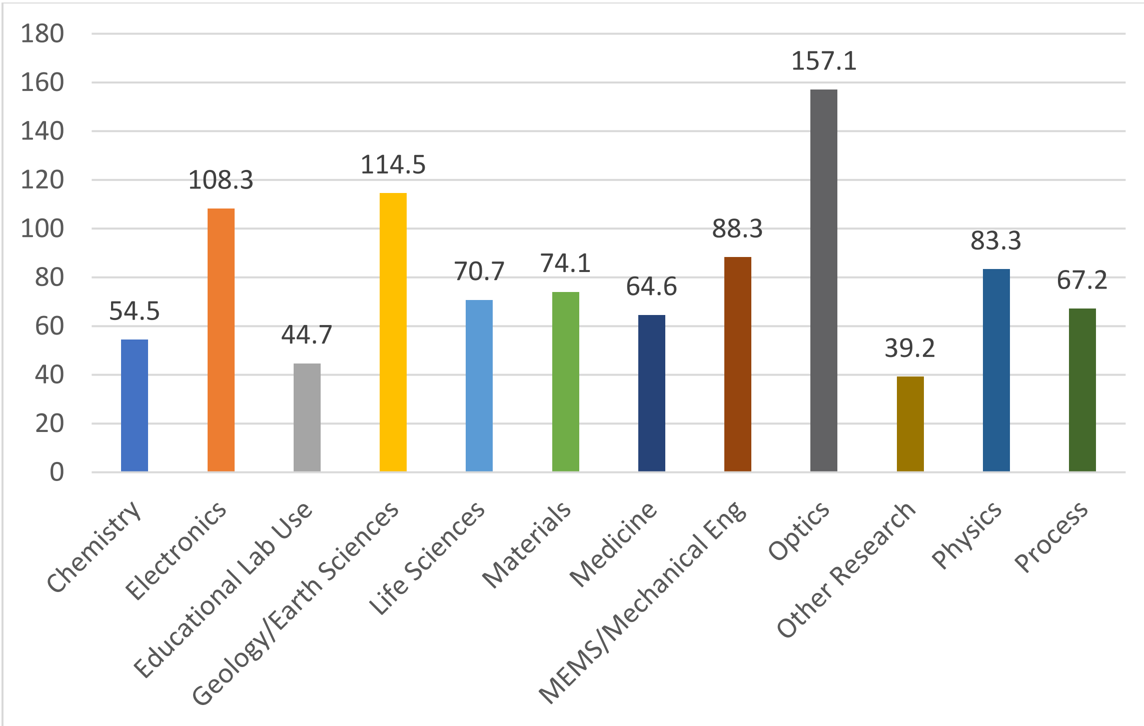


Figure 29: NNCI Hours/User by Discipline (Year 9)

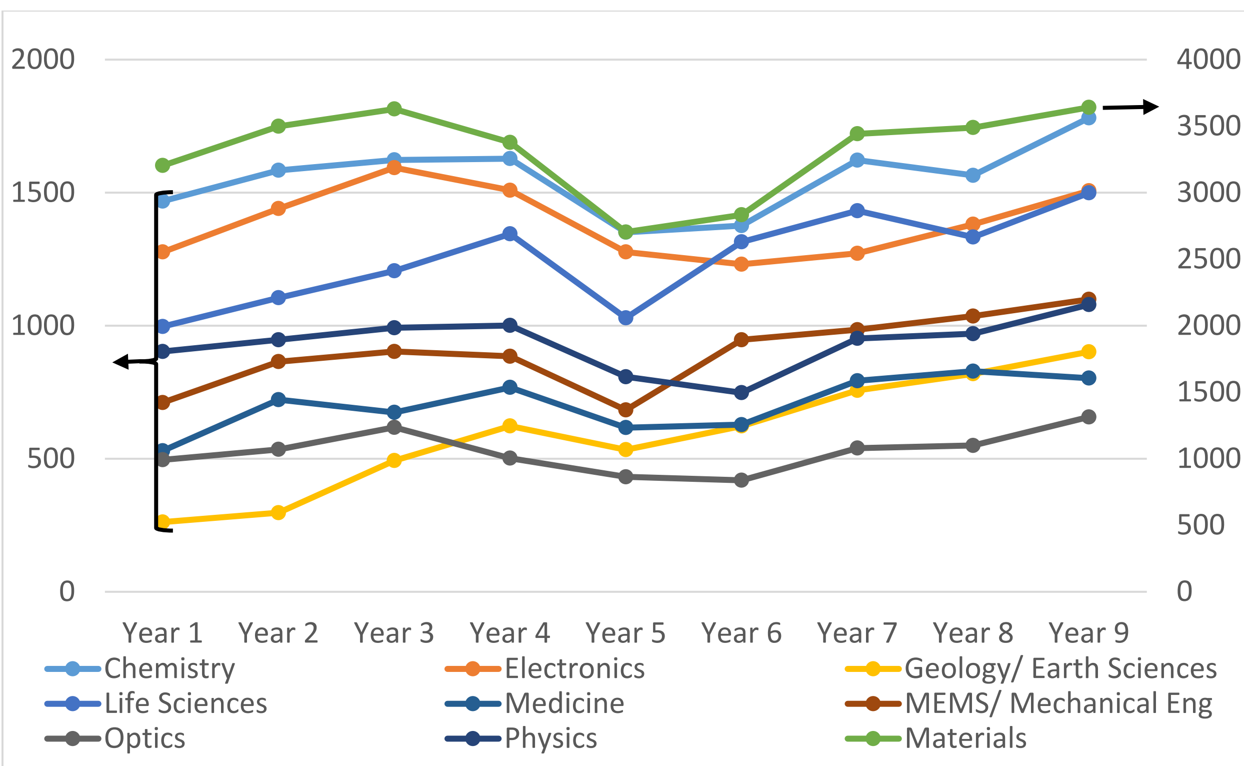


Figure 30: NNCI Yearly Users by Discipline ("Materials" indicated by the right Y-axis for comparison purposes.)

Beginning with the Year 1 annual report NNCI has opted to define "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 15 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 relative proportion of non-traditional usage hours decreased temporarily during pandemic Years 5 and 6.

Table 15: Usage by Traditional and Non-Traditional Disciplines

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
# of Users									
Traditional*	5,386 (51%)	6,063 (50%)	6,384 (50%)	5,997 (47%)	4,791 (47%)	5,148 (47%)	5,893 (46%)	6,110 (46%)	6,500 (46%)
Non-Traditional**	5262 (49%)	6044 (50%)	6383 (50%)	6750 (53%)	5408 (53%)	5,804 (53%)	7,046 (54%)	7,157 (54%)	7,764 (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%)	524,643 (49%)	546,815 (48%)
Non-Traditional**	409,935 (45%)	424,855 (46%)	490,992 (49%)	588,980 (52%)	382,140 (50%)	476,194 (50%)	544,732 (51%)	548,349 (51%)	592,214 (52%)

* 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 31 below. Between Years 4 and 9 there is relative consistency with approximately 50-60% of highlights tagged with the NSF Big Ideas of *Quantum Leap*, *Understanding the Rules of Life*, and *Growing Convergence Research*. Previously, other NSF Big Ideas were represented, although this decreased to just a few in Year 9. Over the past three years, highlights related to *Advanced Materials* and *Microelectronics* (DoD Critical Technologies) have been tagged, and these continue to be a significant focus of research. Finally, this year includes several highlights associated with *EPA Goals, Environment, and DOE Energy Earthshots*. The remainder are either associated with other priorities or are not indicated.

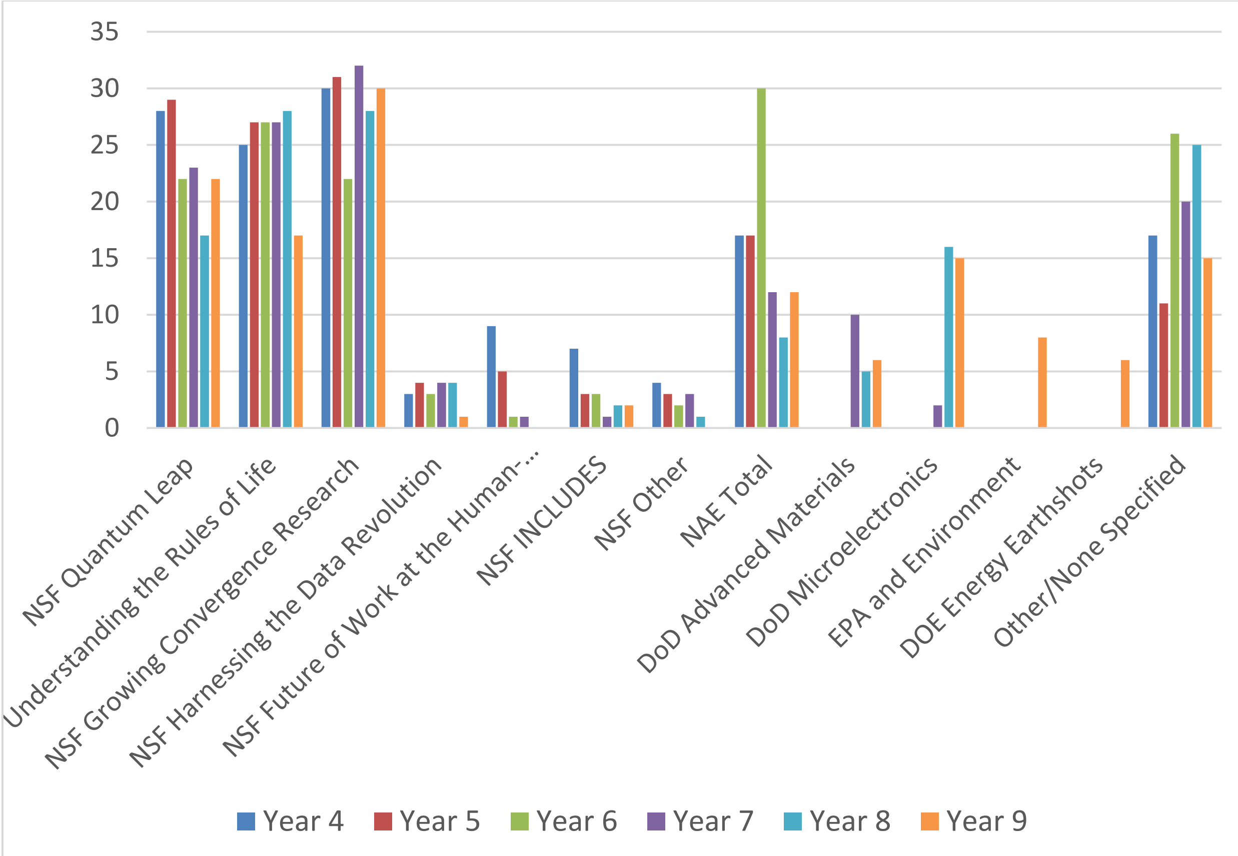


Figure 31: NNCI Highlight Slides Research Priorities (Years 4-9)

As indicated above, another measure of non-traditional usage within NNCI is reflected in the diversity of users' home academic institutions, particularly those that serve under-represented minority populations as defined by the US Dept. of Education and the Hispanic Association of Colleges and Universities.

- As constituted, NNCI primary sites and partners consist of the following minority serving institutions:
  - North Carolina A&T State Univ. (SENIC), *Historically Black College and University* (HBCU)
  - Northern Arizona Univ. (NCI-SW), Rio Salado Community College (NCI-SW), and Univ. Texas-Austin (TNF), *Hispanic-Serving Institution* (HIS, 25+% Hispanic undergraduate students)
  - Community College of Philadelphia (MANTH), *Primarily Black Institution* (PBI)
  - Stanford University (nano@stanford), *Emerging Hispanic Serving Institutions* (EHSI, 15+% Hispanic undergraduate students)
  - Univ. California-San Diego (SDNI), Univ. Texas-Austin (TNF), Community College of Philadelphia (MANTH), and Virginia Tech (NanoEarth), *Asian-American and Native American Pacific Islander Serving Institution* (AANAPISI)
- During Year 9, external academic users came from 71 institutions serving minority students: 20 HSI, 27 EHSI, 12 HBCU, 23 AANAPISI, and 1 *Native Hawaiian-Serving Institution* (ANNH). This total is more than 71, because 12 institutions have multiple designations. Thus,

33% of the US academic institutions using NNCI facilities serve under-represented populations. This is a significant increase from the 21% observed during Year 6 and similar to the 34% in Year 8.
  - Examples of these institutions are: Hampton University, Florida Atlantic University, Norfolk State University, Phoenix College, San Jose State University, University of Miami, University of Hawaii-Manoa, and Winston Salem State University.
- Based on the Carnegie Classification of research universities, where R1 are doctoral universities with very high research activity and R2 are doctoral universities with high research activity, we find the following for the 217 Year 9 US institutions:
  - 104 R1 Universities (out of 146 in the Carnegie list)
  - 54 R2 Universities (out of 133 in the Carnegie list)
  - 59 Non-R1/R2 Universities or Colleges
  - 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 16) was collected by sites for the calendar year 2023. Due to the challenge in getting compliance from users for this requested information, this should only be considered a lower limit for the actual publications data. In addition, no attempt was made to remove duplicates, where authors might have been from multiple NNCI sites. The 4,131 publications collected for CY 2023 continues the decrease in number collected since the start of NNCI, but only slightly less than the previous three years (2020-2022). Whereas previously most of the post-2019 decline resulted from fewer conference presentations (approximately 50% of peak value in 2020 and 2021, compared to 2019), in 2023 both journal publications and conferences decreased slightly. Publications reported by each site range from 94 to 588. Patents/applications/invention disclosures returned to more than 500, after a decline in 2022. These trends can be observed in Figure 32.

Table 16: NNCI 2023 Publications

Publication Type (CY 2023)	
Internal User (Site) Papers	2,512
External User Papers	419
Internal User Conference Presentations	620
External User Conference Presentations	52
Books/Book Chapters	19
Patents/Applications/Invention Disclosures	509
Total	4,131

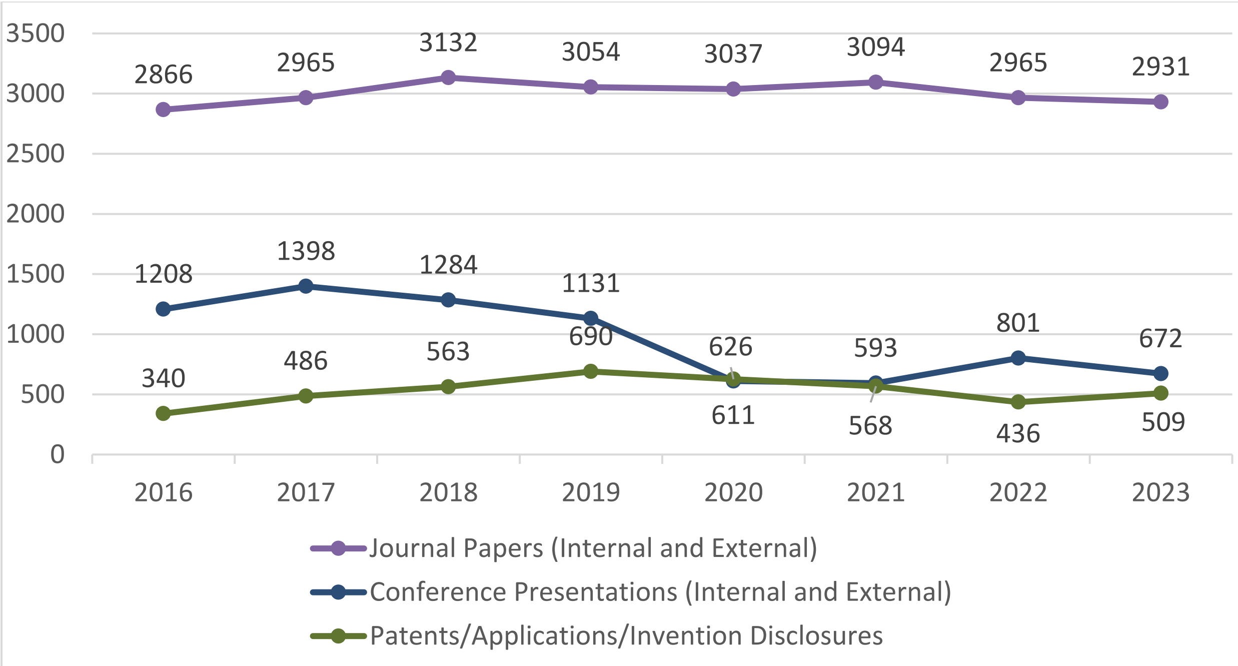


Figure 32: Number of NNCI-enabled Publications by CY.

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 33 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 14,000 journal articles published between 2018-2024 that acknowledge the NNCI 2015 or 2020 award numbers (Figure 34). "Semiconductor" is found in 26-32% of publications over that time frame while "quantum" is mentioned by 30-35% of these publications. An earlier version of this analysis, with additional search terms, was featured in the *2021 National Nanotechnology Initiative Strategic Plan*.

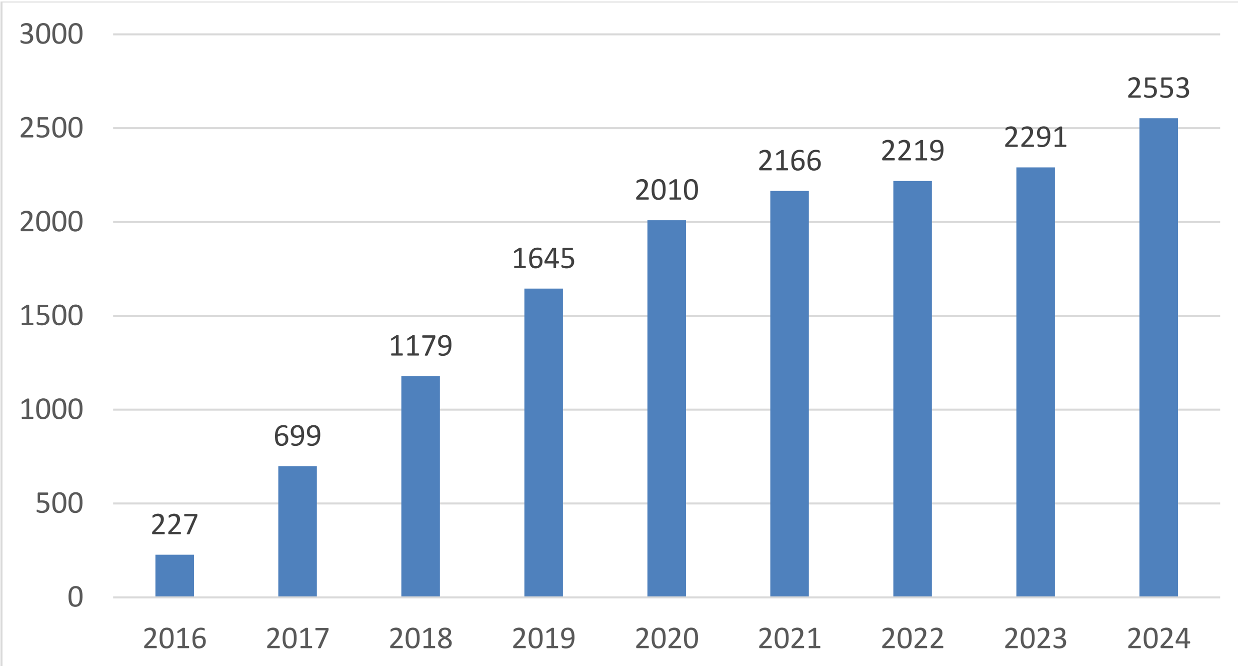


Figure 33: Number of Publications with NSF NNCI Award Numbers based on Google Scholar (NNCI-Award # or ECCS-Award #). Both 2015 and 2020 award #s were used. Search conducted 1/7/2025.

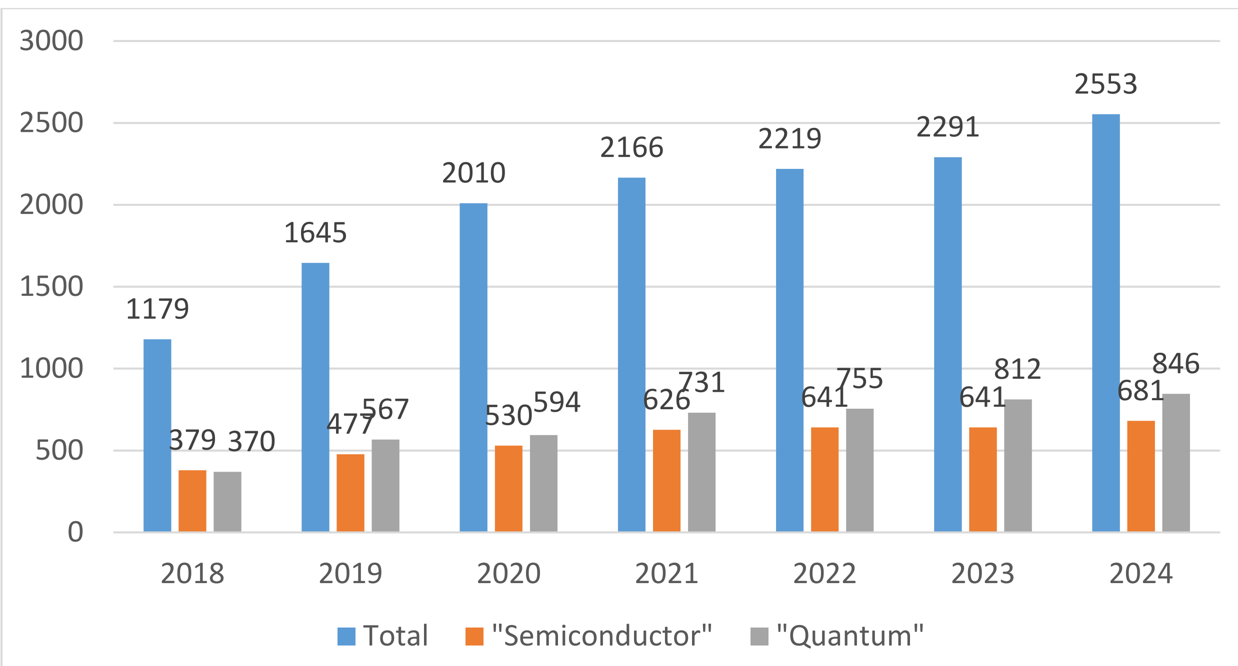


Figure 34: Number of NNCI publications (which cite the NSF award #s) on Google Scholar that also contain search terms "Semiconductor" or "Quantum" (2018-2024). Search conducted 1/7/2025.

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 was supplemented in Years 6-8 with 47 additional centers, including 3 of the 6 new NSF Science and Technology Centers awarded in 2021 and all 8 of the Microelectronics Commons Hubs awarded in 2023. Table 17 below provides a Year 9 update, indicating 10 *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 17: NNCI Supported Research Centers (New in Year 9)

Research Center	Supporting Site	Funding Source
AIRFoundry	MANTH	NSF
Applied Quantum CORE	MONT	US Air Force Research Lab
Center for Community Empowering Pandemic Prediction and Prevention from Atoms to Societies (COMPASS)	NanoEarth and CNF	NSF Predictive Intelligence for Pandemic Prevention (PIPP)
Center for Regenerative Nanomedicine	SHyNE	Northwestern University
FMRG: Cyber: Scalable Precision Manufacturing of Programmable Polymer Nanoparticles Using Low-temperature Initiated Chemical Vapor Deposition Guided by Artificial Intelligence	CNF and RTNN	NSF Future Manufacturing Research Grant (FMRG)
Interdisciplinary Bioengineering Core (IBEC)	SENIC	Dept. of Education and State of North Carolina
Montana Headwaters Tech Hub Consortium	MONT	DoC Economic Development Agency (EDA)
Paula M. Trienens Institute For Sustainability and Energy	SHyNE	Trienens Foundation
Regional Energy Business, Education, and Commercialization Convergence Accelerator (REBECCA)	KY Multiscale	DoC Economic Development Agency (EDA)
Texas Institure of Electronics	TNF	DARPA

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 NNCI Year 5 (Oct. 2019 – Sept. 2020) and reported in the Year 6 Annual Report (Feb. 2022). Data was again collected for NNCI Year 7 (Oct. 2021 – Sept. 2022) and reported in the Year 8 Annual Report (Feb. 2024).

The collected data excludes any sources of internal funding, such as state funding for most of the public universities. Grants data are used to assess the number and type of funding sources as well as the level of financial support (new in this iteration) for research at NNCI facilities along with the academic disciplines that received the funding (by grant PI). This data is not completely exhaustive, but the general trends provide some indication as to how NSF's NNCI funding is used to support the broader scientific community.

While there are additional pieces of information and trends that can be gleaned from the raw aggregate data provided in the full report, major findings are summarized here:

- NNCI facilities during the 12-month period of October 2021-September 2022 (Year 7) supported *at least* 2,609 Principal Investigators (PIs) with a total of 3,899 grants valued at more than $5 billion.
- The top academic departments of primary award PIs (approximately 65% of awards) were: Electrical and Computer Engineering, Materials Science and Engineering, Chemistry, Physics, Chemical Engineering, and Mechanical Engineering.
- The average PI uses 1.5 grants valued at $1.2 million/grant for support of NNCI access.
- NSF remains the largest single external funding source with 859 grants (22.0%), an increase from 19.7% in 2021.
- For federal funding agencies, DOE had the largest change in number of awards supported, from 8.5% of awards in 2021 to 11.0% in 2023.
- The NSF Engineering (ENG) and Mathematical and Physical Sciences (MPS) directorates comprise 79% of awards and 84% of total NSF funded value supported by NNCI.
- Within ENG, the support is distributed among most of the divisions, while in MPS it is dominated by DMR and CHE.
- Non-traditional users are primarily supported by NSF, DHHS, NASA, and Industry.

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 all sixteen of the NNCI sites for the academic year Fall 2023-Summer 2024 (corresponding to NNCI Year 9).

More than 140 individual courses were supported from 32 different academic departments listed below. Similar department names were combined for simplicity. Each individual NNCI site supported a range of 1-23 individual courses during this time frame with total course enrollment of 4,270 students (site range: 10-1,933). A word cloud of the course titles is shown in Figure 35.

Aerospace Engineering
Applied Physics
Bioengineering
Biology
Biomedical Engineering
Biotechnology
Chemical and Biological Engineering
Chemical and Biomolecular Engineering
Chemical Engineering
Chemical, Biological, and Environmental Engineering
Chemistry
Chemistry and Biochemistry
Civil & Environmental Engineering
Earth Sciences
Education
Electrical and Computer Engineering
Electrical and Systems Engineering
Electrical Engineering
Electrical Engineering and Computer Science
Electrical, Computer and Energy Engineering
Engineering and Applied Sciences
Industrial Engineering
Materials Science
Materials Science and Engineering
Mechanical Engineering
Mechanical, Industrial, and Manufacturing Engineering
Nanoengineering
Nanoscience
Penn Engineering
Philosophy
Physics
Southwestern College Physical Sciences Department

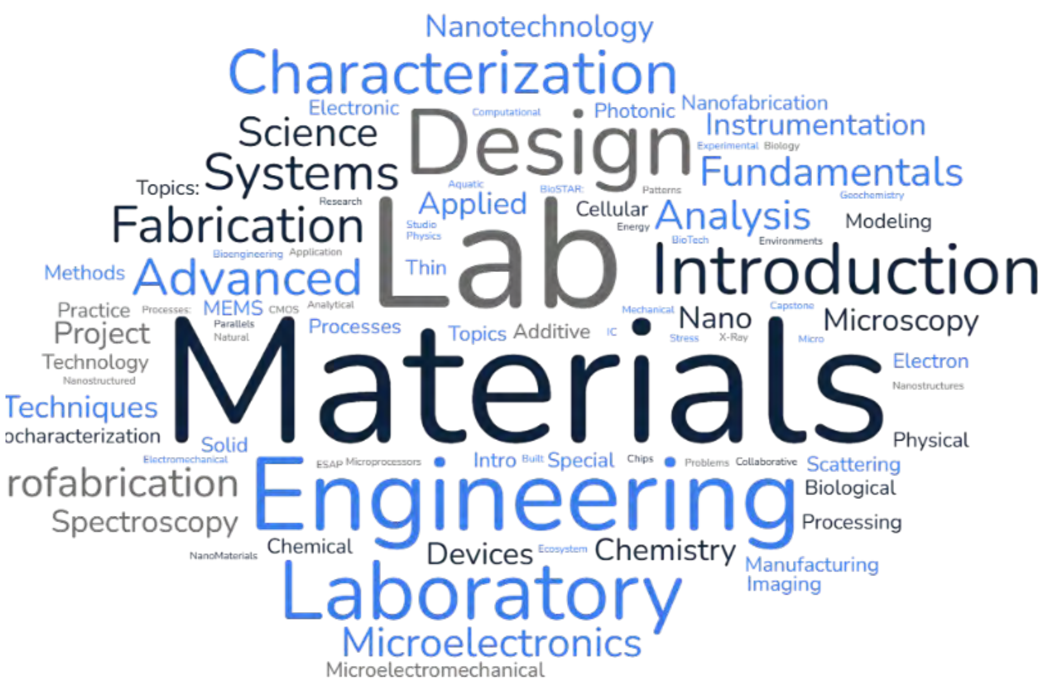


Figure 35: Word Cloud for Course Titles Supported by NNCI Facilities

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 are able to obtain that data, although some only in a limited fashion, so this reporting should be considered a lower bound only for degrees granted. The degrees awarded for Fall 2023, Spring 2024, and Summer 2024 (corresponding to NNCI Year 9) are shown in Table 18.

Table 18: Degrees Awarded to NNCI Users (Fall 2023-Summer 2024)

Academic Department	BS Degrees*	MS Degrees*	PhD Degrees	Other Degrees**	Total
Aerospace Engineering	5	5	0	0	10
Biomedical Engineering	23	54	59	11	147
Chemical Engineering	31	49	82	3	165
Civil and Environmental Engineering	1	21	32	0	54
Electrical and Computer Engineering	40	84	86	5	215
Industrial Engineering	6	7	10	0	23
Materials Science and Engineering	44	124	142	0	310
Mechanical Engineering	42	69	57	4	172
Nanoengineering	14	28	24	0	66
Nuclear Engineering	3	2	6	0	11
Biology	24	4	23	0	51
Chemistry and Biochemistry	27	25	130	0	182
Earth and Atmospheric Sciences	9	7	17	0	33
Physics	17	34	64	3	118
Nanoscience	0	13	13	3	29
Computer Science	20	11	0	1	32
Medical School	6	3	7	7	23
Veterinary School	0	0	1	0	1
Other	29	15	41	26	111
Total	**341**	**555**	**794**	**63**	**1,753**

*May also include other bachelor's or master's degrees, such as BA or MA.
**May include certificates or professional degrees such as MD.

Note that department names 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 1,753 degrees were awarded by the 14 sites (mean=125, range=19-356). NNCI users were awarded 794 doctorates, 555 masters, 341 bachelors, and 63 other degrees (including MD or other graduate certificates) during this NNCI Year 9. These values are significant increases in bachelors (+32%), doctorate (+18%), and other (+50%) degrees compared to the previous year, but this may reflect better collection of this data by sites. For 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, 67% of all degrees (63% for PhD degrees) were awarded by engineering departments. Materials Science and Engineering is the top awarder of all degree types, followed by Chemistry/Biochemistry, Electrical and Computer Engineering, Chemical Engineering, Physics, and Mechanical Engineering for Ph.D. degrees. Disciplines in the "Other" category include Food Science and Technology, Forestry and Forest Products, Mining Engineering, Neurosciences, Structural Engineering, and Mathematics 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 impact with selected anecdotes from NNCI-affiliated companies during the past year.

CNF has supported 171 different companies (44 Large and 127 Small) for research/prototyping under NNCI, including 19 new start-up companies. CNF also works with business incubators **Praxis** (Engineering and Physical Sciences) and **Center for Life Science Ventures** (Life Sciences).

CNS company **Metalenz**, a Harvard University spin out, is based in Boston and has 40+ employees. In 2022 they launched the first metasurface optics and used these in 2024 to unveil new facial recognition technology.

Since the beginning of the NNCI program, over 70 small companies and startups have utilized MANTH to create new nanotech products and services. More than one-third of these small companies have received external support, tying overall small company engagement to more than $85M of funding, of which more than 40% is attributed to SBIR/STTR grants.

During Year 9, MONT has served the needs of 18 industrial partners (13 small businesses), including 4 new companies, and all are based in or have satellite locations in Southwest Montana and employ over 550 people. Recent SBIR/STTR Phase I and Phase II grants, totaling >$36M, were recently awarded to **AdvR**, **Resodyn**, **NWB Sensors**, **Biosqueeze Inc.**, **Aesir Technologies**, and **Quench Medical**.

RTNN demonstrates the value of its facilities to small businesses and economic development with 52% of their industry users from companies with less than 50 employees and more than 220 patents filed or issued in 2023.

SDNI has supported 69 companies in their product development, and 60% of these are small businesses. A recent example is **Fabric8 Labs** which SDNI helped to grow from a small business into a major player in semiconductor packaging and 3D integration with its unique electrochemical additive manufacturing process. Fabric8 Labs has transitioned its process developed at SDNI to build a full-scale manufacturing facility. Fabric8 Labs is also a user of facilities at SENIC.

SENIC user company **Absolics, Inc.** will receive up to $75 million in funding under the CHIPS and Science Act to support the construction of a 120,000 square-foot facility in Covington, Georgia and the development of substrates technology for use in semiconductor advanced packaging, medical device company **Artelon**, which develops soft tissue fixation products for foot and ankle and sports medicine procedures, was acquired by Stryker, and **Kepley Biosystems** was awarded an NSF SBIR Phase II grant to continue product development in sepsis diagnosis and management.

The nano@stanford site had three students participate in the NNCI NTEC Program. Joshua Yang won 2nd place for his “Laser on Chip” project and has created a startup company, **Brightlight Photonics**, to commercialize the technology.

12. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 9 report. Specific information requested included:

1. A brief narrative corresponding to the NNCI Year 9 (Oct. 1, 2023 - Sept. 30, 2024).
    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 9, 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 activities, including proposals, facility operations, education/SEI programs, staff interactions, or other events. This is provided in Section 10.1 above.
4. For this Year 9 report, all sites were asked to provide information that contributes to understanding the impact of NNCI.:
    a. The number of publications in each category for calendar year 2023. The list of publications may have been part of each site's Year 9 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 9 (Section 11.4)
    c. Academic courses supported – 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 9 period (Fall 2023-Summer 2024). 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).
    d. Student degrees granted – Number of degrees awarded to facility users during Year 9 (Fall 2023-Summer 2024) per academic department (Section 11.7)
5. User survey data, if the site did not participate in the common NNCI user survey for 2024. This data was added to the survey results presented in Section 8.3.

In addition, the user statistics for NNCI Year 9 (Oct. 2023-Sept. 2024) 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)

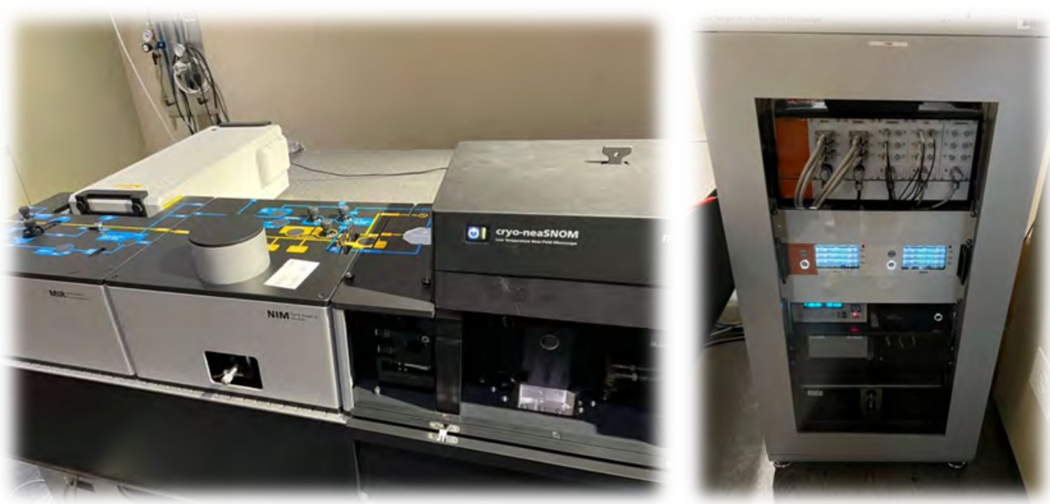
<u>Facility, Tools, and Staff Updates</u>

This past cycle, CNS has essentially returned to a *normal mode of operation*, as our labs approach their *"pre-Covid"* level of use. We have new researchers whose groups are becoming bigger users, as well as research groups that are using the facilities in different ways. We continue to assess, revamp, and augment the tools and instrumentation available at CNS for advancing transformative Nano and Quantum science.

*Instrumentation/Tool Additions (*acquired with AWS support):*

Below is a list of key tools added in 2024

- Cryo-neaSNOM Temperature variable scan-probe Near-field Microscope
- Elionix ELS-Boden 150*
- Sentech SI-500 ICP-RIE *
- AJA Sputtering/E-beam evaporator system for Complex oxides *
- Atlas Micro XRF system
- EMS-plus Sputtering system (for teaching lab)
- Samco RIE-10NR system (for teaching)
- Heidelberg micro-MLA Lithography system (for teaching)



Cryo-neaSNOM acquired with DURIP support.

Photonic packaging tools.

CNS has also added a number of tools that support our teaching efforts by enhancing our ability to support device development in two key quantum materials efforts and by enabling us to teach our lab courses more effectively. This year we were awarded an NSF MRI grant to acquire a photonic wirebonder, part of our expanding integrated photonics effort with its needed packaging activity.

(Left) thin film sputter tool, (right) micro XRF system

New CNS Staff: We added four new CNS staff, listed below. Their primary work areas are also listed. These new staff will allow us to support photonic packaging and expand other lab activities.

- Yumian Zhu, Equipment Engineer-Nanofabrication
- Seyyed Soroosh Sharifi Asl, FIB Scientist
- Haojie Ji, Sr. Photonics Integration Engineer
- Kassidy Desauguste, Administrative Assistant

<u>User Base</u>

This year, the accumulated CNS userbase in both facilities topped 1,268 active users as of 09/30/2024. (Note: active users are users that have accessed CNS resources during the reported grant period). Importantly ~52% of our user base is non-Harvard, 31% being external academic users and ~23% industrial users, (~78% of which are from small companies). Approximately 18% of our userbase over the last fiscal year are from small businesses.

Research Highlights and Impact

Summaries of a few key research efforts are listed below. Work this year resulted in 92 publications in the reporting window.

Neutrophils bearing adhesive polymer micropatches as a drug-free cancer immunotherapy; Ninad Kumbhojkar, Supriya Prakash, Tatsuya Fukuta, Kwasi Adu-Berchie, Neha Kapate, Rocky An, Solomina Darko, Vineeth Chandran Suja, Kyung Soo Park, Alexander P. Gottlieb, Michael Griffith Bibbey, Malini Mukherji, Lily Li-Wen Wang, David J. Mooney & Samir Mitragotri: Harvard University: *Nature Biomedical Engineering* volume 8, pages 579–592 (2024). Tumour-associated neutrophils can exert anti-tumour effects but can also assume a pro-tumoural phenotype in the immunosuppressive tumour microenvironment. Here the Mitragotri group showed that neutrophils can be polarized towards the anti-tumour phenotype by discoidal polymer micrometric 'patches' that adhere to the neutrophils' surfaces without being internalized. Intravenously administered micropatch-loaded neutrophils accumulated in the spleen and in tumour-draining lymph nodes, and activated splenic natural killer cells and T cells, increasing the accumulation of dendritic cells and natural killer cells. In mice bearing subcutaneous B16F10 tumours or orthotopic 4T1 tumours, intravenous injection of the micropatch-loaded neutrophils led to robust systemic immune responses, a reduction in tumour burden and improvements in survival rates. Micropatch-activated neutrophils combined with the checkpoint inhibitor anti-cytotoxic T-lymphocyte-associated protein 4 resulted in strong inhibition of the growth of B16F10 tumours, and in complete tumour regression in one-third of the treated mice. Micropatch-loaded neutrophils could provide a potent, scalable and drug-free approach for neutrophil-based cancer immunotherapy.

All-Glass 100 mm Diameter Visible Metalens for Imaging the Cosmos; Joon-Suh Park*****, Soon Wei Daniel Lim, Arman Amirzhan, Hyukmo Kang, Karlene Karrfalt, Daewook Kim, Joel Leger, Augustine Urbas, Marcus Ossiander, Zhaoyi Li, Federico Capasso***:** *ACS Nano* 2024, vol. 18, 4, 3187; Harvard University; Metasurfaces, optics made from subwavelength-scale nanostructures, have been limited to millimeter-sizes by the scaling challenge of producing vast numbers of precisely engineered elements over a large area. In this study, we demonstrate an all-glass 100 mm diameter metasurface lens (metalens) comprising 18.7 billion nanostructures that operates in the visible spectrum with a fast *f*-number (*f*/1.5, NA = 0.32) using deep-ultraviolet (DUV) projection lithography. Our work overcomes the exposure area constraints of lithography tools and demonstrates that large metasurfaces are commercially feasible. Additionally, Capasso's group investigated the impact of various fabrication errors on the imaging quality of the metalens, several of which are specific to such large area metasurfaces. We demonstrate direct astronomical imaging of the Sun, the Moon, and emission nebulae at visible wavelengths and validate the robustness of such metasurfaces under extreme environmental thermal swings for space applications.

Time-reversal symmetry breaking superconductivity between twisted cuprate superconductors; S. Y. Frank Zhao, Xiaomeng Cui, Pavel A. Volkov, Hyobin Yoo, Sangmin Lee, Jules A. Gardener, Austin J. Akey, Rebecca Engelke, Yuval Ronen, and Philip Kim: Harvard University, *Science*, 7 Dec 2023, Vol 382, Issue 6677, pp. 1422-1427; Twisted interfaces between stacked van der Waals (vdW) cuprate crystals present a platform for engineering superconducting order parameters by adjusting stacking angles. Using a cryogenic assembly technique, we construct twisted vdW Josephson junctions (JJs) at atomically sharp interfaces between $Bi_2Sr_2CaCu_2O_{8+x}$ crystals, with quality approaching the limit set by intrinsic JJs. Near 45° twist angle, The Kim Group observed fractional Shapiro steps and Fraunhofer patterns, consistent with the existence of two degenerate Josephson ground states related by time-reversal symmetry (TRS). By programming the JJ current bias sequence, we controllably break TRS to place the JJ into either of the two ground states, realizing reversible Josephson diodes without external magnetic fields. Our results open a path to engineering topological devices at higher temperatures.

Quantum metric nonlinear Hall effect in a topological antiferromagnetic heterostructure; Gao, AY , Liu, YF, Qiu, JX, Ghosh, B, Trevisan, TV, Onishi, Y, Hu, CW, Qian, TM, Tien, HJ, Chen, SW, Huang, MQ, Bérubé, D, Li, HC, Tzschaschel, C, Dinh, T, Sun, Z, Ho, SC, Lien, SW, Singh, B, Watanabe, K, Taniguchi, T, Bell, DC, Lin, H, Chang, TR, Du, CR, Bansil, A, Fu, L, Ni, N, Orth, PP, Ma, Q, Xu, SY; *Science* Volume 381 Issue 6654. Page 181-186; Quantum geometry in condensed-matter physics has two components: the real part quantum metric and the imaginary part Berry curvature. Whereas the effects of Berry curvature have been observed through phenomena such as the quantum Hall effect in two-dimensional electron gases and the anomalous Hall effect (AHE) in ferromagnets, the quantum metric has rarely been explored. Here, The Xu group reported a nonlinear Hall effect induced by the quantum metric dipole by interfacing even-layered MnBi2Te4 with black phosphorus. The quantum metric nonlinear Hall effect switches direction upon reversing the antiferromagnetic (AFM) spins and exhibits distinct scaling that is independent of the scattering time. Our results open the door to discovering quantum metric responses predicted theoretically and pave the way for applications that bridge nonlinear electronics with AFM spintronics.

Education and Outreach Activities

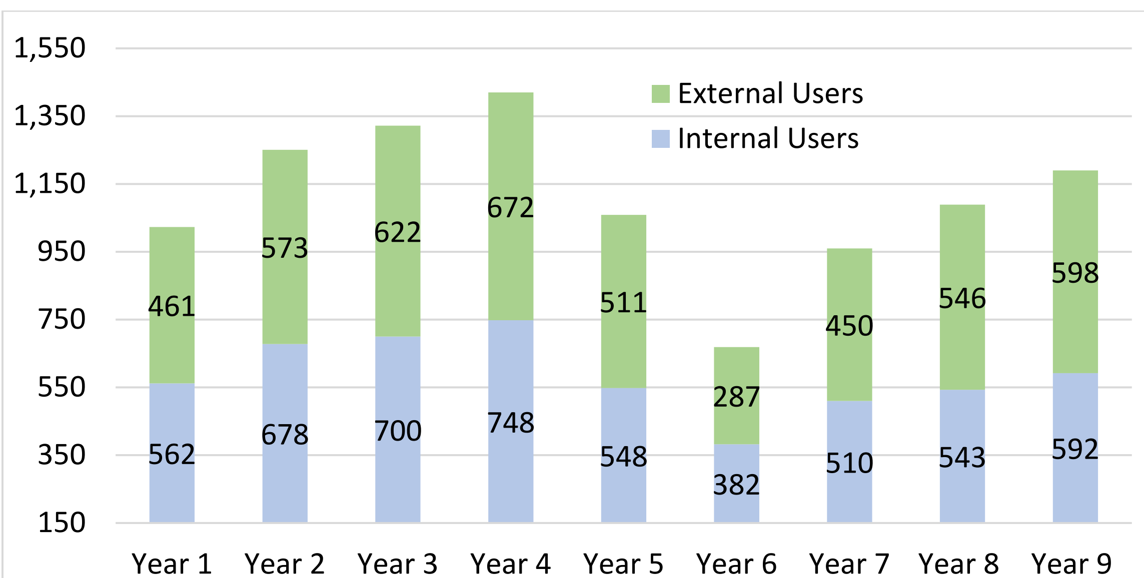
Last year CNS expanded educational efforts in the lab. We now support two advanced processing courses in our cleanroom. The classes Engineering Sciences ES 177/277 and ES 176/276 are advanced undergraduate and graduate offerings where students get direct “hands-on” training as they process devices for the class projects. The entire experimental curriculum was developed with CNS staff input and support. The goal has been to offer comprehensive nanofabrication training with minimal disruption to the research mission of the lab. We have been successful thus far in striking the proper balance between class size, training burden, and cleanroom traffic. Both classes, offered in the fall and spring respectively, have an enrollment of 25-30 students, broken up into subgroups. The class cohort has 25-30 students both at the graduate and undergraduate levels. ES 177/277 is a traditional electronic device class. While ES 176/276 is a complementary class on the processing and fabrication of microelectromechanical devices and systems. These new academic offerings are part of our efforts to expand workforce development activities at CNS. The students and their devices are featured in the engineering students design fair held each spring. In addition, many students develop projects as part of the assigned that compete for summer support. We note that in general we support a variety of academic offerings in our lab spaces, including Advanced Electron Microscopy (Applied Physics AP 291) and Advanced instrumentations classes (Chemistry 165). We continue to evolve our Master Class Lecture series and our CNS lecture series, the videos of which are hosted on our website. We have re-booted our CNS NanoFab summer school and have been expanding the “re-connecting” with our CNS scholars as they again begin the “spin-up” of their research activities, *post-pandemic*.

This year CNS recruited more broadly for the CNS Scholars program at HBCUs. The goal is adding at least two new scholars. Bill Wilson went on a recruiting trip to Spellman, Morehouse, and Clark Atlanta University. In addition, we plan to finish our “*Glove-box*” based 2D Assembly system with the hope to have it open for users this summer. These tools are part of our expanding tool based being optimized to enable fabrication of high-end integrated photonics. Finally, with new support from a DURIP award, Our NNCI supported PostDoc will begin development of a Low-Temperature Scan-Probe Spectroscopy tool. The PostDoc, Dr. Ibrahim Abdelwahab, is also finishing work exploring exciton-polariton dynamics is both 2D Janus TMDCs and an array of 2D perovskites using Scan-probe Near-field Microscopy. This low temperature system has been installed we took our first data this summer.

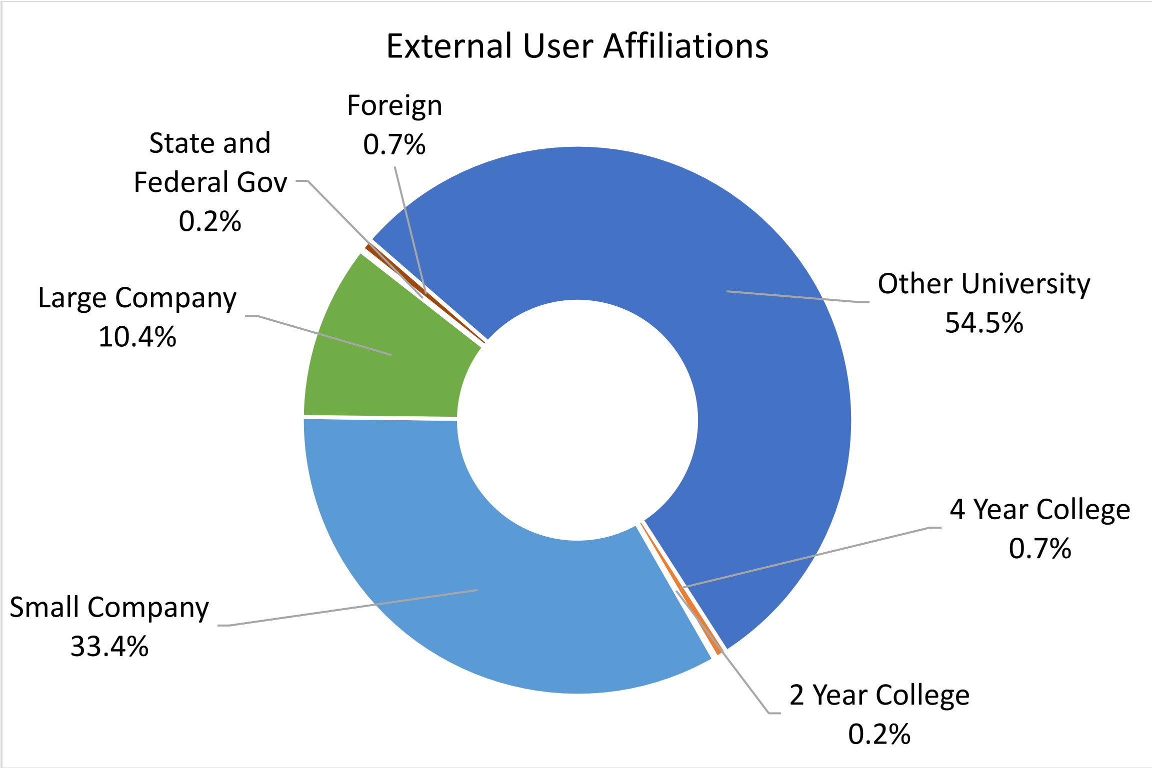
We celebrated completion of the 1st Quantum Noir: Quantum Noir is a meeting/summer school focused on connecting scientists of color, and others, to each other and to the greater Quantum research community. Modeled somewhat after the Conference for African American Researchers in the Mathematical Sciences (CAARMS), Quantum Noir has a community building focus, but will also has a topical focus, (like a Gordon Research Conference). This year the primary theme was an overall mapping of Quantum Information, Quantum Networking, and Quantum Materials, from fundamental principles to device advances and implementations and an overall view of the system possibilities and applications. The first meeting was held, 06/11/2024 – 06/14/2024, *all the conference talks and tutorial slides are available at Quantum-noir.org, the conference website.* This program was assembled by our Geographically Diverse program committee which was comprised of faculty and industry researchers of color from around the nation. The initial members are ***Chairman*** William L. Wilson (PI), *Harvard University*. ***Co-Chairs*** Dean Nadya Mason, *University of Chicago*, Professor Charles Brown *Yale University*, Dean Kimani Toussaint, *Brown University*, Professor Deji Akinwande, *University of Texas*, Professor Thomas Searles, *University of Illinois at Chicago*, Professor Stephon Alexander, *Brown University*, Dr. Kenneth Evans-Lutterodt, *Brookhaven National Laboratories*, Dr. Donnell Walton, *Corning Corporation*, Professor Trevor David Rhone, *Rensselaer Polytechnic Institute*, Professor Jacob Gayles, *University of Southern Florida*, Professor Boubacar Kante, *University of California*, and Dr. Kayla Lee, *IBM Corporation*. The conference poster is shown below. The program was highlighted by a welcome from 2023 Noble Prize winner Prof. Moungi Bawendi, *MIT*. Moreover, Professors Misha Lukin, *Harvard University* and Pablo Jarillo-Herrero, *MIT*, for example, gave spectacular talks on Rydberg Atom Quantum Logic and Moiré Quantum Materials respectively.

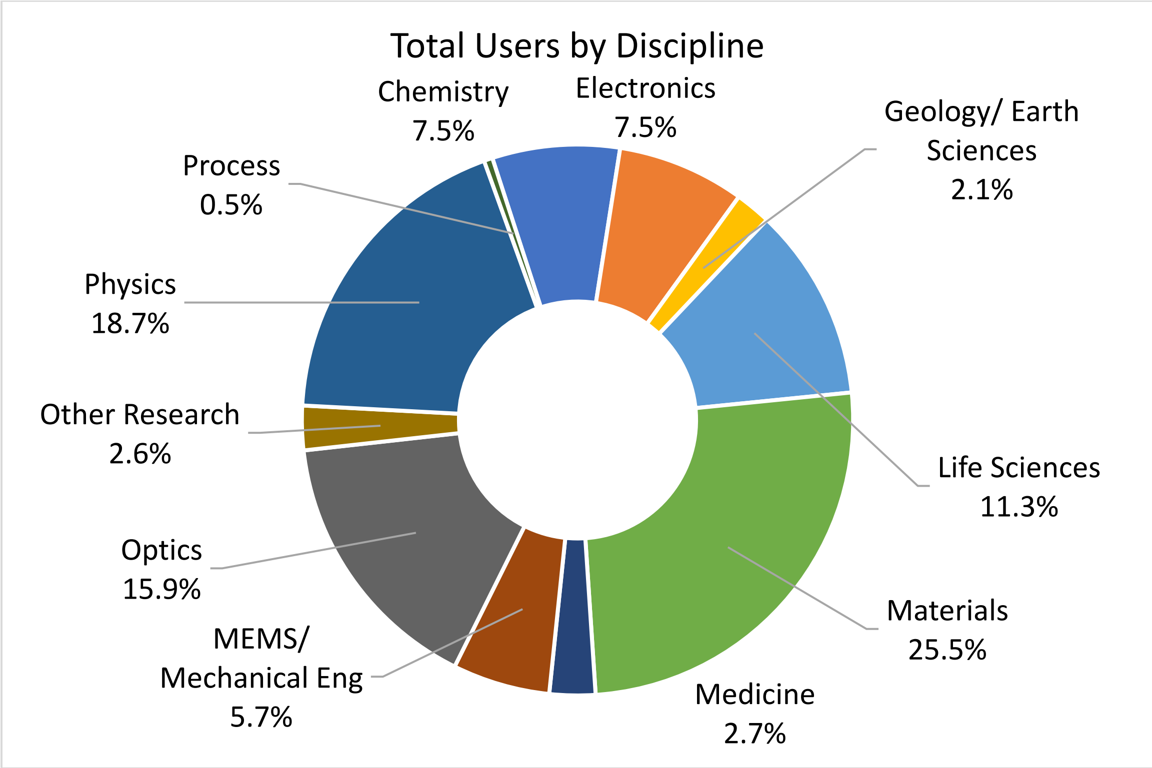
CNS Site Statistics

Yearly User Data Comparison	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Total Cumulative Users	1,023	1,251	1,322	1,420	1,059	669	960	1,089	1,190
Internal Cumulative Users	562	678	700	748	548	382	510	543	592
External Cumulative Users	461 (45%)	573 (46%)	622 (47%)	672 (47%)	511 (48%)	287 (43%)	450 (47%)	546 (50%)	598 (50%)
Total Hours	174,710	181,826	185,288	204,221	114,523	116,357	142,332	157,121	153,193
Internal Hours	124,256	133,020	126,662	117,615	69,904	66,051	75,954	90,924	86,067
External Hours	50,454 (29%)	48,806 (27%)	58,626 (32%)	86,607 (42%)	45,519 (40%)	50,307 (43%)	66,378 (47%)	66,198 (42%)	67,126 (44%)
Avg. Monthly Users	511	514	538	565	317	260	379	442	471
Avg. External Monthly Users	201 (39%)	196 (38%)	218 (40%)	250 (44%)	137 (43%)	102 (39%)	160 (42%)	192 (43%)	213 (45%)
New Users Trained	415	404	452	483	191	116	366	352	386
New External Users Trained	196 (47%)	200 (50%)	233 (52%)	240 (50%)	89 (47%)	43 (37%)	183 (50%)	207 (59%)	198 (51%)
Hours/User (Internal)	221	196	181	157	126	173	149	167	145
Hours/User (External)	109	85	94	129	89	175	148	121	112



CNS Year 9 User Distribution





12.2. Cornell Nanoscale Science and Technology Facility (CNF)

Facility, Tools, and Staff Updates

The Cornell NanoScale Science and Technology Facility (CNF) facilitates rapid advancements in nanoscale science, engineering, and technology by providing open access to state-of-the-art nanotechnology infrastructure and expertise. As a flexible user facility, CNF serves both Cornell-affiliated and external users from academia and industry, drawing on 47 years of proven experience as a leading national and international resource. CNF's expert staff ensures optimal equipment performance, comprehensive training, and technical support for users. The facility operates 24/7, offering hands-on access to over 180 tools critical for nanoscale research, process development, and prototype fabrication. CNF is recognized for its ability to bridge disciplinary boundaries and tackle complex micro- and nanofabrication challenges.

CNF's expansive toolset provides unique capabilities and the flexibility to process a wide range of materials without cross-contamination. CNF has the most advanced e-beam and photolithography facilities in the NNCI network including: 2 electron beam lithography systems; i-line, g-line and DUV steppers; nanoimprint; contact aligners; maskless photolithography, in-house mask maker; 20 dry etcher chambers; 11 chemical vapor deposition (CVD) and 10 atmospheric tubes, graphene and carbon nanotube deposition; physical vapor deposition; plasma-enhanced CVD; atomic layer and molecular vapor deposition; chemical mechanical polishing; rapid thermal processing; electron microscopy; atomic force microscopy; advanced packaging; high frequency electrical testing; advanced 3D characterization/imaging tools; 3D printers and laser cutters, and a suite of CAD and modeling software.

In 2023, CNF received $8.2 million to expand fabrication capabilities through NORDTECH, one of eight Microelectronics (ME) Commons hubs selected by the Department of Defense supported by the CHIPS and Science Act. This funding is part of a $2 billion initiative to enhance U.S. microelectronics development. CNF, as a founding partner of the NORDTECH hub alongside IBM, University at Albany, NY CREATES, and RPI, is using this investment to expand capabilities in Quantum Science and Technology, Heterointegration, and 200 mm wafer processing. These upgrades represent CNF's largest capital expansion since its inception, with numerous new tools and capabilities acquired, installed, or qualified over the past year (see Table and Figure).

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

Recent Capital Equipment Acquisitions via ME Commons			
Zeiss GeminiSEM 560 (200 mm)	Plasma-Therm Plasma Dicing System	Osiris- Temporary Bonding and Debonding	Logitech Orbis 200 mm Upgrade Kit
AJA UHV Sputter Deposition	YES Polyimide Cure Oven	Nano- Master SWC-4000 Brush Cleaner	Heidelberg MLA150
Angstrom UHV E-beam Evaporator	KLA SPTS E2 XeF2 Etcher	REYNOLDSTECH Custom Electroplating	Oxford ASP ALD

SEKI Microwave Plasma CVD	Oxford PlasmaPro 100 Cobra 300	Disco Wafer Back Grinding and DI H20 Recycling Unit	Keyence Digital Microscope

Newly added capabilities at CNF: AJA UHV Multi-Technique Deposition system, Heidelberg MLA150, Keyence Digital Microscope, and 200 mm capable Zeiss GeminiSEM 560

An additional UHV multi-technique deposition system ordered back in 2022 and specifically designed for superconducting quantum devices was delivered in the summer of 2024 and recently installed. The CNF will also be getting a new Fiji XT cluster system configured with dedicated ALD and ALE chambers. This tool is scheduled to arrive in early 2025. All these tools will be housed in the CNF and be available to the broader user community. In early 2024 the CNF replaced its 20-year-old lab management software with NEMO, an intuitive and easy to use laboratory logistics software designed by NIST.

CNF has a dedicated technical management team (2 FTE + Faculty Director and Associated Faculty Director), administrative staff (2.75 FTE), and a laboratory technical staff of 20 (18.5 FTE). The main purpose of CNF is to support the user program, provide instructions, and to maintain equipment to ensure the operational success of the CNF.

Prof. Allison Godwin

In January 2024, Professor Allison Godwin, professor of Chemical Engineering, was appointed as Associate Director for Workforce Development. She joined Cornell in 2023 from a faculty position at Purdue University. Her research specialty is Engineering Education. As Associate Director, she supports and expands CNF's growing workforce development programs in support of both NNCI and other programs.

In February 2024, George (Mac) McMurdy who worked at the CNF since 2019, departed for a new position at MIT Lincoln Laboratory. In March 2024, Paul Pelletier returned to CNF after serving as the Director of Facilities at a local power semiconductor start-up. Paul had worked at CNF from 2004 to 2014, and he will focus on tool installations. His return has been critical as CNF progresses with the ME Commons equipment installations. After 28 years of service at the CNF Melanie-Claire Mallison retired in October of 2024.

<u>User Base</u>

The CNF user base spans a wide range of nanotechnology areas. As part of its strategic plan, CNF held a workshop during its annual meeting in October 2022. The workshop reaffirmed the existing strategic focus areas of quantum technologies, 2D materials, 3D patterning/characterization, and life sciences, while introducing an additional emphasis on heterointegration—specifically, the capability to perform advanced, high-resolution integration with foundry-derived chiplets. Over this period, these strategic thrusts have guided our activities and equipment acquisitions.

Research Highlights and Impact

CNF compiles annual technical research reports in the CNF Research Accomplishments. The impact of technical reports generated by CNF users can be measured through publications in respected peer-reviewed scientific journals such as *Science*, *Nature*, *Cell,* and others as well as patents filed and granted. Research highlights from recent user projects are included in this report's appendix. User publications are collected on an annual basis. In 2023, CNF-supported research resulted in a minimum of 206 publications, 13 presentations (this number is vastly under-reported), and 43 patents/patent applications. Efforts are made to ensure proper crediting of CNF and the NSF NNCI award #2025233 in publications. Users are encouraged to report their publications, and CNF compiles these outputs annually, acknowledging that reporting could be further improved for accuracy.

Economic Impact: CNF is a key resource for advancing nanotechnology to the market. One hundred seventy-one companies, comprising 127 small/startups and 44 large businesses, have utilized CNF for substantial research, development, and prototyping under NNCI. CNF actively contributes to the growth of small businesses, with an average of two new startup launches annually since the beginning of NNCI (see Table below).

Startup companies that used the CNF to develop technology.

JR2J	**Logrus**	**Odyssey Semiconductor**	**OWIC Technologies**	**Esper Biosciences**	**Halo Labs**
Inso Bio	**CyteQuest**	**Kanvas Biosciences**	**Jan BioTech**	**Heat Inverse**	**FloraPulse**
Xallent	**Ultramend**	**White Light Power**	**GeeGah**	**Soctera**	**REEgen**
Diagmetrics	**VOC Health**	**Lux Semiconductor**			

CNF fosters innovation by offering access to advanced materials and cutting-edge instruments within a flexible environment designed to accelerate technology development. This approach has directly supported industry leaders such as DuPont, Pacific Biosciences, INFICON, Applied Materials, Qualcomm, ASML, JEOL, Wolfspeed, Corning, GE, Google, BAE Systems, MACOM, Facebook/Oculus, Qorvo, Samsung, and others. In the past year, 44 small U.S. companies and 10 large U.S. companies benefitted from this access.

Education and Outreach Activities

CNF supports diverse education and outreach efforts spanning K-12, post-secondary, professional, and public audiences. In 2024, CNF reached over 9,000 individuals through 140 events, including national meetings and K-12 classroom visits. On-site K-12 visits averaged over two hours of interactive engagement, making a lasting impact on students' career pathways. The annual CNF Nanoday event, which welcomed 500 attendees for a public, nano-focused STEM experience, was the year's largest and most successful event.

This year, CNF hosted four summer interns supported by NORDTECH workforce development funds and one intern through an NSF FuSe proposal, focusing on hands-on training, cleanroom operations, and advanced research. CNF staff members played key mentoring roles, ensuring the interns gained valuable skills and experience to support their career development.

CNF has been a key leader in the New York State Nanotechnology Network (NNN), a collaborative initiative connecting academia and industry to address shared challenges in the region and promote the state's micro- and nanotechnology capabilities. In September 2024, the NNN hosted the "Growing the Semiconductor Workforce" event at RIT, attracting 130 participants. These events, along with workforce development efforts tied to the CHIPS & Science Act and the upcoming Micron fabrication complex in Syracuse, have highlighted student talent, fostered collaboration, and reinforced NNN's vital role.

The CNF Annual Meeting serves as a forum for researchers, students, and industry to share advancements in nanotechnology and highlight research enabled by CNF's state-of-the-art facilities. At this year's CNF Annual Meeting, Dr. Beth Keser, Vice President of Manufacturing Technology at Zero ACIS Corporation, delivered a keynote address sharing her insights on chiplets and the future of electronic packaging. The event also featured presentations on sustainability for electronics manufacturing, education and workforce development, and AI applied to the CNF. The meeting proceedings can be found at https://www.cnf.cornell.edu/events/annual_meeting/2024.

For thirty-four years, CNF has hosted an NSF-funded Research Experiences for Undergraduates (REU) program. The CNF REU program is a hands-on, immersive ten-week summer research program for exceptional undergraduates selected from a diverse, highly talented pool of applicants. To date over 335 students have participated in the REU program.

2024 REU students at CNF

This past year, the CNF supported six undergraduates for the CNF REU program and specifically worked with the Cornell College of Engineering to support a Morgan State University CNF REU student. In addition, we incorporated four undergraduates hired via Prof. H. Grace Xing's Army Educational Outreach Program (AEOP). To assist several smaller summer programs on campus, we managed the logistics for five additional students including two hosted by our new Associated Director, Prof. Allison Godwin. Additionally, seven students from the 2023 NNCI REU class and 4 students from the NNCI Global Quantum Leap program traveled to Japan to work with our partners at the National Institute for Materials Science (NIMS) in Tsukuba. These competitive programs provided unique learning opportunities for all who participated. Final student reports can be found online at https://www.cnf.cornell.edu/education/reu/2024.

Annually, CNF presents the Whetten Memorial Award in recognition of women scientists whose work and professional lives exemplify a commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and enthusiasm for life. The 2024 award was presented to Kathleen Smith from Applied and Engineering Physics, Cornell University.

2024 Whetten Award winner

We work closely with Micron and hosted three "Micron Chip Camps" at our facility, engaging more than 100 junior high students per event in nanotechnology exploration and cleanroom activities. We also participated in Micron's "Careers in a high-tech world" events at local schools and engage with the regional Future Ready Workforce Innovation Consortium (FRWIC) that brings educators, industry, unions, state representatives and career centers together to ensure the successful growth of high-tech industry in central New York.

Micro Chip Camp attendees

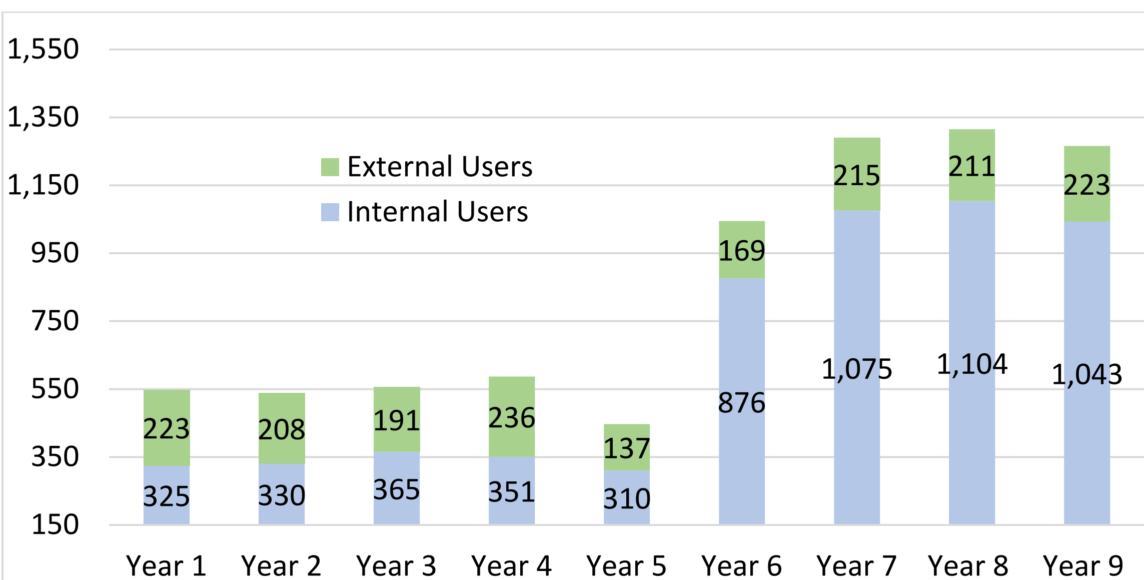
Our relationship with Tompkins County Community College (TC3) continues to advance as we assist them in curriculum development, creation of microcredential programs and acquisition of new equipment for semiconductor education. In partnership with TC3 and Penn State, we hosted our first cohort of students in our microelectronics and nanofabrication program for veterans and their dependents. CNF continues its partnership with the NYS Board of Cooperative Educational Services (BOCES). The CNF ATLAS program, a two-week immersive experience for high school seniors in the Tompkins-Seneca-Tioga (TST) BOCES New Visions Engineering program, has shown significant success, with students advancing to CNF's summer REU program and paid internships. To address workforce needs, CNF launched an ultrahigh purity welding program in collaboration with TST BOCES and Swagelok Inc. This program's rapid expansion helped nine regional BOCES instructors be certified in orbital welding. Additionally, CNF collaborated with Onondaga-Cortland-Madison (OCM) BOCES and TC3 to create a two-year Career and Technical Education (CTE) program, combining electronics, mechatronics, and micro/nanofabrication training, which launched in fall 2024. Our most compelling education and workforce development activity is our digital learning and virtual reality (VR) educational initiative. We are working with e-Cornell to create digital classroom content focused on the core principles of semiconductor processing. We have also partnered with the Cornell Center for Teaching Innovation (CTI) in the development of a uniquely immersive VR educational experience. Combined, these programs will allow students to learn, upskill, reskill and gain workforce readiness from anywhere in the country. To date we have completed seven VR modules (Youth Outreach, Gowning, Cleanroom Safety, and 4 photolithography modules) with funding provided by NORDTECH. We plan to develop additional modules, a public engagement module, and guided fabrication modules to teach industry-relevant process flows.

CNF continues to offer the Technology and Characterization at the Nanoscale (TCN) short course and its annual outreach events, including Tompkins County Expanding Your Horizons, 4-H Career Explorations, New York State Fair, alumni reunion tours, Junior First Lego League, Kangaroo Math, and various science classroom visits. Nanooze is the CNF's kid friendly publication (also @ 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 100,000 copies have been distributed this year.

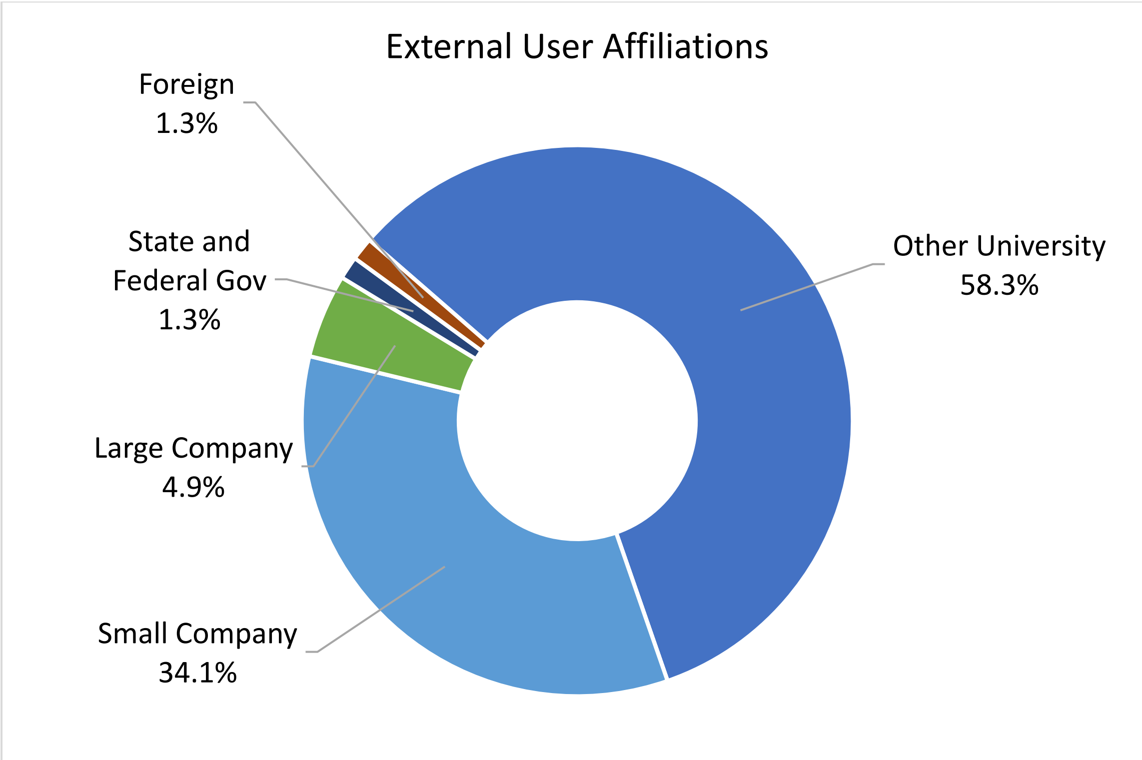
CNF is dedicated to leading education, outreach, and workforce development in micro- and nanotechnology. We are grateful to innovate, build partnerships, and advance this growing U.S. industry.

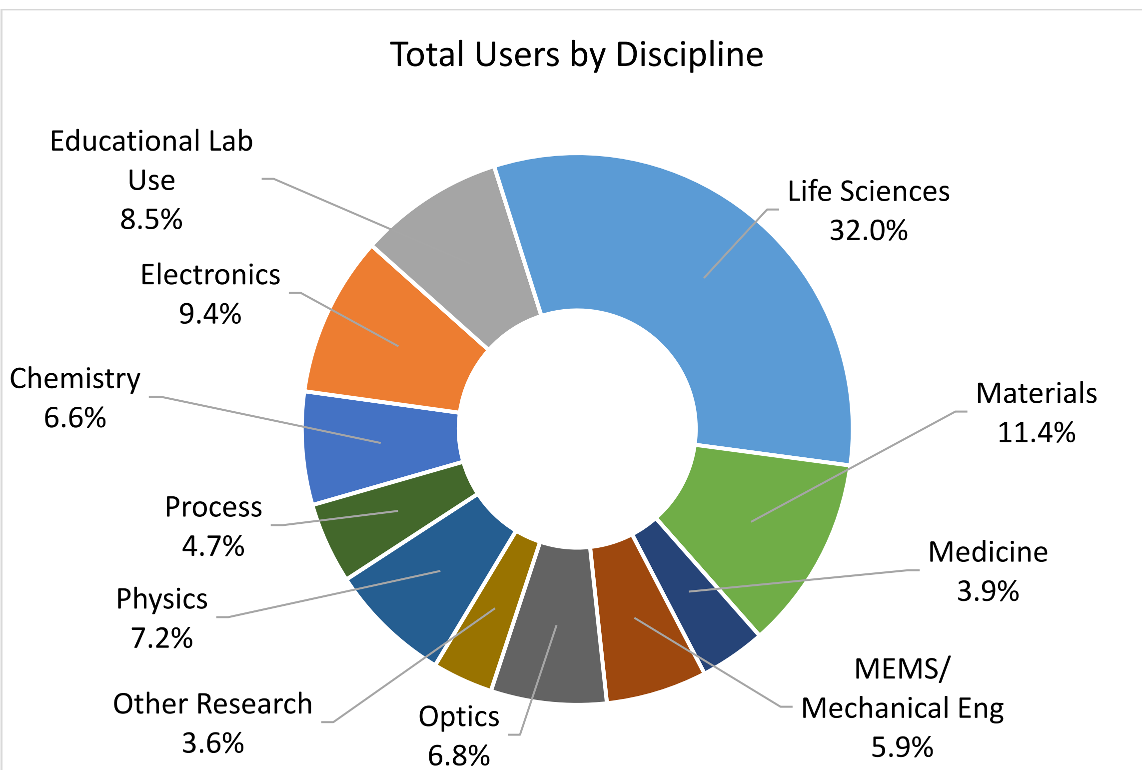
CNF Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	548	538	556	587	447	1,045	1,290	1,315	1,266
Internal Cumulative Users	325	330	365	351	310	876	1,075	1,104	1,043
External Cumulative Users	223 (41%)	208 (39%)	191 (34%)	236 (40%)	137 (31%)	169 (16%)	215 (17%)	211 (16%)	223 (18%)
Total Hours	40,544	45,340	53,680	56,668	31,415	53,688	63,421	62,069	71,925
Internal Hours	22,965	25,201	31,143	34,627	20,446	38,571	46,695	47,544	53,356
External Hours	17,579 (43%)	20,139 (44%)	22,537 (42%)	22,041 (39%)	10,968 (35%)	15,117 (28%)	16,726 (26%)	14,525 (23%)	18,570 (26%)
Average Monthly Users	210	204	225	235	149	332	396	397	410
Average External Monthly Users	67 (32%)	66 (32%)	68 (30%)	71 (30%)	39 (26%)	59 (18%)	65 (16%)	55 (14%)	63 (15%)
New Users Trained	131	161	174	208	77	355	361	338	487
New External Users Trained	46 (35%)	51 (32%)	42 (24%)	91 (44%)	12 (16%)	42 (12%)	77 (21%)	72 (21%)	81 (17%)
Hours/User (Internal)	71	76	85	99	66	44	43	43	51
Hours/User (External)	79	97	118	93	80	89	78	69	83



CNF Year 9 User Distribution





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

Facility, Tools, and Staff Updates

Facilities: A new Engineering Student Success and Research Building opens at UofL on Aug 1, 2025. This 4-story, 120,000 sq ft, $90M building will be the new home for the Conn Center of Renewable Energy Research Center (CCRER), which will occupy the top 2 floors. The CCRER will enhance its visibility and better attract undergraduate participation with this important move.

UofL new Engineering Building

Tools and Equipment: Our NNCI site made several important equipment acquisitions during this reporting period. The UofL Additive Manufacturing Institute of Science and Technology (AMIST) purchased a new metal additive machine. The *EOS M280* is a *laser powder bed fusion metal additive manufacturing machine*. It uses a laser to melt metal powder feedstock into a 3D printed part. Additionally, AMIST purchased a new *Metal DED Machine* called *BeAM Modulo 400 DED machine*, another powder-based metal 3D printer. It uses a single 500W laser to melt a stream of metal powder flowing conically through a CNC controlled nozzle. The BeAM M400 has 2 nozzle options: one for coarse deposition and one for fine deposition. The machine is controlled by a 5-axis CNC mill and driven by a Siemens CNC controller programmed using traditional CAM software. Some applications of this technology are rapid prototyping, part repair, and the production of large metal parts. The deposition head allows for both building parts from scratch and adding material to existing parts. Additionally, the UK CeNSE Core Facility purchased a new *stylus profilometer* through the University of Kentucky Materials Research Priority Area Equipment Competition programming. Upgrading an aging profilometer is an example of a critical, but often challenging, small equipment purchase (~$50K) that was enabled by the university's recognition of such needs in its shared core facilities.

Staff Updates: The UofL MicroNanoTechnology Center (MNTC) welcomed Dr. James (JD) Morris to its technical staff. Dr. Morris earned his Bachelor of Science degree in Chemical Engineering from Trine University in 2014. He then joined industry as a catalyst engineer at Cummins Inc until 2018, where he designed catalyst aftertreatment systems for reducing diesel engine emissions. Afterwards, he began his graduate journey and completed his PhD in Chemical Engineering from the University of Louisville in the fall of 2023. During his research, he developed silicon-based microreactors that were used to detect aldehydes and ketones in exhaled breath and help detect COVID-19 in patients. He presented at several conferences, including the Transducers 2023 conference in Kyoto, Japan and the 2021 AIChE Annual Meeting in Boston, MA.

Dr. JD Morris, UofL MNTC Research Scientist

Pamela "Pam" Edwards joined UK's Department of Electrical and Computer Engineering on January 8, 2024 as an Administrative Services Assistant. She brings a skillset which includes grant-writing and oversight, marketing, and event planning. Her knowledge has grown through employment as a fairgrounds manager, a communications director for non-profits, a production manager for a publishing company, and volunteering. She has a BA in journalism from Marshall University and an MSLS in archives/information management from the University of Kentucky. Pam serves as the UK KY Multiscale Coordinator, replacing Jilian Cramer.

Pam Edwards, KY Multiscale Coordinator at UK

Faculty Updates: Dr. Jonathan Zuidema became a new Assistant Professor hire at the University of Kentucky in the summer of 2024. Prof Zuidemena has experience in engineering biomaterials at the nano, micro, and macroscales as a means to design enhanced control over mechanical properties, biocompatibility, drug delivery, and other desired functionalities. This skillset makes him a great addition to our KY Multiscale Site. Dr. Zuidema's research interests include multiscale biomaterials, neuro-muscular connectivity and repair, mechanics and characterization of biomaterials, nanotechnology and nanomedicine, digital light projection 3D-printing, drug delivery.

Dr. Jonathan Zuidema, UK Assistant Professor

<u>User Base</u>

Growing our user base has continued to be one of our top priorities in Year 9. Below we highlight some of our most successful efforts, initiative, and programs.

KY Multiscale Newsletter, Email Campaigns, and Social Media: The main reason we have been able to grow our contact list so rapidly is because of our targeted efforts to identify regional contacts who are in the micro/nano/AM spaces. Using this strategy, we are able to tailor our email marketing campaigns to reach a specific audience, while focusing on information aligned with their interests. <u>*We are proud to now have **over 16,000 recipients** of our KY Multiscale Marketing Campaigns!*</u> In Year 9, we had much success reaching out to new audiences via social media using LinkedIn, Facebook, and Instagram.

2024 Nano+AM Summit: In Year 9, our signature event continued to be our *Annual Nano+Additive Manufacturing Convergence Summit.* We are pleased to report that the NNCI 2024 Nano+AM Summit was well attended with over 150 in-person participants. This highly interdisciplinary conference is dedicated to bringing together researchers/users in the advanced manufacturing fields of additive findings, share results, showcase capabilities, generate ideas, debate the future, and network with one another. The 2024 Nano+AM Summit was held on July 30-31 in Louisville KY. The 2-day event included 150+ participants, 36 Presenters, 7 Guest Speakers, 38 research posters, and 4 nationally-renown keynote speakers. Our 4 Keynotes are shown in the

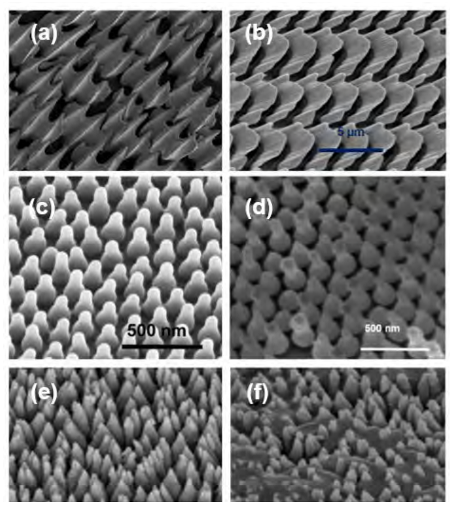
Keynote Speakers for our 2024 NNCI Nano+Additive Manufacturing Convergence Summit.

figure above: Dr. Costas Grigoropoulos of U. of California Berkeley, Dr. Andrew Wells of NSF, Dr. Rayne Zheng of U. of California Berkely, and Dr. Stephen Jesse of Oak Ridge National Laboratory. This organized effort by the KY Multiscale NNCI site has proven successful in bringing collaborations, awareness, professional and academic partnerships to the Kentucky Commonwealth region, as well as nationally.

Outreach Programs: In Year 9, we continued our *2 Internal Seed Programs* at UofL and UK for core facility users from under-represented populations and non-traditional users in the areas of microtechnology, nanotechnology, additive manufacturing, and advanced materials. In addition, in Year 9, we finalized several new semiconductor-related academic initiatives/programs. This included the following: *Masters in ECE with a Concentration in Semiconductor Manufacturing*, *Midwest Regional Semiconductor Chip Design Hub Initiative with Ohio State*, *New Applied Engineering UG Degree in Semiconductor Manufacturing*, *New Emphasis on Semiconductor Manufacturing within an Engineering Technology Program*, and a *Chips Camp* (in collaboration with the UofL CSE department for HS students). Other outreach programs included our very successful IMPACT REU Program, which began its third generation in the summer of 2024 (NSF award #2348869). Additionally, in this period, we offered the Research in Symmetries REU at the University of Kentucky, a new REU in Additive Manufacturing at the University of Louisville, an RET in Energy at UofL, and an RET in Additive Manufacturing at UofL, a Middle School Teacher Program (NanoSISMT in collaboration with nano@Stanford), and several Additive Manufacturing Summer Camps for Grades 7-12.

Research Highlights and Impact

Site Research Highlights: Our complete annual report presents several research projects that made extensive use of the KY Multiscale core facilities. Here we present one interesting project entitled "Using Glancing Angle Deposition (GLAD) to Develop Bio-Inspired Smart Surfaces". Dr. Chuang Qu (UofL Micro/Nano Technology Center) and his team of researchers from Electrical Engineering and Biology specialize in mimicking the unique surface properties found in nature. Many interesting mechanical, chemical, and hydrodynamic properties in nature and biology are due solely to the interesting nanostructures found on their naturally occurring surfaces. Three examples are highlighted in this research and shown in the figure at right. First, (a) shows a highly-magnified SEM image of **Shark Skin**, which has both oleophobic (oil resistant) and hydrodynamic properties due to its uniquely angled and overlapping nanostructures. Dr. Qu's team was able to synthetically replicate that using a combination of GLAD and photolithographic seeding, as illustrated in (b). Furthermore, (c) and (d) shows naturally occurring and synthetically replicated **Cicada Wing** surfaces, which are both antibacterial and superhydrophobic. Finally, the **Glasswing Butterfly Wing** has a naturally occurring spike-like surface that is both antibacterial and transparent, as



(a) SEM of natural Shark Skin. (b) synthetic Shark Skin produced using GLAD and photolithographic seeding. (c) SEM of the natural annual (i.e. dog-day) Cicada Wing. (d) synthetic Cicada Wing using GLAD and spherical seeds. (e) SEM of synthetic Glasswing Butterfly Wings using Inverted GLAD or I-GLAD. (f) SEM showing the penetrating antibacterial properties of I-GLAD.

shown in (e) and (f), illustrating Dr. Qu's synthetic mimicry and its effectiveness in killing bacteria. All of these interesting and unique nano-structures were created using creative variations of Glancing Angle Deposition in combination with other nanotechnology processes. GLAD is an especially versatile and scalable bottom-up process which uses physical vapor deposition while maneuvering the substrate with an extreme incident angle and constant rotation. This research was performed at the University of Louisville Micro/Nano Technology Center (MNTC) and was supported by NSF Award #2025075.

Education and Outreach Activities

Our NNCI site was involved in many educational and outreach activities during this reporting period. We highlight a few of our most popular and successful E&O activities below.

REU Programs: The UofL MNTC and AMIST core facilities hosted 9 external undergraduate STEM students for an exciting NSF REU program entitled IMPACT-GEN 3 (Interdisciplinary Micro/nano/additive Program Addressing Challenges Today). The students received hands-on micro/nano/additive manufacturing training in our state-of-the-art core facilities, professional development, and a personalized research experience. They also attended the NNCI REU Convocation at Lincoln, NE. This was the first year of our newly funded Gen 3 IMPACT NSF grant renewal (our 7th year for this program). In addition, UofL also offered a brand new NSF REU program solely in Additive Manufacturing that included 8 additional undergraduate students for a research experience at the KY Multiscale AMIST facility. Students from both groups interacted on several educational activities during the 10 weeks of these 2 programs, including presenting their research results in poster form at the NNCI 2024 Nano+AM Summit. Additionally, UK's CeNSE, EMC and CAM core facilities hosted 2 NSF REU programs in the areas of Engineered Bioactive Interfaces Devices and Material Symmetries.

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 NSF RET program that focused on Manufacturing Automation and Simulation, which leveraged the UofL AMIST core facility.

NanoSIMSTs: KY Multiscale joined forces with Nano@Stanford and sponsored 6 Middle School Teachers to participate in the virtual NanoSIMSTs program. Dr. Kevin Walsh, Director of the KY Multiscale site, presented a talk about *"MEMS Technology and Sensors"* to program participants during the workshop. This was KY Multiscale's second year of partnering with Stanford on this program and is planning to support an additional 6 MS teachers in the summer of Year 10.

Industry Outreach: In summer 2024, Dean Emmanuel Collins invited a group of leaders and design engineers from General Electric Appliances (GEA) to tour the Core Facilities and Research Centers at the UofL Speed School of Engineering. This was an initiative to increase the research collaboration between the 2 organizations. UofL and KY Multiscale in general have so many state-of-the-art facilities and capabilities that are not apparent to all companies in the region, and we need to continue to promote such partnerships. The ultimate goal of this collaboration will be the creation of a UofL/GEA Research Center where researchers will jointly solve technical issues for GEA. GEA has a proposal from Dean Collins under consideration.

Educational Initiatives: With the announcements of the CHIPS Act and Intel building a $20B fabrication facility in our adjacent state of Ohio, there is the need to train engineers in the Midwest region with the technological skillsets needed for the semiconductor industry. Additionally, Skywater is building a $2B fabrication facility in our neighboring state of Indiana. Experts predict we need an additional 10,000 processing engineers and technicians in the Midwest alone (i.e. the Silicon Heartland). In response to that demand, the UofL ECE Department created a *Concentration Track in Semiconductor Manufacturing* as part of its MSEE degree. In addition, the University of Kentucky continued its undergraduate Nanoscience Course partnership with Transylvania University. Other educational initiatives include: *Midwest Regional Semiconductor Chip Design Hub Initiative with Ohio State*, *New Applied Engineering UG Degree in Semiconductor Manufacturing*, and *new emphasis on Semiconductor Manufacturing within an Engineering Technology Program.*

Training Courses: The AMIST Core Facility is used as a learning laboratory fully equipped with the latest AM technologies, machining, metrology and powder handling systems. AMIST staff offers on demand, <u>one-day AM metal safety trainings</u> in the center and on-site. These courses cover PPE (person protection equipment), material handling, facility development, and other safety topics in metal AM. Upon completion, participants receive a training certificate and copies of training materials. Additionally, AMIST also offers a <u>4.5 day metal AM production course</u>. This course covers a full one-day safety training along with build set up, design practices, machine set up/breakout, post-processing and hands-on machine time with machines like EOS M290 and Kurtz Ersa Alpha140. Upon completion, participants receive a training certificate and copies of the training materials. KY Multiscale also continued its KY INBRE Partnership allowing MNTC to network with biomedical researchers and educators within the Commonwealth of KY. Through KY INBRE, MNTC provides imaging training and seminars to the state medical community.

Summer Camps: Due to the overwhelming response in summer camp registration from previous years, AMIST expanded its offerings and coordinated 3 camps for youth groups (grades 7^{th}-12^{th}) with 55 school participants. The camp called *"Nuts, Bolts, and Thingamajigs"* is a 3-day hands-on experience that introduces participants to additive manufacturing design and fabrication. Additionally, KY Multiscale MNTC designed a *Summer Chips Camp* in collaboration with the UofL CSE department for HS students.

Nano Image Competition & E-DAY Celebrations: KY Multiscale participated in the NNCI Image Contest "Plenty of Beauty at the Bottom" in celebration of National Nanotechnology Day. In addition, we hosted our own image competition. All submissions collected from our core facilities were framed and permanently displayed in our own Nano-Gallery that we created in the Shumaker Research Building, home of the Micro/Nano Technology Center. KY Multiscale at both UofL and UK Cores, continues to support E-Day demonstrations on both campuses highlighting our KY Multiscale Cores annually for engineering day.

<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, Materialize 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.

Innovation and Entrepreneurship Activities

Kentucky Wins EDA Tech Hub (Phase 1)

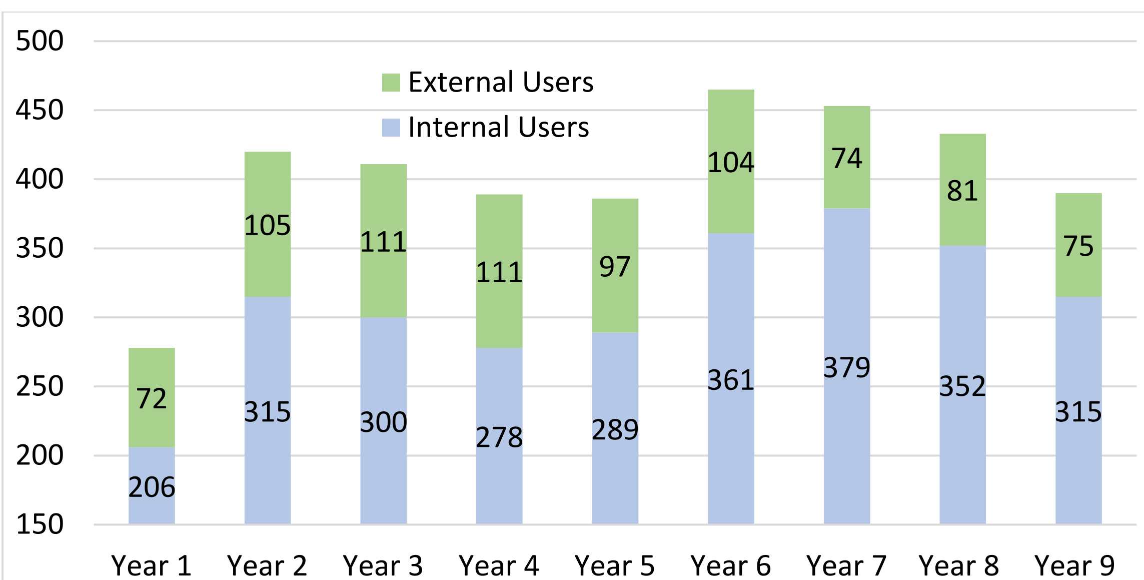
Kentucky received a $500,000 grant from the U.S. Tech Hubs Program to establish REBECCA (Regional Energy Business, Education, and Commercialization Convergence Accelerator) in Louisville, focusing on advanced materials science and energy innovation, including research in composites, batteries, hydrogen, and solar power. REBECCA, located on a 60-acre site, will drive innovation in advanced manufacturing while fostering collaboration with underserved communities and educational institutions like Jefferson Community & Technical College. Led by Professors Mahendra Sunkara (of KY Multiscale's Conn Center) and Sundar Atre, and partnering with local organizations, REBECCA aims to secure up to $75 million in further funding through a Phase 2 implementation grant.

Kentucky Wins NSF Engines Development Award (Type 1)

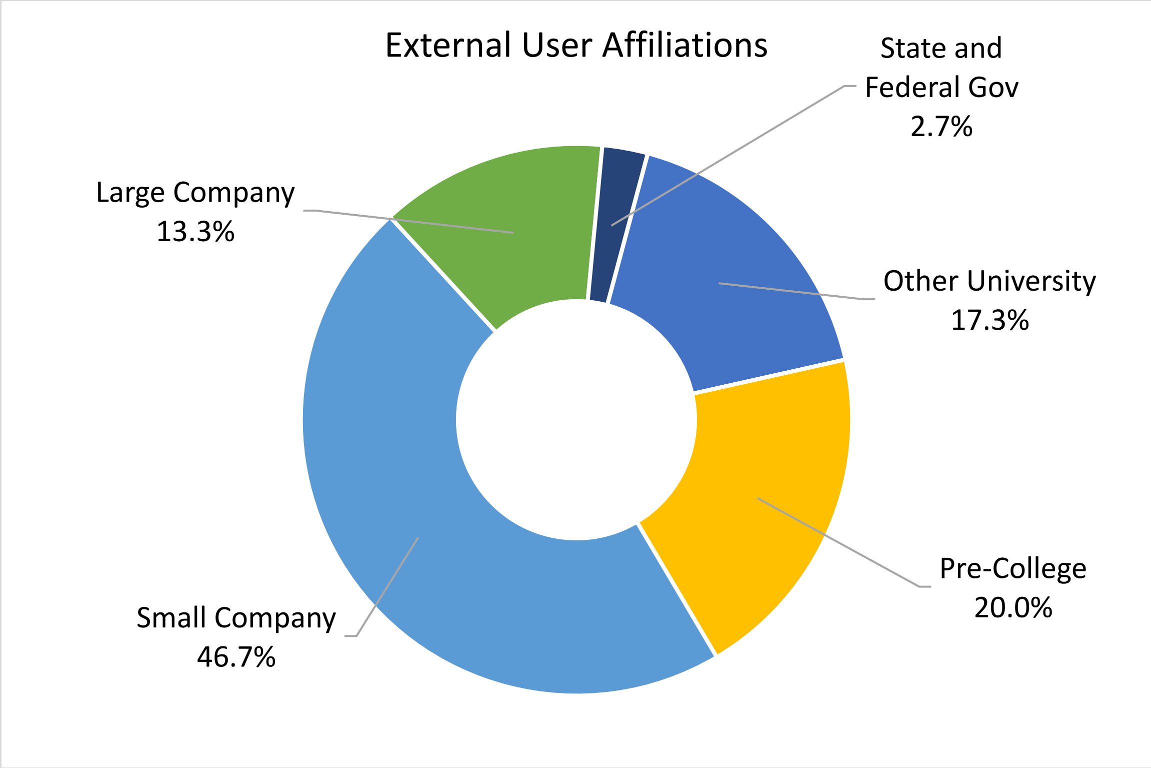
This Regional Innovation Engines Development Award focuses on creating an innovation ecosystem for next-generation manufacturing and supply chains across the Southeastern Commerce Corridor (SCC) of Kentucky and Tennessee. By 2034, the SCC aims to be a global leader in circular economy manufacturing, supported by an inclusive workforce. The region, a hub for logistics and critical industries like metals and EV batteries, encompasses key cities such as Louisville, Lexington, Nashville, Knoxville, and Chattanooga, along with economically distressed areas. Led by the University of Kentucky and 12 core partners, including research universities and national labs, the initiative—GAME Change Engine—focuses on advanced technologies like robotics and advanced materials, with support from 53 collaborating partners, including industry leaders. Prof. Ian McClure leads the project.

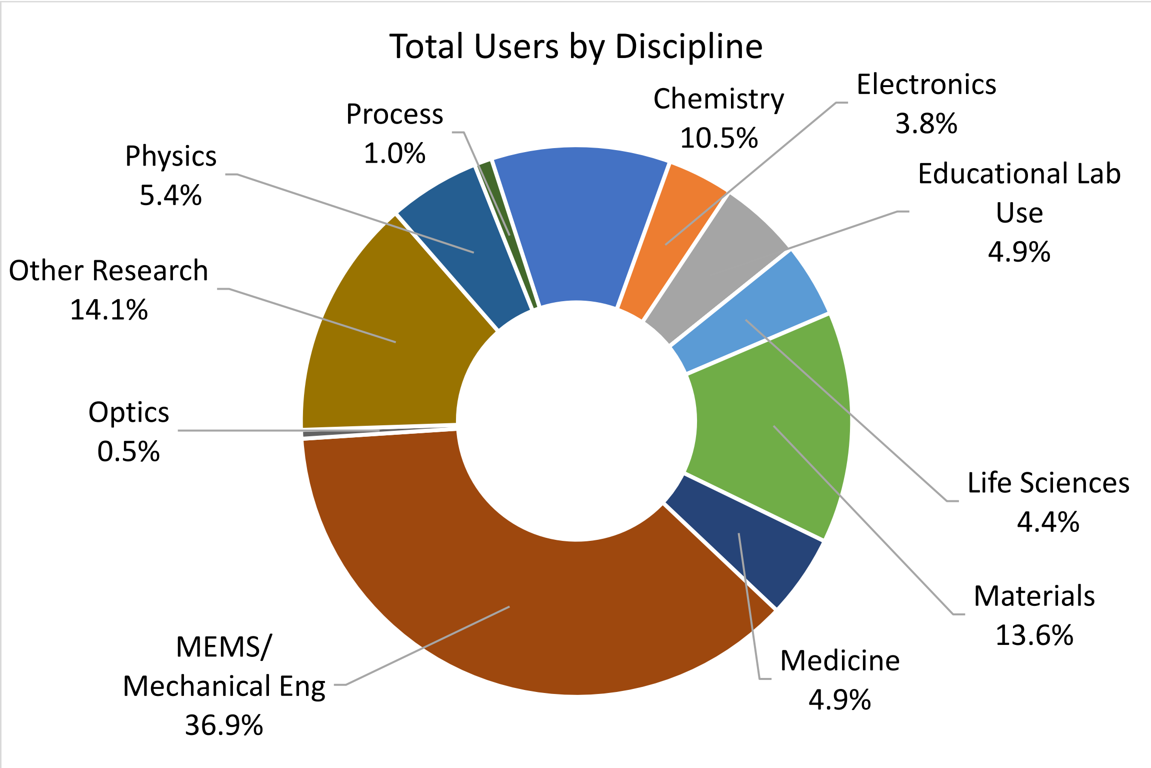
KY Multiscale Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	278	420	411	389	386	465	453	433	390
Internal Cumulative Users	206	315	300	278	289	361	379	352	315
External Cumulative Users	72 (26%)	105 (25%)	111 (27%)	111 (29%)	97 (25%)	104 (22%)	74 (16%)	81 (19%)	75 (19%)
Total Hours	14,629	17,151	17,301	15,651	12,895	14,220	12,387	14,440	14,816
Internal Hours	9,726	12,166	10,960	11,869	9,032	10,282	10,128	11,884	12,452
External Hours	4,903 (34%)	4,986 (29%)	6,341 (37%)	3,782 (24%)	3,862 (30%)	3,938 (28%)	2,259 (18%)	2,557 (18%)	2,364 (16%)
Average Monthly Users	104	141	120	140	97	127	121	137	135
Average External Monthly Users	22 (21%)	25 (18%)	25 (21%)	25 (18%)	20 (20%)	25 (20%)	17 (14%)	22 (16%)	19 (14%)
New Users Trained	111	251	164	223	118	165	151	125	129
New External Users Trained	26 (23%)	43 (17%)	28 (17%)	22 (10%)	18 (15%)	19 (12%)	17 (11%)	10 (8%)	6 (5%)
Hours/User (Internal)	47	39	37	43	31	28	27	34	40
Hours/User (External)	68	47	57	34	40	38	31	32	32



KY Multiscale Year 9 User Distribution





12.4. Mid-Atlantic Nanotechnology Hub (MANTH)

The Mid-Atlantic Nanotechnology Hub (MANTH) represents a vital partnership between the University of Pennsylvania (Penn) and the Community College of Philadelphia (CCP). The hub's core facilities are housed within the Singh Center for Nanotechnology at Penn, comprising an 11,000 ft² class 100/1000 Nanofabrication Facility that supports a broad spectrum of materials from silicon to soft materials (the QNF), alongside a 10,000 ft² Nanoscale Characterization Facility (NCF) and Scanning Probe Facility (SPF).

Through these advanced facilities, MANTH provides open access to leading-edge R&D capabilities and expertise for academic, government, and industry researchers working across all disciplines of nanoscale science, engineering, and technology. The center maintains a staff of fourteen professionals who support these diverse research activities.

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 paid summer technician internship program at the Singh Center.

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

The past year has brought significant growth in both human resources and technical capabilities at MANTH, including new leadership in our core user facility.

Staff: Eric Stach has been named the new Scientific Director of the Singh Center for Nanotechnology. Eric is a professor in the Department of Materials Science and Engineering at the University of Pennsylvania. He has held positions as Staff Scientist and Principal Investigator at the National Center for Electron Microscopy at the Lawrence Berkeley National Laboratory, as Associate, then Full Professor at Purdue University, and as Group Leader at the Center for Functional Nanomaterials at the Brookhaven National Laboratory. He is a co-founder and Chief Technology Officer of Hummingbird Scientific and is Secretary of the Board of Directors for the Materials Research Society.

Professor Eric Stach, Scientific Director of the Singh Center for Nanotechnology at MANTH.

The center also welcomed 2 key staff members who bring diverse expertise to support its expanding operations. Dan Sabrsula is a member of the process team at QNF and assists users by training them on equipment and helping with process troubleshooting. His main area of focus is physical vapor deposition, including sputtering, and thermal and electron-beam evaporation. Lucas Barreto, another member of the QNF team, has a background in surface science, focusing on the electronic and structural properties of quantum materials and thin films.

Equipment: The facility's technical capabilities saw substantial enhancement through strategic equipment acquisitions. A state-of-the-art Raith EBPG5200+ electron beam lithography system is now fully operational and provides users with high-resolution patterning capabilities at 100 kV. The QNF cleanroom expanded to include a sixth process bay, creating space for new capabilities while optimizing existing processes. The SPF enhanced its optical characterization capabilities with the addition of an NKT Photonics SuperK Fianium supercontinuum laser with an acousto-optic tunable filter. The NCF electron microscopy suite received significant upgrades, including a Gatan Metro 2k x 2k direct-electron camera for the JEOL F200 TEM and a Gatan STEMx system for the JEOL NeoARM TEM. Additionally, an environment-controlled glove box was installed to support temperature-controlled, air-free sample preparation.

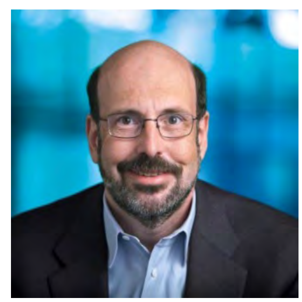
User Base

MANTH has demonstrated robust growth in its user community and research impact throughout 2023-2024. The facility served 515 users in NNCI Year 9, marking the highest number since the pandemic began. Equipment utilization reached levels on par with recent years, with over 60,000 hours logged. The facility maintained an average of 209 monthly users and 237 new users received training during Year 9, indicating the strength of the research community's utilization of MANTH's capabilities.

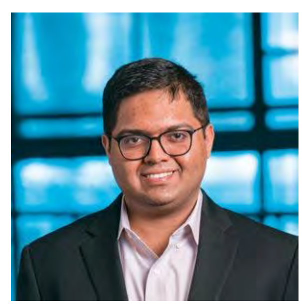
The user community reflects a diverse mix of academic and industrial researchers. External users comprised 112 researchers, representing 22% of the total user base. Small companies proved particularly active, accounting for over 54% of external equipment hours, while external academic researchers made up 63% of external users. The research disciplines represented at MANTH span a broad spectrum, with 17% of users working in life science and medicine, 34% in materials research, 43% in physical sciences and engineering, and 12% specifically focused on electronics research.

Research Highlights and Impact

Awards: **Mark Allen**, Alfred Fitler Moore Professor in Electrical and Systems Engineering and in Mechanical Engineering and Applied Mechanics, and Department Chair of ESE, has been elected to the **National Academy of Engineering** (NAE) for "contributions to the technology and commercialization of Micro-Electro-Mechanical Systems (MEMS) for health care." Mark joins a group of 106 new members and 18 international members that comprise the NAE Class of 2023.



MANTH PI Mark Allen, above, and Deep Jariwala, below.



Deep Jariwala, Assistant Professor in the Department of Electrical and Systems Engineering, is a 2023 recipient of the **ACS Nano Lectureship Award**. ACS Nano is a publication of the American Chemical Society (ACS) and is dedicated to nurturing talent and promoting diversity among early career nanoscientists worldwide. Deep was selected to receive this Award for his "trailblazing work in the field of solid-state optoelectronics and low-dimensional materials."

Research: The facility has also fostered significant research breakthroughs in materials and device development. Notable achievements include the development of high-quality 2D InSe on 2-inch substrates for advanced computing applications, creation of self-hybridized exciton-polariton photovoltaics for enhanced solar energy harvesting, and advancement in understanding lithium-ion batteries through innovative cryo-electron microscopy techniques. These developments demonstrate MANTH's crucial role in pushing the boundaries of nanoscale research and development.

Impact: The facility's research impact is evidenced by its substantial scholarly output, including 297 publications, 36 conference proceedings, and 26 patents in calendar year 2023. The MANTH NNCI contract received 154 citations, demonstrating the facility's crucial role in advancing nanoscience and nanotechnology research. Research activities aligned strongly with NSF 10 Big

Ideas, particularly in the areas of Rules of Life and Quantum Leap, with growing emphasis on nano-IoT, quantum computing, and 2D materials.

External users from institutions including the University of Delaware, Drexel University, Temple University, and Villanova University have made substantial contributions to this body of work, highlighting MANTH's role as a catalyst for regional scientific advancement.

The graduation of 12 PhD and 29 MS student users from Penn in the past year, along with supporting 191 students through facility-based courses, underscores MANTH's vital role in developing the next generation of technology leaders.

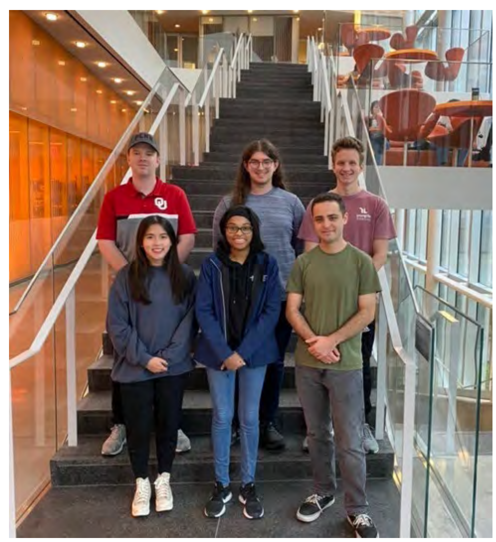
Education and Outreach Activities

Nanotechnology Training Collaboration with the Community College of Philadelphia: The partnership between MANTH and the CCP continues to flourish, creating valuable opportunities for community college students to enter the field of nanotechnology. The third cohort of four CCP interns completed their 14-week paid internship program in 2024, gaining invaluable hands-on experience in cleanroom operations and research practices. Throughout their internship, these students not only developed technical skills but also participated in research presentations and collaborative projects with MANTH staff and researchers.

2024 Cohort of CCP Interns in the MANTH QNF cleanroom gowning area.

REU: The Research Experience for Undergraduates (REU) program maintained its strong trajectory in 2023 with six students representing diverse institutions across the country. The cohort included two women and four men from institutions including Rowan University, Howard University, the University of Oklahoma, Hendrix College, Haverford College, and Auburn University. Five of these students presented their research at the NNCI REU Convocation at Montana State University, demonstrating the program's commitment to professional development and research excellence.

The 2024 Cohort of 6 from Rutgers, NYU, Cornell, University of Maryland, Illinois Institute of Technology, and Notre Dame conducted research at MANTH this past summer. All 6 attended the NNCI REU Convocation at the University of Nebraska in August 2024.



The 2023 REU cohort at the Singh Center.

Nanoday: NanoDay@Penn underwent transformative expansion in 2023, reaching over 600 students through a reimagined approach to outreach. The program provided 17 in-person laboratory sessions at local schools and four online sessions, making nanotechnology education more accessible than ever before. Sessions covered a wide range of topics including semiconductors, energy, nanomaterials, and quantum dots. The program's impact was evident in post-event surveys, with 94.3% of participants reporting maintained or increased interest in STEM careers.

In-person NanoDay hands-on education sessions at middle/high schools. In addition, middle school teachers learned about CdSe Quantum Dot synthesis and characterization protocol at MANTH.

Other Programs: The Graduate Student Fellow (GSF) Program continues to serve as a cornerstone of MANTH's educational mission. Since its inception in 2015, the program has supported 119 students, with 41 women among the participants, demonstrating a strong commitment to diversity in STEM fields. The program's success is evident in its outcomes: 55 fellows have pursued doctoral or other advanced degrees, while 58 have secured positions as engineers and managers in industry. Among the current cohort of eleven fellows, seven are pursuing doctoral studies at leading institutions, further testament to the program's role in developing future leaders in nanotechnology.

The Engineering Summer Academy at Penn (ESAP) provided comprehensive nanotechnology education to 33 high school students in 2023. Participants engaged with over 20 different fabrication tools while completing both foundational and advanced laboratory modules. The program's curriculum integrated hands-on technical training with career development opportunities, including presentations from industry professionals and research scientists. This holistic approach has proven highly effective in inspiring the next generation of nanoscience researchers and practitioners.

MANTH staff have also provided hands-on cleanroom processing experiences for students and teachers throughout the past year, in addition to several 6-hour hands-on microfluidic soft lithography workshops.

Innovation and Entrepreneurship Activities

The Innovation Seed Grant Program continues to catalyze groundbreaking research across the Mid-Atlantic region. The 2024 cohort includes fifteen finalists representing nine organizations, including three startups and six academic institutions. Their projects span crucial areas of technological development, from healthcare and medicine to environmental sustainability and quantum computing. This diversity of research focus reflects MANTH's commitment to advancing multiple frontiers of nanotechnology simultaneously.

MANTH Small Company Grants

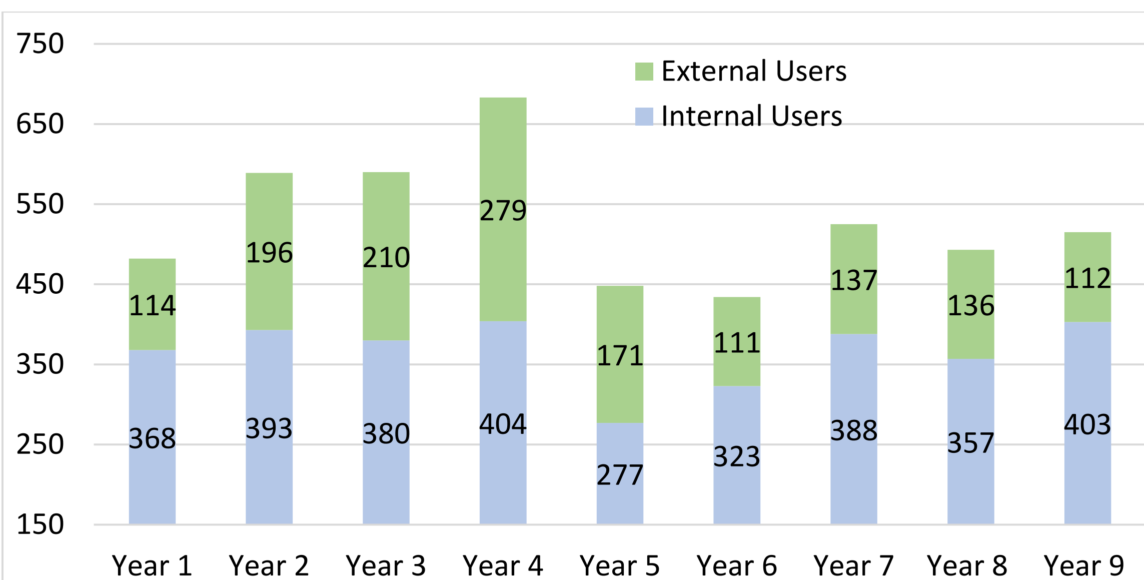
Funding Source	2015	2016	2017	2018	2019	2020	2021	2022	2023	Grand Total
CrowdFund	$ -	$ -	$ -	$ -	$1,070	$ -	$ -	$ -	$ -	$1,070
Grant	$ -	$ -	$ -	$ -	$ -	$15	$ -	$221	$100	$336
In-Kind	$ -	$ -	$ -	$ -	$ -	$ -	$6	$ -	$330	$336
Other	$ -	$ -	$ -	$ -	$ -	$260	$ -	$ -	$ -	$260
SBIR	$300	$3,075	$681	$1,291	$4,861	$5,508	$11,687	$5,567	$3,372	$37,238
Seed	$ -	$ -	$ -	$ -	$ -	$755	$1,488	$ -	$ -	$2,243
Series A	$ -	$ -	$ -	$6,000	$8,000	$ -	$ -	$ -	$ -	$14,000
Series B	$ -	$ -	$ -	$ -	$ -	$ -	$20,500	$ -	$ -	$20,500
STTR	$ -	$233	$223	$ -	$ -	$420	$840	$ -	$ -	$1,716
VC	$ -	$ -	$ -	$1,250	$ -	$ -	$ -	$4,060	$1,000	$6,310
Yearly Total	**$300**	**$3,308**	**$904**	**$8,541**	**$13,931**	**$6,957**	**$34,522**	**$9,848**	**$4,802**	**$85,297**

MANTH's influence on technological innovation and economic development continues to grow through its support of small companies and startups. Since the facility's inception, over 70 small companies with 50 or fewer employees have leveraged MANTH resources for their research and development needs. These companies have demonstrated remarkable success in securing external funding, garnering over $86M in total, with approximately 40% coming from SBIR/STTR grants. The year 2023 proved productive, with MANTH-affiliated companies securing $3.372M in SBIR grants alone. This success underscores the facility's vital role in bridging the gap between academic research and commercial application.

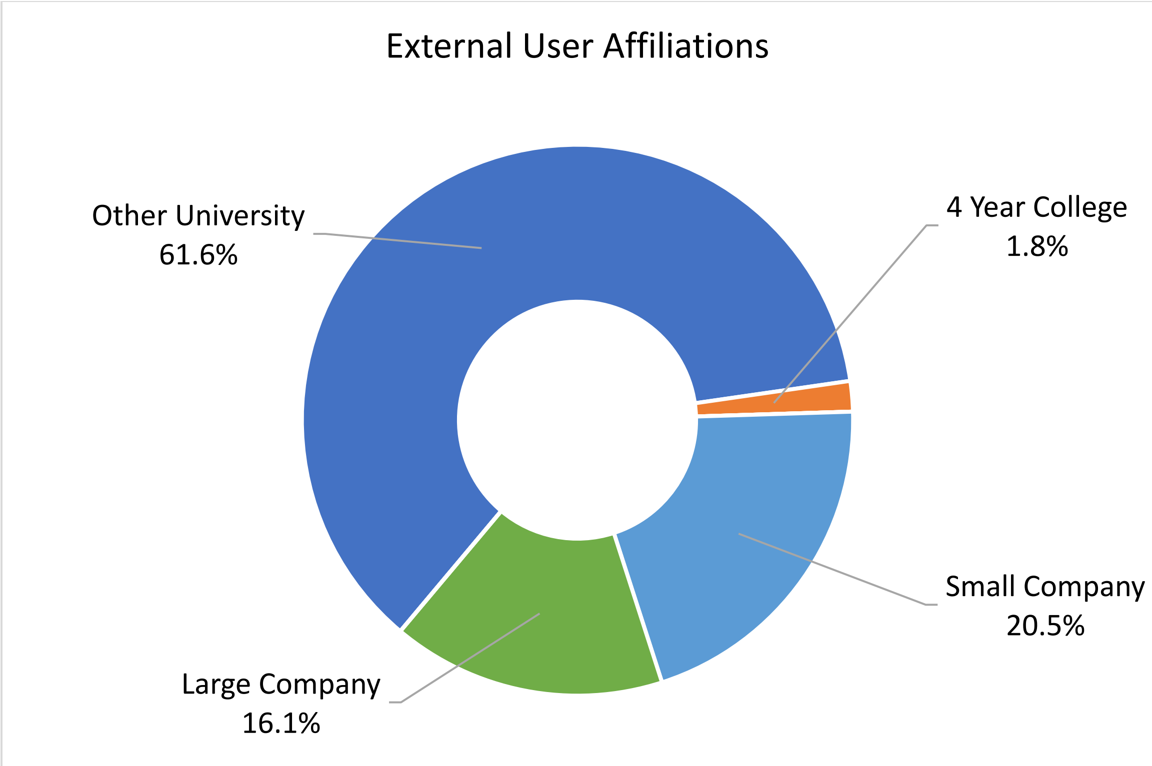
Through these comprehensive initiatives and achievements, MANTH continues to fulfill its mission as a leading nanotechnology hub, fostering innovation, education, and technological advancement in the Mid-Atlantic region and beyond. The facility's impact resonates across academic research, industry collaboration, and workforce development, positioning it as an essential resource for the future of nanotechnology.

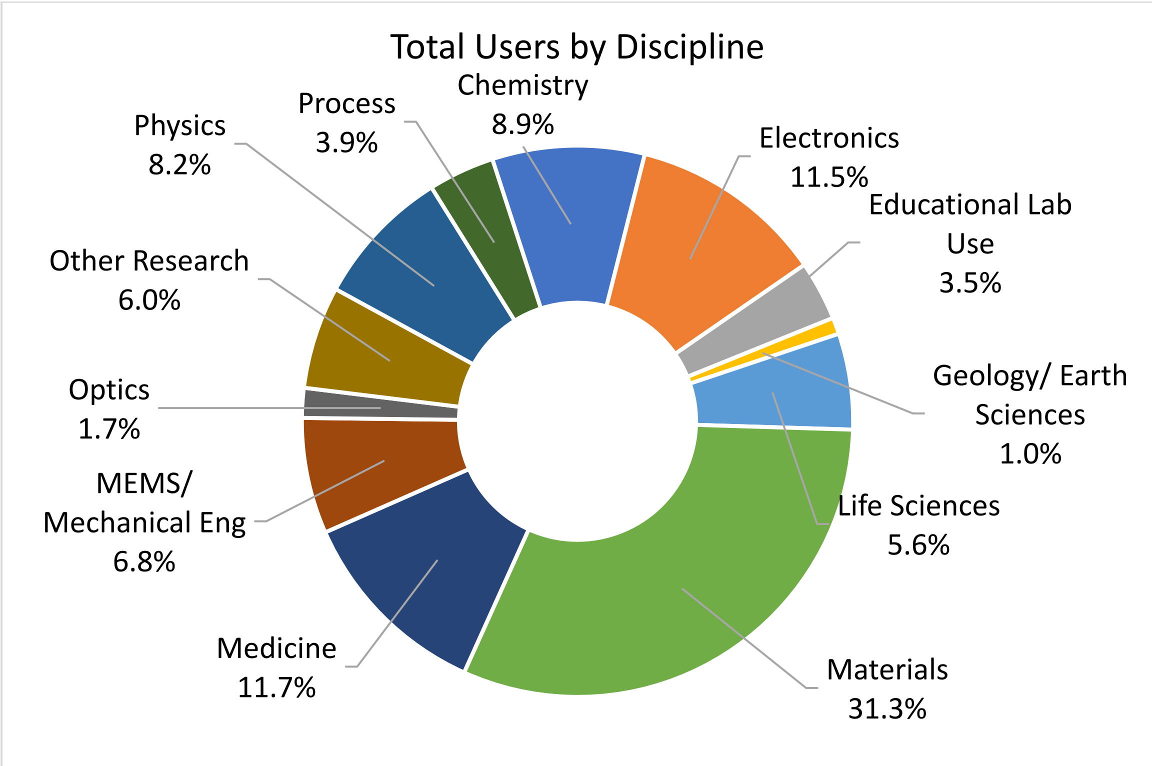
MANTH Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	482	589	590	683	448	434	525	493	515
Internal Cumulative Users	368	393	380	404	277	323	388	357	403
External Cumulative Users	114 (24%)	196 (33%)	210 (36%)	279 (41%)	171 (38%)	111 (26%)	137 (26%)	136 (28%)	112 (22%)
Total Hours	36,970	37,933	34,796	56,849	45,551	63,945	56,729	63,902	60,536
Internal Hours	34,545	31,542	27,436	43,673	39,379	58,094	50,921	56,042	55,610
External Hours	2,425 (7%)	6,409 (17%)	7,360 (21%)	13,176 (23%)	6,172 (14%)	5,851 (9%)	5,807 (10%)	7,860 (12%)	4,926 (8%)
Average Monthly Users	171	194	186	210	142	180	216	212	210
Average External Monthly Users	29 (17%)	44 (23%)	45 (24%)	61 (29%)	31 (21%)	25 (14%)	37 (17%)	36 (17%)	29 (14%)
New Users Trained	270	339	270	418	180	186	215	213	237
New External Users Trained	73 (27%)	138 (41%)	104 (39%)	203 (49%)	95 (53%)	52 (28%)	72 (33%)	79 (37%)	64 (27%)
Hours/User (Internal)	94	80	72	108	142	180	131	157	138
Hours/User (External)	21	33	35	47	36	53	42	58	44



MANTH Year 9 User Distribution





12.5. Midwest Nanotechnology Infrastructure Corridor (MiNIC)

Facility, Tools, and Staff Updates

MiNIC Site Overview:

The Midwest Nano Infrastructure Corridor (MiNIC) is based at the University of Minnesota – Twin Cities (UMN) and provides a broad suite of capabilities to support a wide variety of research on micro- and nano-scale technology. The core facilities of MiNIC include the Minnesota Nano Center (MNC) and the Characterization Facility (CharFac). The MNC also has BioNano and Nanomaterials Labs specializing in creating and characterizing materials for use in biological applications. MiNIC has a total of 25 full-time staff members, as well as numerous graduate and undergraduate staff and interns. The MiNIC node has two focus areas – Quantum Leap and Rules of Life – that are well aligned with two of the current NNCI Research Communities.

Tool Updates: MNC

The MNC purchased a Finetech *FinePlacer Sigma* die bonder using internal funds. The die bonder is configured with an array of modular components enabling several different kinds of bonding (thermocompressive, solder, adhesive, ultrasonic, etc), and can accommodate a plethora of die package sizes and configurations. This system is being used by several users to support a variety of projects involving 3D heterogeneous integration.

The MNC also acquired an Anton Paar *Autosorb iQ* gas sorption system. The *Autosorb* provides users with physisorption measurements of powder materials, enabling studies of specific surface area and BET (Brunauer–Emmett–Teller) adsorption. It is also equipped for chemisorption experiments, needed in the development and characterization of catalyst particles. It has attracted users from Chemical Engineering, Environmental Engineering, and Pharmaceutics.

The MNC was also awarded an internal grant to purchase a new direct-write laser lithography tool. We purchased a Raith *Picomaster* 200 configured with backside alignment, dual laser sources of 375 nm and 405 nm, and multiple write-heads. This capability will enable customized patterns to be written that blend high write-speed with a resolution limit of 0.3 µm. The new direct-write system will replace the capabilities lost with the departure of our Canon stepper (sold in 2023), while providing new capabilities for direct-write of SU-8 patterns and high-resolution grayscale (3D lithography) patterns. This system is scheduled for installation in January 2025.

The MNC was awarded internal funding to acquire a new state-of-the-art nanoparticle analyzer. We selected the Particle Metrix *Zetaview* PMX-230 nanoparticle tracking analyzer, which determines particle size distribution and concentration based on the diffusion behavior of small particles dispersed in a fluid. The system was installed in September 2024 and is in high demand among users working with extracellular vesicles and other nanoparticles of biological interest.

Tool Updates: CharFac

We have upgraded a Leica UC7 microtome for improved section collection with a *Diatome* micromanipulator. Under the original system, users could lose 50% of sections on average. With the *Diatome* micromanipulator upgrade, even ribbons of cryo-sectioned material can be collected with confidence and ease. In addition, our Woollam VASE ellipsometer was upgraded to enable measurements of complex refractive index on operating devices, which require small spot sizes to probe between contacts. The upgrade extends the wavelength range of the instrument by more than double, to 2500 nm.

Major internal funding was competitively awarded for four new systems:

Keyence VK-X3050 3D Laser Scanning Microscope: This is an optical profilometer with three different scanning methods: laser confocal, focus variation and white light interferometry. It allows users to select the best scanning method for the target material, shape and measurement range (nm's to cm's) and will be customized to handle large/heavy samples many cm's in size.

Horiba LabRAM Soleil spectromicroscope: This system is a high-grade research Nikon optical open microscope with 5x, 50x and 100x objectives and spatial resolution approaching the diffraction limit. It includes an integrated imaging spectrometer in the NUV-Vis-NIR spectral range with two gratings to cover the full spectral range as well as a narrower, higher resolution spectral region. It includes a fully automated high precision x-y sample stage. LabSpec 6 software for instrument control, data acquisition and analysis.

ThermoFisher Glacios 2 cryo TEM: This system used to analyze biological samples includes a 200-kV FEG-TEM with Ceta-D bottom-mounted camera and CompuStage. It also features an autoloader, fringe-free imaging, EPU and Velox software plus scripting, MicroED, and Tomography DAQ software. The anticipated installation is early 2025.

ThermoFisher Aquilos 2 cryo FIB: This dual-beam cryo-FIB with xT Software, AutoTEM Cryo, NICol Electron Column, High-throughput ion column, CCD IR Camera, in-chamber Nav-Cam, lower and upper in-lens detectors, SE detector (ET-SED), and integrated current measurement, will support sample preparation for the new cryo TEM. The anticipated installation is also early 2025.

New MNC and CharFac Staff

Funding was committed by two UMN Medical School departments (encompassing biochemistry, molecular biology, biophysics and pharmacology) to staff the new cryo-EM systems in the CharFac with a dedicated Ph.D. expert. Final candidates have visited, and a hiring decision will be made within days of this writing.

In addition, the MNC hired Paul Mikkelson as a laboratory maintenance engineer after the departure of Robert Amundson. Paul joined from ASML and has extensive experience in lithography systems maintenance and repair. He will help with the installation and bring up of the Raith *Picomaster* DWL system. Paul is also responsible for maintenance of the new Finetech die bonder system.

User Base

User Recruitment and Outreach

During this reporting period, MiNIC continued its successful user incentive program, *Explore Nano*, which seeks to recruit new users and/or those returning after an absence of over two years. The program offers a $2000 credit against fees for lab and tool use and training. During the current reporting period, MiNIC received nine applications for the *Explore Nano* program by researchers from industry and/or external academic institutions. We awarded six grants before funds were exhausted. At least two previous E*xplore Nano* awardees have continued their work in MiNIC facilities beyond their award. Other outreach efforts by MiNIC staff during this reporting period include: exhibits at the Medical Devices and Materials (MD&M) conference in Minneapolis (Oct. 2023); exhibits at the 2024 Design of Medical Devices conference connecting MiNIC capabilities to local and national companies working with medical devices and pharmaceuticals (April 2024);

a two-day X-ray scattering laboratory workshop with internal and invited talks from users and scientists (Oct. 2023); a hybrid workshop with eight speakers as part of the mid-year meeting of the Industrial Partnership for Research in Interfacial and Materials Engineering (IPRIME) (Jan. 2024); continued outreach efforts using our LinkedIn pages and newly redesigned newsletter.

Research Highlights and Impact

Below are brief summaries of some of the notable research projects performed at MiNIC during the past year. More details and figures are found in the accompanying highlight slides.

Zero-Dimensional Valley-Chiral Modes in a Graphene Point Junction. (Davydov, et al., *Sci. Adv.* 2024) Ke Wang's group at UMN used the MNC to fabricate a graphene point junction device in which valley-polarized current can been realized at the boundary between two regions of bilayer graphene. This work demonstrated that a valley-chiral zero-dimensional (0D) PN junction can be configured to be capable of carrying electrical current with an estimated valley polarization of ~80%. This work provides a building block in manipulating valley quantum numbers for scalable "valleytronics". ***Quantum Leap.***

Using Machine Learning to Overcome Interfering Species Interactions in Graphene Sensors. (Capman, et al., *ACS Appl. Mater. & Interfac.* 2024). The Koester group at UMN fabricated graphene sensors in the MNC to detect volatile organic compounds (VOCs). Graphene sensors are notoriously sensitive to oxygen, so they developed machine learning algorithms to distinguish different VOCs in the presence of various interfering concentrations of oxygen. These results are important for practical applications of graphene sensors for detection of diseases in breath such as lung cancer. ***Rules of Life.***

Enhanced Detection of Sickle Cell Disease Using Microfluidics. (Williams, et al., *PNAS* 2023) David Wood's group at UMN fabricated microfluidic devices at the MNC to study the misshapen and stiffened red blood cells (RBCs) that cause sickle cell disease. The microfluidic platform simultaneously measured single-cell deformability and oxygen saturation under physiologically relevant oxygen environments. They found that RBCs with detectable amounts of polymerized fibers had decreased oxygen affinity and decreased deformability, and that the fraction of polymer-containing RBCs increases as oxygen decreases. This work could be important for understanding the pathophysiology of sickle cell disease and provides clearer targets for evaluating therapies. ***Rules of Life.***

Improved Oxygen Barriers using Polyethylene Microstructures. (Kim, et al., *ACS Appl Polymer Mater.* 2023) In this **collaboration between CharFac staff, the Macosko group at UMN, and Los Alamos National Lab (LANL)**, researchers explored blending high-density polyethylene (HDPE) into linear low-density polyethylene (LLDPE) to improve oxygen barrier performance of packaging materials without using ethylene-vinyl alcohol (EVOH) additives. Photothermal AFM-IR analysis provides stark images of spherulitic crystalline morphologies in both pure HDPE and blended LLDPE/HDPE (80/20%), but they are essentially absent in pure LLDPE. The work shows the role of processing in controlling microstructure and the benefits of photothermal imaging for advanced materials analysis.

Magnetic Tunnel Junction-Based Computational Random-Access Memory. (Lv, et al., *npj Unconv. Comp.* 2024) Research led by Prof. Jian-Ping Wang at **UMN, in collaboration with the University of Arizona**, investigated "computational random-access memory (CRAM)," which addresses the fundamental limitation of data transfer between logic and memory. A new CRAM platform based upon magnetic tunnel junctions (MTJs) was demonstrated. The basic logic and memory operations were shown, and a suite of models was developed to characterize functions such as matrix multiplication. This work forms the basis for using CRAM to realize highly power efficient AI applications.

Gate-tunable superconducting diode effect in a three-terminal Josephson device. (Gupta et al., *Nat. Commun.* 2023) Researchers from the **UMN, UC-Santa Barbara, and Stanford University** used the MNC cleanrooms to fabricate a three-terminal Josephson device based on an InAs quantum well two-dimensional electron gas, proximitized by an epitaxial aluminum superconducting layer. The research team demonstrated that the diode efficiency in such a device can be tuned by a small out-of-plane magnetic field or by electrostatic gating. The work points the way to establishing a scalable approach to realize potential applications of the Josephson diode effect, among which is using Josephson as gate-tunable building blocks in designing topologically protected qubits for quantum computing.

Education and Outreach Activities

Microfabrication Technology Short Course

Responding to the training needs of local semiconductor companies, MiNIC has developed a short course to train new and incumbent workers on the basics of microfabrication technology. The *Microfabrication Technology Short Course* (MTSC) offers ten self-paced online modules complemented by several weeks of hands-on training on the tools of microfabrication at the MNC. Staff of several prominent manufacturers have taken the training course, including Polar Semiconductor, Honeywell Aerospace, Collins Aerospace, Seagate, and Medtronic. The enrolled employees began the online MTSC content on December 1, 2023; hands-on training sessions began January 20, 2024, and were completed on April 11, 2024. A second cohort of staff members began work on the course in September 2024.

Research Experience for Teachers (RET) Program

During the reporting period, MiNIC completed the final year of its Research Experience for Teachers (RET) program. Six science teachers (our largest group ever) were recruited from a mix of urban and suburban high schools in the Twin Cities metro area. The teachers were paired with six University of Minnesota faculty research groups, where they were immersed in cutting edge academic research. They also developed classroom activities on some aspects of nanoscience and technology for their own classes. These activities have been written up and after some editing will join the educational resources available via the NNCI website. The RET program was professionally evaluated by Dr. Mary White of ASU, and Dr. White’s report for the 2023-24 cohort is available to the NNCI Coordinating Office.

Lab Internship Program

During the current reporting period, MiNIC continued to host its popular laboratory internship program, which offers students from two-year community and technical colleges the chance to work in a nanoscience lab. During the spring of 2024, MiNIC staff supported four students from St. Paul Community and Technical College, whose research projects explored size-controlled synthesis of CdS quantum dot nanoparticles and synthesizing biocidal silver nanoparticles using green chemistries.

Facility Tours and Classes

MiNIC continued to offer a variety of K-12 education offerings during the current reporting period, providing regular introductions to microelectronics and full cleanroom tours for visiting student groups. Over the past year the MNC collaborated with the Northstar STEM Alliance and the Minnesota Academy of Science to provide several programs; both groups are actively working to reach students from groups underrepresented in the professional ranks of STEM. A total of 783 K-12 students and teachers were reached by our outreach effort during the reporting period.

Quantum+Chips Program

In the summer of 2024, MiNIC hosted the "Quantum+Chips" program, designed to introduce early undergraduate students to key topics in quantum phenomena and computing devices. This 2-week summer school was crafted for undergraduate students to immerse them in the physics and technology of cutting-edge computing technologies, spanning quantum computing, spintronics, and semiconductor chips. This year, 48 exceptionally bright undergraduate students joined the program, both from Kyung-Hee University in Korea as well as several US universities. The program offered lectures, computer labs, experimental lab demos, company visits, and talks by industry and academia experts on the frontiers of quantum computing devices and technologies.

Minnesota SCALE Program

In the summer of 2024, UMN marked the launch of the initial Minnesota Scalable Asymmetric Lifecycle Engagement (SCALE) program. SCALE is a network of universities brought together to meet the semiconductor workforce needs of the defense sector. Led by Purdue University, and administered through the Naval Surface Warfare Center Crane Division, SCALE provides coursework, internships, and focused research projects for both graduate and undergraduate students aimed at targeted microelectronics specialty areas. The new program brings together, Metro State University, University of St. Thomas, and UMN in this initial pilot program.

The program is broader Upper Midwest Microelectronics Consortium, which would renew micro-electronics leadership in Minnesota and the entire Upper Midwest region in areas such as high voltage and radiation-hardened chips. As part of this program, MNC trained several students from the University of St. Thomas as part of a broader effort to enhance semiconductor workforce training. At a kickoff meeting in June 2024, congresswoman Betty McCollum told the assembled audience of business and academic leaders that she would continue to advocate strongly for funding for SCALE in her leadership role on the House Appropriations Defense Subcommittee.

Innovation and Entrepreneurship Activities

MiNIC supported the R&D efforts of over two dozen small companies during the reporting period, including Grip Molecular Technologies and Zeptofile, two UMN biotech startups. Below, we highlight two innovative startups using MiNIC who we have not highlighted previously.

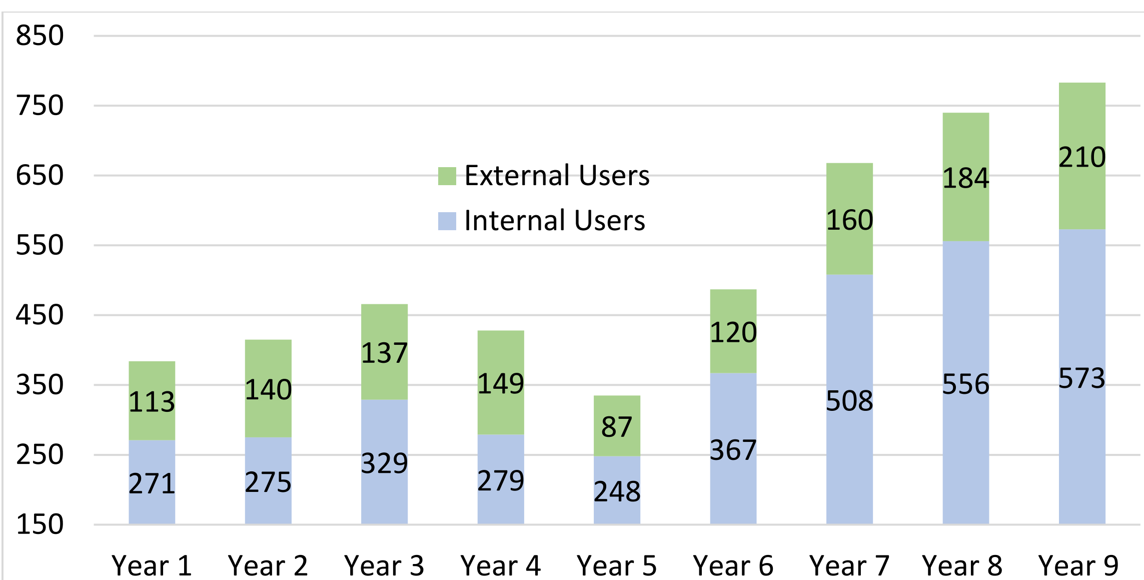
Resource Electromembrane LLC seeks to develop separation membrane technology for water, environmental, chemical, and energy applications, employing a unique carbon nanotube-based design. These advanced electromembranes promise improved performance in water desalinization, electrodialysis, and waste brine recovery. The entrepreneur founder of the company has used our Nanomaterials lab for nanotube synthesis, processing, and characterization.

Utopia Borealis is working to develop new consumer products in the health and nutrition space. Its first product is an electrolyte beverage with only three locally sourced ingredients. Utopia

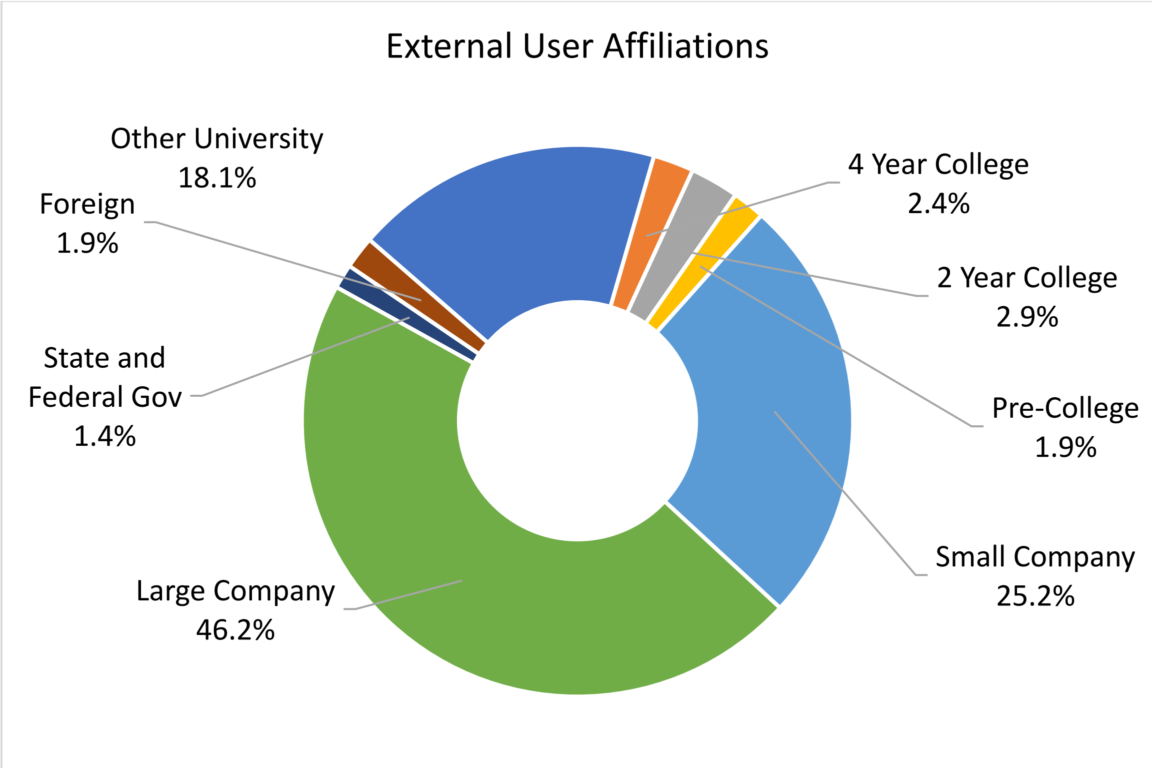
Borealis' founder has employed the MNC nanobio labs for small batch emulsification tests and for product stability characterization.

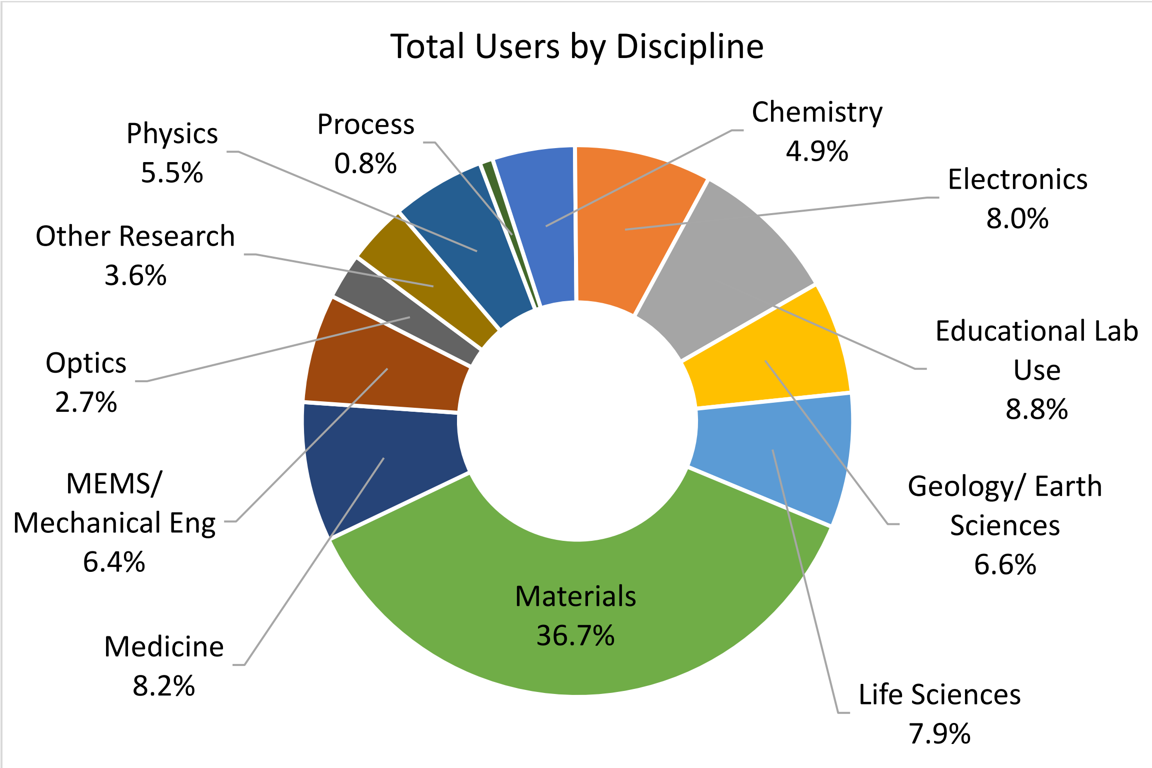
MiNIC Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	384	415	466	428	335	487	688	740	783
Internal Cumulative Users	271	275	329	279	248	367	508	556	573
External Cumulative Users	113 (29%)	140 (34%)	137 (29%)	149 (35%)	87 (26%)	120 (25%)	160 (24%)	184 (25%)	210 (27%)
Total Hours	27,002	26,443	26,851	27,782	17,682	27,317	31,916	32,707	34,358
Internal Hours	20,495	19,733	21,324	17,780	11,491	21,303	27,384	26,540	28,584
External Hours	6,507 (24%)	6,710 (25%)	5,527 (21%)	10,002 (36%)	6,191 (35%)	6,014 (22%)	4,532 (14%)	6,167 (19%)	5,774 (17%)
Average Monthly Users	156	156	161	161	116	165	235	254	277
Average External Monthly Users	26 (17%)	33 (21%)	30 (18%)	37 (23%)	27 (23%)	31 (19%)	36 (15%)	38 (15%)	46 (17%)
New Users Trained	151	150	189	136	101	213	280	298	313
New External Users Trained	57 (38%)	59 (39%)	48 (25%)	45 (33%)	17 (17%)	39 (18%)	87 (31%)	118 (40%)	137 (44%)
Hours/User (Internal)	76	72	65	64	46	58	54	48	50
Hours/User (External)	58	48	40	67	71	50	28	34	27



MiNIC Year 9 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 Facility, cryo-EM facility; Partner site Science Education Resource Center (SERC) at Carleton College. Some facilities within the NSF MonArk Quantum Foundry are now available to MONT users.

Facility, Tools, and Staff Updates

MONT facilities saw multi-million-dollar investments in Y6-Y8 with the addition of about $9.4M in new instrumentation. Y9 has been more modest with about $60k in new equipment placed in MMF. Facility investment continues with new tools purchased or in the pipeline.

ICAL staff created quantitative standards-based analysis for our Oxford EDS system on the FE-SEMs. This allows quantitative EDS analysis for several common phase types found in natural rocks, such as olivine, feldspars, garnets, micas, etc.

The MMF was an integral part of the application for the for a Headwaters Technology Hub grant through the U.S. Economic Development Administration. The Tech Hub Phase II application was submitted in February 2024 and was announced in November of 2024. The MMF is part of the Integrated Photonic Ecosystem component project, and we have budgeted ~$2.1M in equipment. MMF's equipment list includes a flip chip bonder, an automated wire bonder, a dual-six axis fiber and fiber array alignment and test system, polishers, a vacuum reflow oven, a scanning confocal microscope, a wafer and chip scale automated photonic test system, and a vector network analyzer.

The MMF also purchased a new RAITH Voyager electron beam lithography tool in June of 2024 for ~$1.6M, which we expect to install sometime in 2025. This was purchased with funds from the Quantum Core (funded by USAFRL). The Quantum Core selected the MMF to install and operate the equipment to generally maximize usage and impact. MMF also installed a $60k thermal evaporator through the university's Equipment Fee Allocation Committee.

Upcoming RAITH Voyager ebeam lithography tool will automate and streamline work in the fab facility. (RAITH stock image)

In staffing updates, co-PI Dave Mogk has retired from his duties in ICAL. ICAL is conducting a search for a new staff scientist/engineer. The cryo-EM facility has hired a facility manager. Dr. Ravindra Thakkar. Dr. Thakkar was most recently the assistant cryo-EM manager at UC Berkeley. He received his Ph.D. from the University of Kansas.

User Base

We are pleased that the Y9 user count has again reached an all-time high. MONT served 264 users, which is an increase from the Y8 user count of 250 users. MONT served 63 external users who are 24% of user base and account for 31% of usage hours.

MONT awarded 8 **user grants to seed new projects** in Y9.

Four internal user grants were awarded to:

- Zeynep Malkoc, Doctoral student, Separation Behavior of Superparamagnetic Micro-beads by Evaluating Inertial Microfluidic Devices
- Dr. Yang Cao, Fabricating Microfluidic Chips for Magnetic Microrobots Testing
- Dr. James Crawford, Catalyst Characterization for Renewable Energy Applications
- Travis van Leeuwen, Doctoral student, Reactive Condensation of Cr Vapors on Aluminosilicate Surfaces

Four external user grants were awarded to:

- Spencer Dahl, Aesir Technologies, NiZn Battery Active Material Optimization
- Robert Haushalter, Lawrence Berkeley National Lab, Chip Fabrication for PKS Mutant Screening
- Giorgia Ghiara, Polytechnic University of Turin, Italy, Investigation of Bacteria Electroactive Properties
- COLDEX Group, Oregon State Univ, Univ of Washington, & Princeton, Characterization of the World's Oldest Ice

Northwest Nano Lab Alliance (NWNLA) MONT and NNI Collaboration. Since its first meeting in 2021, the NWNLA has been successful in bringing together regional facility staff from academia and industry throughout the Northwest including, Idaho, Montana, Oregon, Washington, Wyoming, Alberta and British Columbia to join NWNLA. In addition to facilitating transfer of information and collaboration between sites, NWNLA holds regional meetings for our facility staff during the off years of the University Government Industry Micro/Nanotechnology Symposium (UGIM), which is the prime international conference for nanotech facility staff and which occurs in an alternate year cadence.

Map of participating NWNLA institutions.

MONT has added a new initiative to our strategic plan centered on Workforce Development programs and student opportunities with a particular focus on regional employers.

MONT rapidly became an active participant in **Micron's Northwest University Semiconductor Network. MONT received a $10k grant from Micron** through this new network. We are developing a weeklong solar cell course for undergraduates and community college students. We have implemented a **three-session course, Intro to Microfab**, with the Gallatin College Photonics Program. We are working to coordinate more courses within Gallatin College focused on workforce development.

MONT is working to increase the student workforce. **The MMF now employs 17 undergraduate students**, primarily supported by user fees and some funding from Micron. These students help with all levels of lab work, ranging from simple tasks like cleaning, purchasing, and stocking, to complex tasks like user training, documentation, and project work for remote customers. Student training focuses on both technical and professional development.

Research Highlights & Impact

Scholarly impact: During 2023, MONT researchers produced 48 journal papers and 46 other products.

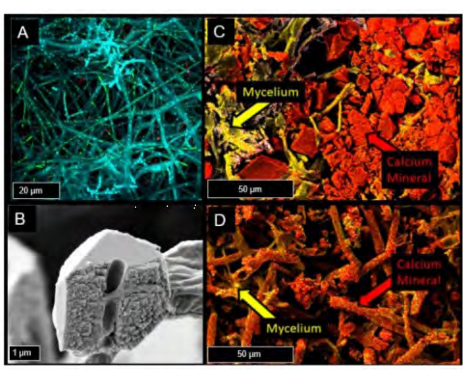
MONT users had several outstanding accomplishments during the reporting period.

MONT Users Work Featured in AAAS Science Advances Cover Illustration. The work of Cryo-EM and TEM facility users Artem Nemudryi and Anna Nemudraia is illustrated on the cover of the September 2023 issue of Science Advances. The post docs are lead authors on the paper "CRISPR-based engineering of RNA viruses," which highlights using CRISPR to precisely cleave and repair RNA without converting the RNA to DNA and back to RNA. A patent application for this new technology has been submitted. Nemudryi also received an NIH National Institute of Allergy and Infectious Diseases **Pathway to Independence**, or K99/R00 for $750,000.

MONT researchers Chelsea Heveran, Lewis Cox and graduate student Ghazal Vahidi in ICAL.

Dr. Chelsea Heveran, **Department of Mechanical and Industrial Engineering,** received **an NSF CAREER** award for a project called, "Osteocyte Regulation of Bone Tissue Fracture Resistance." The project goal is to advance fundamental knowledge about how osteocytes manage, heal and help repair bone tissue, and for improving diagnostics and therapies for bone fractures. Osteocyte bone cells directly resorb and deposit local bone in a process called perilacunar remodeling, but the process is not well understood. Advances in osteocyte understanding may lead to new drugs and therapies to improve bone fracture resistance. **Heveran was the recipient of MONT User Grant that helped kick-start this line of inquiry in 2019.**

MONT co-PI Avci and MONT Users Awarded $3M NSF Grant: **Manufacturing, repairing, and re-using biomineralized infrastructure materials through low-energy biological processes** This Future EcoManufacturing research grant (FMRG: Eco) project envisions more sustainable, eco-manufacturing of building materials through leveraging the natural metabolic activities of microorganisms. The manufacturing of building and infrastructure materials currently heavily relies on cement and concrete with large resource needs and limited re-use and recycling of cement and concrete. The specific goal is to improve the ability to make complex, load-bearing structures



Biomineralization of fungal scaffolds figure from proposal.

through microbial biomineralization. The successful completion of this project will benefit society through the generation of fundamental knowledge about the control of microbes to build, assemble, repair, and reuse or recycle building materials.

MONT continues to impact regional companies. During Y9, MONT served the needs of 23 external companies (44 individual users from 9 large and 14 small entities). Notable successes for our industrial users include 10 new SBIR/STTR Awards granted in 2023, totaling over $30M.

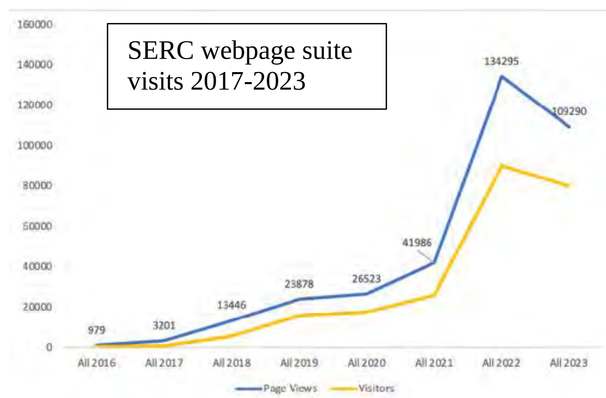
Education and Outreach Activities

We continue to bolster our suite of websites called Teaching Nanoscience, in partnership with Science Education Resource Center (SERC) at Carlton College. During this period, we have added modules on:

- Parallel Beam X-ray Optics: Grazing Incident X-ray Diffraction (GIXRD) and X-ray Reflectivity (XRR)
- Preparing For a Career in Nanoscience in the Earth and Environmental Sciences: A Guide for Students and Their Mentors
- National Nanotechnology Programs--Educational Resources.

Use of the SERC website has seen a marked increase since 2017. Overall, up to the end of 2023, the site had **236,050 engaged visitors and 353,598 intensive page views.** https://serc.carleton.edu/msu_nanotech/index.html

MMF students created an official MSU student group called **NanoCats**. The goal is to bring together students who share a passion for the fields of nanotechnology and microfabrication. The students are passionate about related industries and are serving as campus ambassadors, are engaged with local and regional industry, as well as MONT outreach activities. This student group is well-organized and has dynamic leadership. The NanoCat students have brought enthusiasm and fresh ideas to MONT's outreach activities.



We have been working with the **Salish Kootenai College (SKC)** high school Upward Bound program to incorporate nanoscience/technology education on the Flathead Reservation in northwestern Montana. For the second year, SKC brought 35 students for a three-day nano camp with MONT. This year, the Upward Bound summer program, based at the University of Montana (Missoula, MT), also attended the camp. This group included an additional 35 high school students from the **Blackfeet Nation** and surrounding area. The visit included a day in Yellowstone National Park, making connections with the natural world and nanoscience. The 70 students spent another two days on campus in MONT facilities. They were able to make silver nanoparticles then look at their particles in the SEM. The students engaged with MONT student users, PIs, and staff in several departments. We were also able to show the students other aspects of campus life, spending some time at the new MSU American Indian Hall and learning about support and resources for Native students.

The **MONT Empower Scholars program** awarded four scholarships to place underrepresented undergraduate students with MONT researchers for a research experience and tool training. Projects ranged from food science to bacteria research.

We trained 10 students from different MSU REU programs in our facilities and 4 of the students participated in the **NNCI REU Convocation**.

MONT sponsored and helped to organize MSU Science Day for 170 5th graders. The event features NanoLand where students are "shrunk to 5 nanometers" and perceive how they would interact with everyday objects that represent a virus, bacteria, atom or other particle at the nanoscale. MONT PIs also have interactive displays on their research involving nanoscience and nanotechnology.

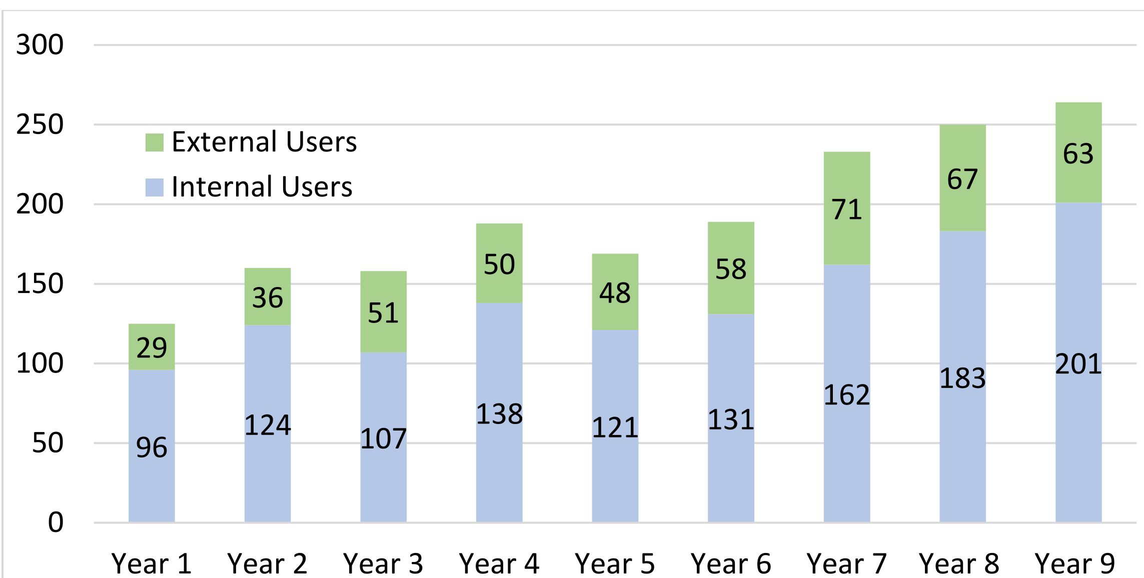
MONT also participated in several additional MSU outreach events including STEAM Day, a 2-day camp for middle school girls, MSU Shadow Day in which high school students shadow an undergrad, several lab tours for school groups (8th - community college), and other events.

Teacher support includes our Solar Cells for Teachers course with 4 students this year; MONT PIs hosted 8 RET teachers who worked in MONT facilities, MONT sponsored 4 Montana teachers for nano@stanford's Nanoscience Institute for Middle School Teachers (NanoSIMST) virtual course. Additionally, MONT sponsored and participated in two Intro to Quantum workshops for Montana science teachers with 20 attendees.

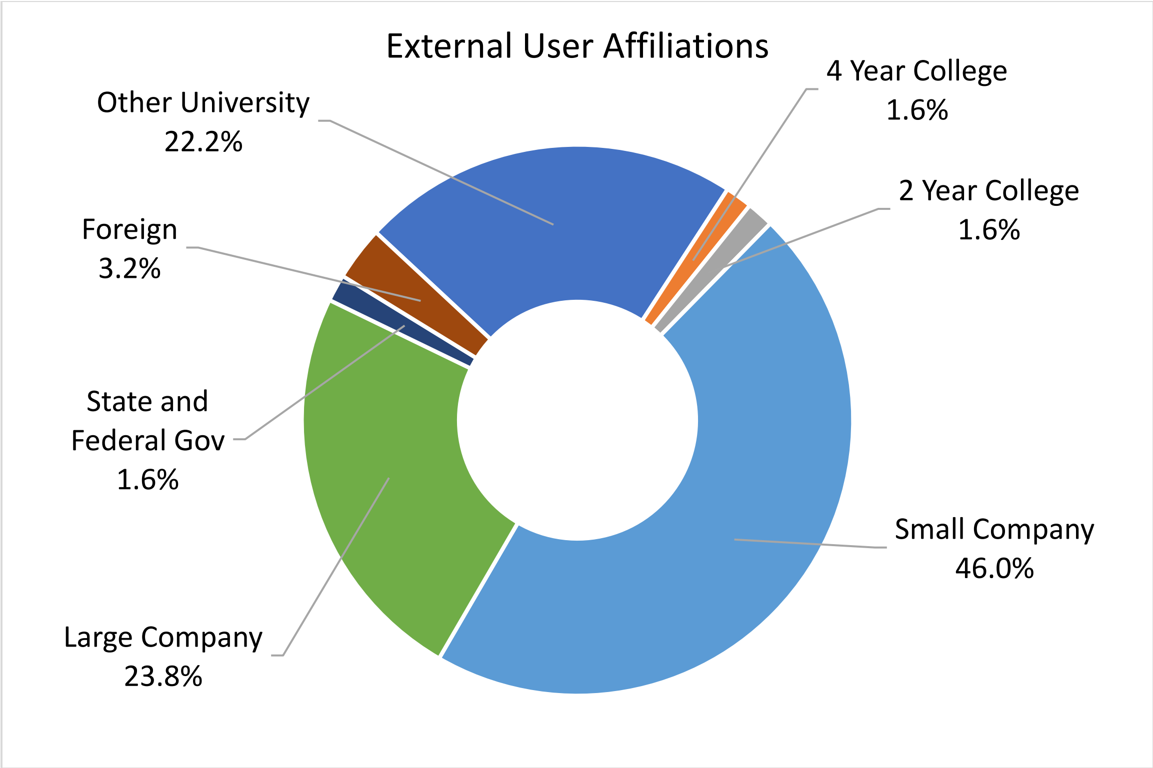
RET students in the clean room.

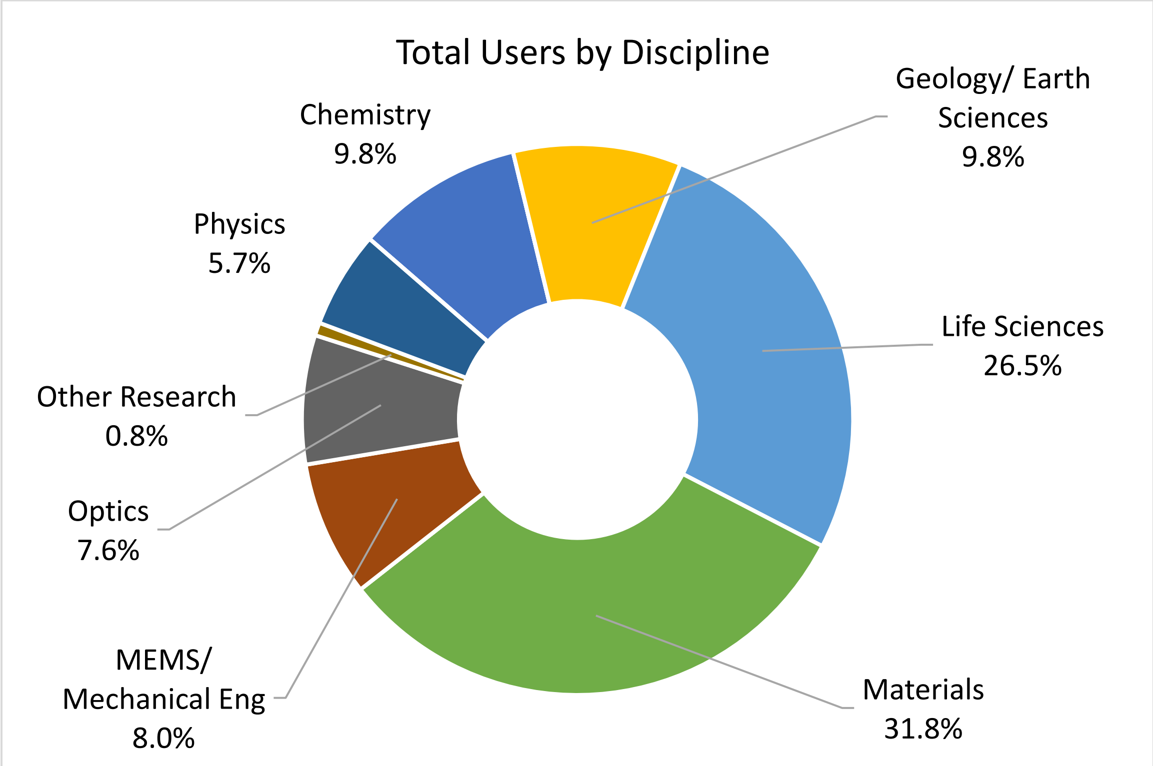
MONT Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	125	160	158	188	169	189	233	250	264
Internal Cumulative Users	96	124	107	138	121	131	162	183	201
External Cumulative Users	29 (23%)	36 (23%)	51 (32%)	50 (27%)	48 (28%)	58 (31%)	71 (30%)	67 (27%)	63 (24%)
Total Hours	3,599	4,713	5,420	6,398	4,858	7,735	9,142	9,548	9,387
Internal Hours	2,842	3,901	4,541	5,332	3,395	6,550	7,512	7,881	7,173
External Hours	747 (21%)	812 (17%)	879 (16%)	1,066 (17%)	1,463 (30%)	1,185 (15%)	1,630 (18%)	1,667 (17%)	2,214 (24%)
Average Monthly Users	46	51	43	62	48	57	75	68	79
Average External Monthly Users	8 (17%)	10 (20%)	7 (17%)	10 (16%)	9 (19%)	13 (23%)	17 (22%)	14 (20%)	16 (20%)
New Users Trained	36	58	58	76	70	86	86	87	124
New External Users Trained	1 (3%)	9 (16%)	8 (14%)	6 (8%)	7 (10%)	20 (23%)	17 (20%)	8 (9%)	34 (27%)
Hours/User (Internal)	30	31	42	39	28	50	46	43	36
Hours/User (External)	26	23	17	21	30	20	23	25	35



MONT Year 9 User Distribution





12.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

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

During Year 9, ASU led a proposal to the National Security Technology Accelerator (NSTXL) that resulted in the establishment of the Southwest Advanced Prototyping (SWAP) Hub within the DoD Microelectronics Commons. The first round of funding will be used for significant infrastructure investments within the NCI-SW Advanced Electronics and Photonics (AEP) core facility. While the SWAP Hub consortium is not an open network like the NNCI, NCI-SW users will have access to the new tools within the AEP core facility, some of which are described below.

New Tools and Capabilities: Several new tools have been installed in the AEP core. These include an Ecopia Hall effect system for measuring the transport properties of metals and semiconductors. The instrument can measure over a wide temperature range up to 500° C which will be useful for our growing number of users who work with wide bandgap and ultrawide bandgap semiconductors such as diamond, boron nitride and gallium oxide.

The Ecopia Hall effect measurement system will allow measurements of free carrier concentration, mobility and sheet resistance over a temperature range 80K to 773K.

A FormFactor probe station for on-wafer RF probing up to 110 GHz on 300 mm wafers has been commissioned in the AEP core along with the corresponding instrumentation from Keysight. The probe station is equipped with a variable temperature chuck along with motorized micro-manipulators that facilitate automated measurements for e.g. SPICE model parameter extraction.

The CM300 semi-automated probe station from FormFactor allows on-wafer probing of samples ranging in size from small pieces to 300 mm diameter wafers, from DC to 110 GHz.

With support from Applied Materials (AMAT), ASU is acquiring a suite of 300 mm processing tools that are designed for state-of-the-art CMOS manufacturing. While these acquisitions may seem counter-intuitive for a multi-user R&D facility, the 300 mm tools can often be used for ‘coupons’ containing smaller diameter wafers or even wafer pieces. And they offer precise control of processing steps that is not possible on earlier 8” systems. The first of the AMAT tools to be made available to NCI-SW users is a Centura AP reactive ion etch tool, a cluster etch system with two process chambers.

New Staff: To accommodate the anticipated new users of the AEP core facility, ASU has hired two new staff members located at the AEP facility in the ASU science park. One of the positions is at a senior level to assist users with the design of experiments for RF characterization using the new 110GHZ probe station, while the other will be an entry level position to assist with cleanroom processing. While a fraction of both salaries will initially be supported by the SWAP Hub funding, they will quickly transition to a cost-recovery model in which the salaries are recovered from user fees, as is the typical NNCI model applied at ASU.

User Base

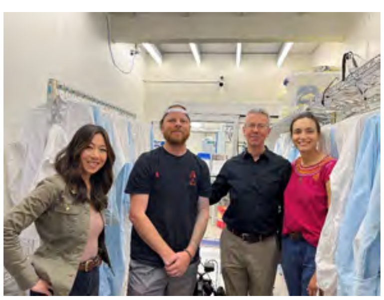
Our focus for user growth has always been external academic users and small business users, followed by large business users. The user numbers have bounced back since the pandemic and the Year 9 cumulative user totals (>1100) and revenue (>$3.3M) are on track to break previous records. In Year 9 we supported users from 35 US universities, 57 small businesses, 16 large businesses, and 7 overseas labs. A significant number of users come from the geological, astronomical, health science, and environmental science communities.

The Eyring Materials Center core facility regularly hosts an annual high resolution electron microscopy winter school. The winter school combines theoretical classes with hands-on sessions for scientists and engineers familiar with transmission electron microscopy but who need more advanced training. The workshops serve as a useful recruitment and outreach tool to attract users of the NCI-SW Eyring Materials Center. For Year 9 the Winter School was held January 8-12, 2024. The total attendance was 31, with the majority of participants being graduate students and postdoctoral scholars. There were four participants from National Labs, and four more from abroad.

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 ¡MIRA! Center at Northern Arizona University brings expertise and infrastructure related to materials science and quantum information. Examples of our users' research projects are summarized elsewhere in this annual report.

REU participant and current NanoFab inter Sierra Monreal presents her research to Senator Mark Kelly.



PBS Newshour anchor Stephanie Sy prepares to film in the ASU NanoFab accompanied by her producer and videographer.

During Year 9 the NCI-SW supported user projects that were published in Nature, IEEE Transactions, Applied Physics Letters, and ACS Nano, with 25 archival publications and presentations from external users and more than 80 from internal users in 2023. Our REU students and interns presented their results to Senator Mark Kelly. Mesa Community College electrical engineering student Darian Rosales represented NCI-SW at the 2023 SACNAS National Diversity in STEM conference held October 26-28 in Portland, Oregon. His research poster on linear carbon chain synthesis methods was recognized. Darian also presented his research poster at the NNI 20th anniversary celebration symposium in Washington DC on March 5, 2024

The NCI-SW contributes to economic impact and workforce development in the regional southwest through multiple training programs. These efforts were recognized in an episode of the PBS NewsHour that aired on June 11, 2024.

Education and Outreach Activities

Broadening Participation in STEM: ASU's Center for Broadening Participation in STEM (CBP-STEM) complements the NCI-SW outreach approach by offering comprehensive support services. These services aim to ensure that K-14 students have access to a welcoming and secure environment for exploring Science, Technology, Engineering & Math (STEM) disciplines. In Year 9, CBP-STEM organized participation in the Native American Men conference at South Mountain Community College. This session focused on the collaborative efforts of Arizona's three research universities ASU, NAU, and the University of Arizona to enhance access to nanotechnology engineering education and employment possibilities inclusive of all Arizona students.

Given the substantial investment of over $50 billion in the U.S. semiconductor ecosystem through the 2022 CHIPS and Science Act, CBP-STEM shifted focus in Year 9 to potential areas for NSF investment in semiconductor education and workforce development. In November 2023, Anna Tanguma-Gallegos (ASU) joined Micronano Technology Education Center partners in Washington D.C., to collaborate and author an NSF report: Semiconductor Education & Workforce Development Convening.

In collaboration with Rio Salado College (RSC), part of the Maricopa County Community College District (MCCCD), the NCI-SW hosts an advanced laboratory curriculum on ASU's Tempe campus for students enrolled in RSC's two-year, 62-credit AAS degree in Nanotechnology which contains an 18-credit Certificate of Completion. Year 9 enrollment remains steady, with 25 in-person labs conducted for 17 RSC students.

Designed specifically for veterans, the 12-week Microelectronics and Nanomanufacturing Certificate (MNC) Program follows a blended model of instruction. In collaboration with Penn State's Center for Nanotechnology Education and Utilization (CNEU) faculty, the program hosts daily, 4-hour live-streamed lectures from CNEU staff, and twice-weekly, half-day, hands-on-site training in the ASU cleanroom and nanotechnology lab environments. This program is free to participants. The first cohort began in 2023 and has since graduated more than 20 students.

RSC also graduated their first cohort of students enrolled in the Integrated Education and Training (IET) program, a combination of education and job skills training for adult education students enrolled in Rio Salado College's GED® Test prep or English as a Second Language (ESL) classes. IET aims to train students for nanotechnology technician roles and address local workforce needs through an 11-credit Certificate of Completion in Nanotechnology (Introduction to Semiconductor Manufacturing). The program includes 4 courses with live-online instruction and hands-on-site training in the ASU cleanroom environment.

Research Experiences for Undergraduates (REU): In partnership with Dr. Inès Montaño and Dr. Gabriel Montaño of the Northern Arizona University ¡MIRA! Research Center, NCI-SW hosted six undergraduate students for the summer 2024 REU program. Students were paired with research mentors at their home institutions while also meeting with NCI-SW PI and co-PIs. NCI-SW Education Outreach Coordinator Jessica Hauer (ASU) scheduled weekly team meetings via Zoom to ensure REU participants had productive experiences and were ready to present at the summer-ending Convocation.

Public Events: NCI-SW strengthened its partnerships and collective works in Year 9 with a robust campaign of outreach initiatives and events that prioritized expanding opportunities for marginalized and minoritized communities of Arizona and the Southwest. NCI-SW outreach teams at Arizona State University and Northern Arizona University have built a southwest-region-wide reputation for creative and committed efforts toward changing the future face of STEM, particularly in quantum and nanotechnologies. Our deliberate approach includes programming efforts that generate opportunities to reach the community during public, non-STEM events such as parades, antique car shows, and cultural events. This last year, special attention has been paid to informing the public of workforce development opportunities that support Arizona and national economies in semiconductor manufacturing.

An attendee at the Navajo Nation STEM Camp with the Girl Scouts at Diné College, Tsaile, AZ, October 2023.

Notable community events in Year 9 include: Indigenous Peoples' Day Phoenix Fest; City of Flagstaff 4th of July Parade; SciTech Institute "Innovation Summit"; ASU "Open Door"; City of Tempe's "Geeks Night Out"; Barrett-Jackson & SciTech Institute STEM FEST "Gearing Towards the Future"; and the Navajo Nation STEM Camp with the Girls Scouts

K-14 School Events and Teacher Professional Development: In Year 9 the NCI-SW expanded the in-person K-14 impact, reaching over 2,500 students. Hands-on activities included the use of an optical microscope to view patterned silicon wafers, real-time remote access to a scanning electron microscope to image samples with micro- and nanoscale features, as well as demos such as illustrating the use of nanotechnology in paper money and stain resistant fabric. The NCI-SW presented to middle and high school teachers during the Arizona Science Center Educate to Innovate Teacher Conference. And we supported the participation of four middle school teachers in the NanoSIMST virtual workshop with NNCI host nano@Standford.

The NCI-SW provides support for the Cartwright School District (Cartwright). Cartwright serves 21 schools in grades PreK-8 in the historic Maryvale community west of Phoenix. There are approximately 13,877 students in the district, with 89.2 % identifying as Hispanic, 5.8 % Black, 2.7 % White, 1 % Native American, 0.8 % multi-racial, 0.4 % Asian, and 0.1 % Pacific Islander. NCI-SW brought together SciTech's Chief Science Officers Program and Cartwright School District to strive to impact the schools' local network of STEM ecosystems. Approximately 25 middle school scholars are training to become Chief Science officers. They will collaborate with the NCI-SW to build their understanding of nano and quantum science principles and career pathways. For this work, Cartwright School District was recognized by YWCA with an Equity in STEAM award.

Societal and Ethical Implications Activities

Dr. Jameson Wetmore leads the NCI-SW SEI User facility with support from NNCI funded RA Toby Shulruff. 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. Dr. Wetmore also leads SEI activities across the NNCI as one of two non-Georgia Tech members of the NNCI Coordinating Office, which includes an annual Winter School in Arizona.

The flagship activity of the SEI user facility is Science Outside the Lab (SOtL), a week-long training program traditionally held in DC every June. In 2024 SOtL received over 700 applications and brought together 16 graduate students representing 12 NNCI universities. A number of SOtL graduates have proven very successful in making the transition from PhD student to science policy professional. For instance, of the alums from our first five years 3 have gone on to be Mirzayan S&T Policy Fellows at the National Academies, 4 have been AAAS S&T Policy Fellows, 1 served as a AAAS Mass Media Fellow, 2 were part of the State of California S&T Policy Fellow program, 1 was an Eagleton Science and Politics Fellow for the State of New Jersey, 1 is an Intellectual Property lawyer in DC, and 1 was poached by ASU to help run its government research liaison office. Many of these alumni have reached out to us and directly credit the SOtL program for introducing them to these opportunities as well as preparing them for the incredibly competitive process of securing a policy fellowship.

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. In Year 9 Dr. Vasileska developed 7 computational labs, the purpose of which is for students to get better understanding of the electronic structure (using the piece-wise-constant potential-barrier tool – PCPBT, and the bandstructure lab), operation of diodes, MOS capacitors, MOSFETs, MESFETs, etc., using the tools on nanoHUB. These simulation labs will be ported to the nanoHUB.

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.

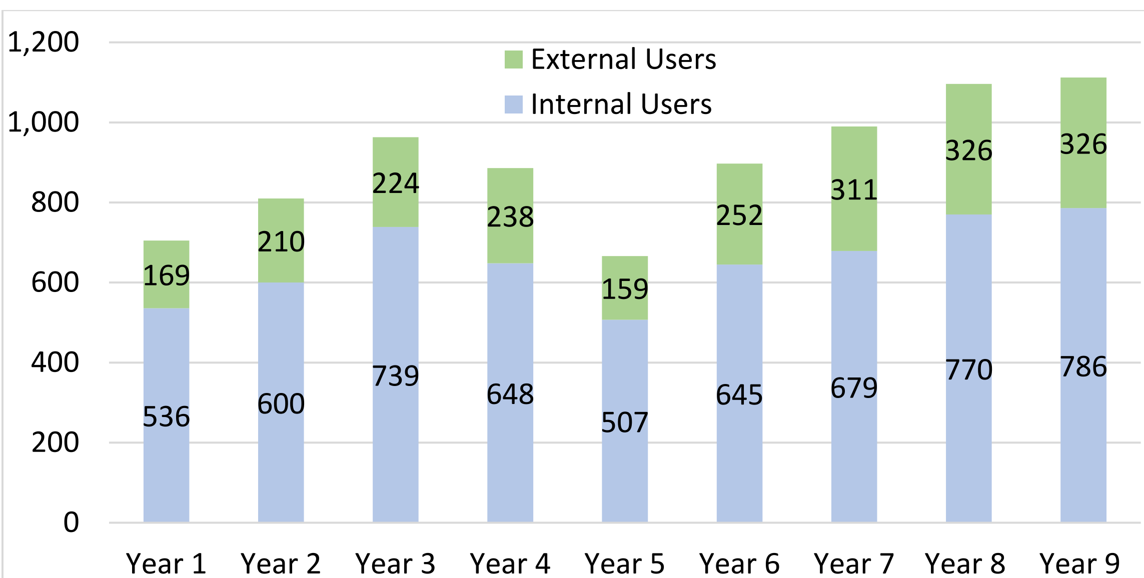
iNanoBio is a startup based out of Scottsdale, AZ and Menlo Park, CA. The company's mission is to develop high-accuracy early-stage disease diagnostics using transformative nano-biotechnology platforms and machine learning. They have received $5.4 Million over four years as part of the Defense Advanced Research Projects Agency 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.

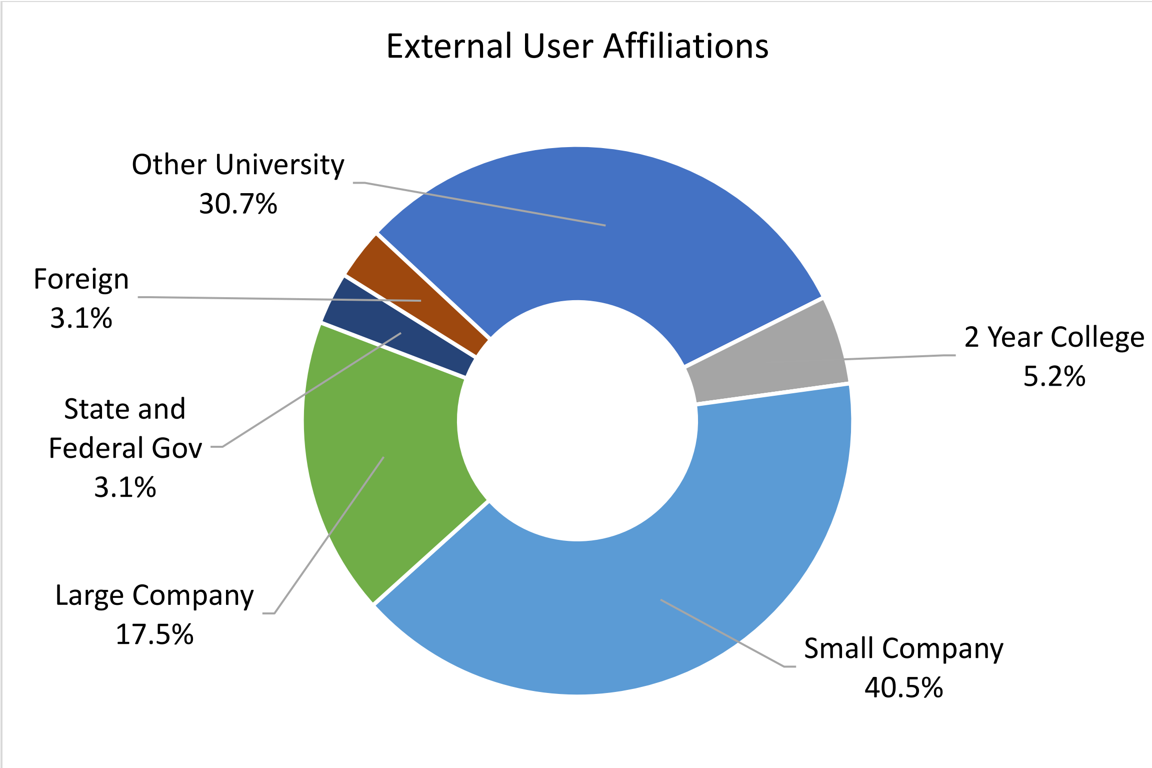
Because we have been using the annual Winter School on Emerging Technologies to help graduate students better understand how their research can have a lasting impact beyond academia, we have been including a significant emphasis on entrepreneurship. In 2024 we invited NNCI Coordinating Office associate director Matt Hull to meet with the student participants and he spent several days working with and coaching them over the course of the Winter School.

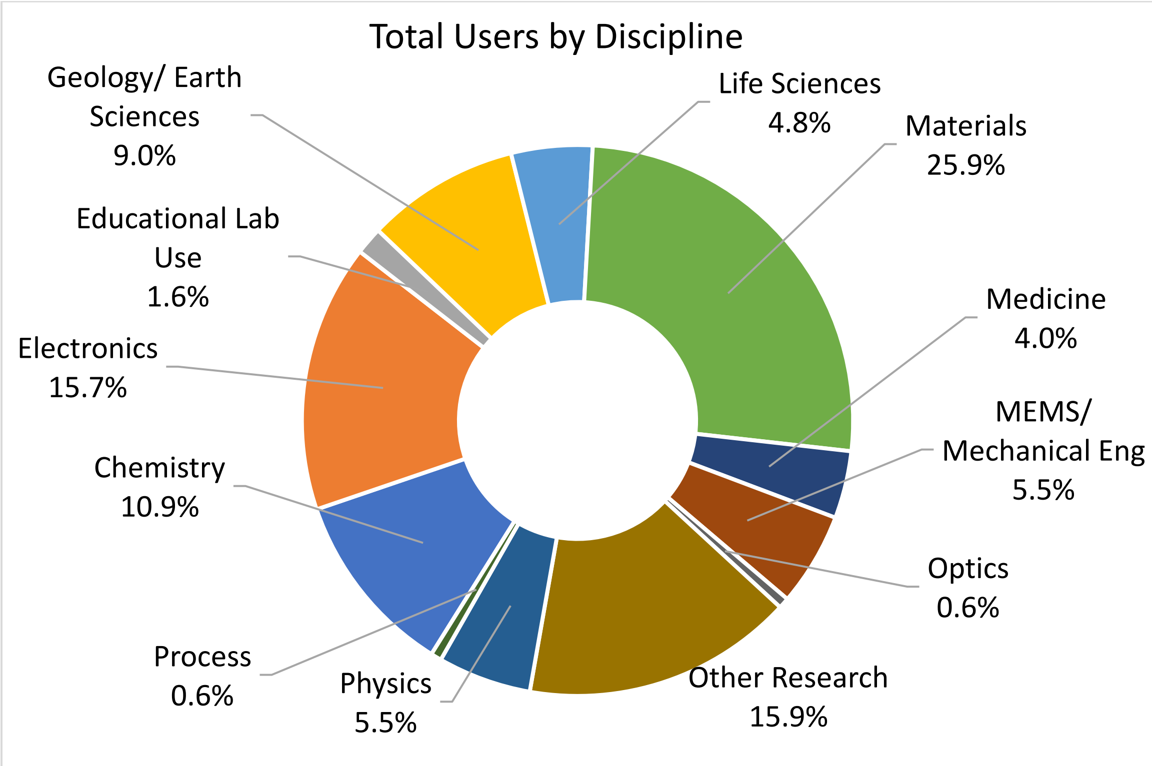
NCI-SW Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	705	810	963	886	666	897	990	1,096	1,112
Internal Cumulative Users	536	600	739	648	507	645	679	770	786
External Cumulative Users	169 (24%)	210 (26%)	224 (23%)	238 (27%)	159 (24%)	252 (28%)	311 (31%)	326 (30%)	326 (29%)
Total Hours	43,098	49,370	46,647	50,630	30,206	51,029	71,372	76,759	75,433
Internal Hours	32,883	38,270	37,954	37,996	23,997	43,124	60,568	63,214	60,185
External Hours	10,215 (24%)	11,100 (22%)	8,693 (19%)	12,834 (25%)	6,209 (21%)	7,904 (15%)	10,804 (15%)	13,545 (18%)	15,248 (20%)
Average Monthly Users	271	313	284	312	272	311	328	386	409
Average External Monthly Users	43 (16%)	49 (16%)	47 (17%)	56 (18%)	45 (17%)	68 (22%)	86 (26%)	98 (25%)	103 (25%)
New Users Trained	275	333	675	700	375	692	628	754	834
New External Users Trained	47 (17%)	53 (16%)	102 (15%)	143 (20%)	35 (9%)	187 (27%)	180 (29%)	193 (26%)	158 (19%)
Hours/User (Internal)	61	64	51	58	47	67	89	82	77
Hours/User (External)	60	53	39	54	39	31	35	42	47



NCI-SW Year 9 User Distribution





12.8. Nebraska Nanoscale Facility (NNF)

Facility, Tools, and Staff Updates

Improvement of NNF facilities has been made possible through funding provided by the University of Nebraska, NRI, NSF EPSCoR, NSF MRI and the Voelte-Keegan Foundation. SMCF Facility placed an order for a Qnami ProteusQ - LT Nitrogen Vacancy (NV) Microscope as a result of a successful NSF MRI proposal led by NNF/NCMN Director Prof. Christian Binek. The Qnami ProteusQ – LT system is a complete quantum microscope system. The system combines the Nitrogen Vacancy magnetometry and scanning probe microscopy into a single instrument and enables the simultaneous acquisition of surface topography and its surface magnetic fields with nanoscale resolution. This NV microscope can do measurements at very low temperatures (4K). The Physical Properties (PP) Facility received an advanced DynaCool PPMS system through the EPSCoR EQUATE grant last year. Recently, the PP Facility placed an order for the VSM Large Bore Option and full AC Susceptibility/DC Magnetization measurement option for the DynaCool PPMS. These new additions will increase the capabilities of the existing DynaCool PPMS system. The large bore option allows users to use larger samples when measuring magnetic properties. The full AC susceptibility/DC magnetization measurement option enables the investigation of low frequency dynamics of magnetic systems. The out of phase component of the susceptibility is of particular interest to study loss mechanisms and gives access to the spin pair correlation function often calculated in theory. The X-ray Structural Characterization Facility purchased a ZetaView Nanoparticle Tracking Analyzer (NTA) system. The NTA system will enable measurements of particle size, concentration, zeta potential and fluorescence. NCMN received an NRI equipment grant to procure an advanced SAXS system for the NNF-NCMN-XRSCF Facility. The NNF-NCMN-Nanofab facility placed an order for procuring an automatic substrate dicing system (DISCO DAD 3241).

Staff members supported wholly or in part by NNCI:NNF in the past and present include NNF Coordinator and User Contact: Dr. Jacob John; NNF Staff Scientists: Dr. Andrei Sokolov, Dr. Wen Qian, Dr. Ather Mahmood, Dr. Xingzhong Li, Dr. Steven Michalski, Dr. Lanping Yue and Bibek Tiwari; NNF Education-Outreach Coordinators: Steven Wignall and Jenna Huttenmaier.

User-Base

The NNF organized in-person events this year aimed at expanding external usage. The NNF Facility Coordinator/User Contact reached out to potential users from other universities, colleges and industries in the region and neighboring states to recruit new users. The NNF Coordinator Jacob John visited several universities and companies in Kansas and Missouri during February this year to recruit new users. He met with faculty members, students, postdocs and engineers from industries during this visit. Several new users started using NNF facilities after this visit. The NNF was able to communicate with several industries during the last six months and a few of them visited NNF facilities for tours and discussion. Some of them are currently using our facilities. Companies like Molex, Lincoln, NE; Ordinal Munitions Technologies, Wichita, KS; General Dynamics, Lincoln, NE; and SLD Photonics, Wyoming, are some of them. **Minicourse: Free Equipment Training for External Students and Industry Engineers:**

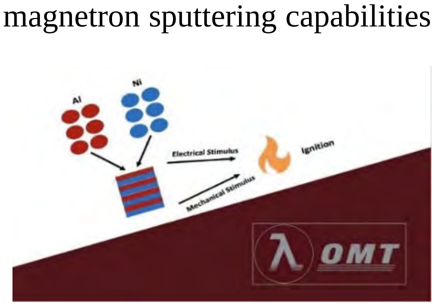
Dr. Binek with NNF Minicourse participants.

Our annual 3-day Minicourse for external users was held on November 8-10, 2023. The NNF provided free hands-on operational training on instruments of their choice for almost 29 external participants during the 3-day free equipment training. 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, Kansas and Missouri. The NNF also covered the accommodation expenses of all the Minicourse participants from neighboring states. Several of these Minicourse participants became users of the NNF facility.

Research Highlights and Impacts

Research Focus Areas in NNF: The NNF supports research projects of the $20M EPSCoR EQUATE (Emergent Quantum Materials and Quantum Technologies) Center led by its scientific director, Prof. Christian Binek, and a team of 20 PIs from 4 universities in the state of Nebraska. The EQUATE Center adds to the pool of NNF users and transforms NE into an internationally recognized hub in the field of quantum materials. The NNF facilities play a critical role in facilitating, supporting and enabling advanced quantum materials and technology research of the 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 partnerships with Little Priest Tribal College and Nebraska Indian Community College. The NNF Director, Prof. Binek, led a team of 21 PIs and secured a $4.17M grand challenge award for the 5-year program "Quantum Approaches Addressing Global Threats" under the UNL grand challenge theme which will continue to strengthen NNF's transitioning to quantum materials science. The NNF also supports major sponsored research programs at the NCMN, an institutional Nanoscale Science and Technology Program of Excellence, the Nebraska Innovation Campus, and several other research centers and programs in other universities and colleges in the western region of the US Midwest.

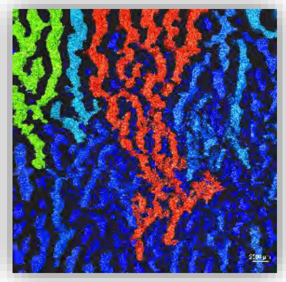
Example Projects of External Users - *Ordinal Munitions Technologies, Inc. KS:* Unlocking the Future of Ammunition: Ordinal Munitions Technologies Embarks on a Lead-Free Revolution. The Wichita-based startup, Ordinal Munitions Technologies, has completed its initial research phase in its quest for a lead-free alternative to ammunition primers. Utilizing the magnetron sputtering capabilities at the NNCI:Nebraska Nanoscale Facility (NNF), the company has successfully synthesized ignitable nanomaterials which will be used for future characterization and testing. This initial research has laid the foundation for an upcoming submission of a NSF Small Business Innovation Research (SBIR) Phase I proposal, scheduled later this year. The company's founders share an unwavering belief in the transformative potential of nanomaterials for combustion applications in both the civilian and military markets. ***SLD Photonics, WY***: NNF supports SLD Photonics, an SBIR award recipient, in the R&D and fabrication of a new detector device. This small company is developing a broadband detector that can capture visible light and near-infrared light, and the detector can be used in unmanned vehicles and defense-related devices. The detector can also be paired with diagnostic tools for improved healthcare. The company uses device fabrication facilities in NNF for its R&D work.



Economic Impacts: The NNF is essential in advancing research in materials and nanoscience at the University of Nebraska. Additionally, it supports the manufacturing sector, contributing to the economic growth of Nebraska and other Midwestern states. Enabled by the NNCI grant, the NNF provides vital resources that assist a variety of companies, along with smaller universities and colleges throughout the Midwest. The NNF supported more than 40 regional institutions in more than 7 states in the Midwest region during the 7th 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.

Education and Outreach Activities

NNF-SPONSORED EVENTS: National Nanotechnology Day Celebrations in October 2024 included a couple of different events: 1) NNF submitted images by graduate and postdoc students to the national NNCI 2024 "**Plenty of Beauty at the Bottom"** image contest. 2) NNF recognized Nano Days in Nebraska by providing a booth in the physics building. Students participated in hands-on activities and had a chance to win prizes. 3) Two of our RETs presented at the Nebraska Association of Teachers of Science (NATS). 4) NNF also participated in UNL's annual Astronomy Day. Total attendance at the events was approximately 500. **Junior/Senior High Tours** Estimated number of participants in 2024 tours was 200-250. We continually try to suggest this activity at educational events to increase this number in the future.



NNCI Nano Art Contest – NNF's Submission

PARTNERSHIPS: Nano and Discover Engineering Days: NNF continued to partner 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 2023 through September of 2024, ~300 junior high students from 10 schools throughout Nebraska received nano lessons using hands-on materials provided for the lesson. **Family Science Night:** We expanded our presence this year with the collaboration between NNF and the Southeast Community College (SCC) system for Family Science Night. We attended this event at the Beatrice and Lincoln campuses in the spring and fall with approximately 1000 in attendance between the two events. **Family Forestry Day:** We attended this event for the second time this year. It attracted 1400 people from around the state of Nebraska and Iowa. We set up multiple tables and presented activities and lesson pertaining to "Nano and Smokey the Bear's 80th Birthday." The attendees were mostly families with younger children, and surprisingly a large amount of "Home Schoolers". **Morill Hall Astronomy Night:** We had a table with both Nano/Quantum activities set up for the public that showed how both of these sciences were found in many of the topics used in Astronomy. This included Nanocomposites, Spectral identification, etc. There was a total of 275 attendees at this event. **Sunday with a Scientist:** NNF partnered with Nebraska's EQUATE team on November 17th at Morrill Hall. Students met quantum and nano scientists and learned about the chemistry of Harry Potter, saw what magnets and magnetic

Summer Girls Inc

fields can do, and used static electricity to light up bulbs through hands-on activities. Our team was featured on the local news that evening as well.

WORKFORCE DEVELOPMENT: Nanotech Lab Course for Student Users: This one-credit-hour per semester course provides graduate students with an introductory, yet comprehensive, view of the large variety of instruments available at NNF. The purpose of this course is to help students master experimental skills in their own research area and to broaden their horizon in experimental nanotechnology methods, complementary to that area. **Nanoscience Classes:** A variety of University of Nebraska graduate classes from different departments used the NNF Facilities. Most courses were designed to promote students' awareness, understanding, and interest in the nanoscience area. **Research Experience for Undergraduates (REU):** Two undergraduate students were selected regionally to work in research labs 8-10 weeks as part of NNF's REU program during the 2024 summer. We were also honored again this summer to represent the NNCI as one of the Host schools for the Japanese exchange program. Yusaku Teraguchi selected "**Additive manufacturing of Yttria-stabilized zirconia ceramics"** with Prof. Bai Cui. All 3 presented their research at the NNCI REU Convocation in Lincoln, NE this year.

Hosting the NNCI REU Convocation

As mentioned above, NNF hosted the annual NNCI REU Convocation in August 2024. Close to 125 affiliates (including 91 REUs) spent three days on campus presenting their work, networking, and attending special programming. Surveys indicated the event was a great success.

NNCI REU Convocation at UNL

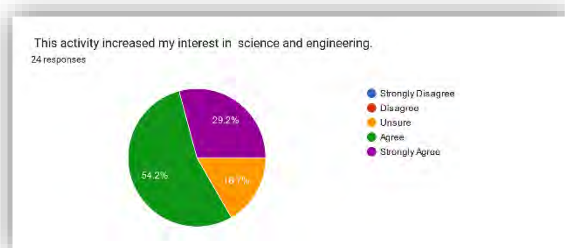
High School Intern Program: NNF hosted 22 high school interns in-person from June-August 2024. Faculty from Chemistry, Physics, and Engineering provided the high school students the opportunity to work in research labs for 8-10 weeks with the help of a graduate student mentor to guide and train them in research techniques. **Rural Workforce Development:** In an effort to support the development of our workforce, we are continually trying to make connections with outside groups and our state community colleges. This is an on-going process and through workshops and activities with groups such as 4H, State Agriculture and Tech teachers, and any group we can preach the wonders and benefits of Nano and Quantum we are getting the message out. **NNCI Site Collaboration**: For the second year we recruited a teacher from SCC in Lincoln to participate in research in our summer RET program. This great connection between NNF's community college partner and us will help to bring future collaboration between SCC and hopefully other community colleges in the state to have further collaboration with the NNF.

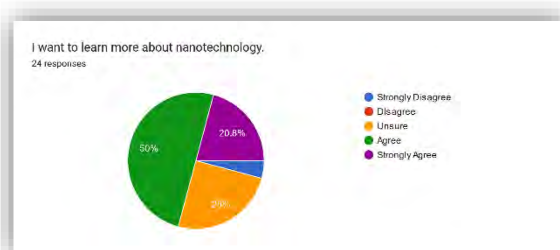
TEACHERS: Teacher Conferences/Workshops: This year we able to attend 4 in person Conferences/Workshops, and one conference virtually. These included the Nebraska Association of Teachers of Science (NATS) Oct 17^{th}-19^{th} and Astronomy Day on Oct 12^{th}. We had a booth, and a Nano/Quantum activity was presented during both the workshops for the attendees. We also did presentations on Nano and Quantum at two other teacher conferences this year, one in Grand Island for 100 Vocational Ag teachers for their state conference, and NNF also helped with the

28th NSF EPSCoR National Conference, which was held in Omaha, NE. Attendance was ~700 for all events. **<u>Research Experience for Teachers</u>**: Four teachers were selected to participate in NNF's 2024 Summer RET Program scheduled from June 17 - July 26. Teachers worked in nanoscale science and engineering labs to gain hands-on experience in the techniques and tools used within NNF facilities, with follow-up support during the school semesters. This RET Program is in partnership with three other RET sites throughout the US (Georgia Tech, Minnesota, and Northwestern). **<u>Nanoscience Summer Institute for Middle School Teachers in Partnership with Stanford</u>:** Last summer eight teachers participated in the NanoSIMST four-day virtual workshop at the end of June. 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.

<u>DIVERSITY: K-12 Diversity Programs</u>: NNF's programs for diverse elementary through high school populations expanded during this year. 1) Thirty diverse Upward Bound high school students were given two 2-hour nano workshops during the summer with career information and hands-on activities. 2) 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. 3) NNF attended Buena Vista High School's Career Fair where the majority of student attendees were minorities.

<u>TRAVELING NANOSCIENCE/ASTRONOMY EXHIBITS:</u> Our two 400-sq.-ft. hands-on exhibits are still active and making their rounds in museums in the Midwest. During this report's time span, the Sun, Earth, Universe Exhibit was viewed at the Kearney Area Children's Museum in Kearney, NE and the Washington Pavilion in Sioux Falls, SD. Our second traveling exhibit, the Nano one, was hosted by the Grout Museum in Waterloo, IA and the SAC museum in Ashland, NE. The museums have had a total attendance of about 100,000 people (2023-2024) and > 300,000 have been reached for the lifetime of the exhibits.





<u>RESOURCES: Nano/STEM Kits</u>: We provided Nano/STEM activity kits (developed by NISE Net, a NSF-funded organization) to teachers in the area. The kits contain hands-on activities to support a variety of science concepts at the middle school level. **<u>Training Modules</u>:** Equipment training videos provided new facility users with an effective and efficient method of learning information needed to work in NNF labs. New users can access "how to" information by facility specialists before and after real-time training, which increases efficiencies and level of learning. Several <u>video tutorials</u> for users have been prepared for introducing instruments, their functions and overall capabilities that will provide the users a proper understanding of the analytical capabilities and operational procedures.

<u>ASSESSMENT ACTIVITIES:</u> The Nebraska Nanoscale Facility (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 Discover

Engineering Days participants. Students in our 2024 Discover Engineering outreach events were assessed and 100% of the students agreed that the DED hands on activities were fun and informative and 83% responded that the activities had increased their interest in studying science and engineering. This resulted in 70% of the students wanting to learn more about nanotechnology.

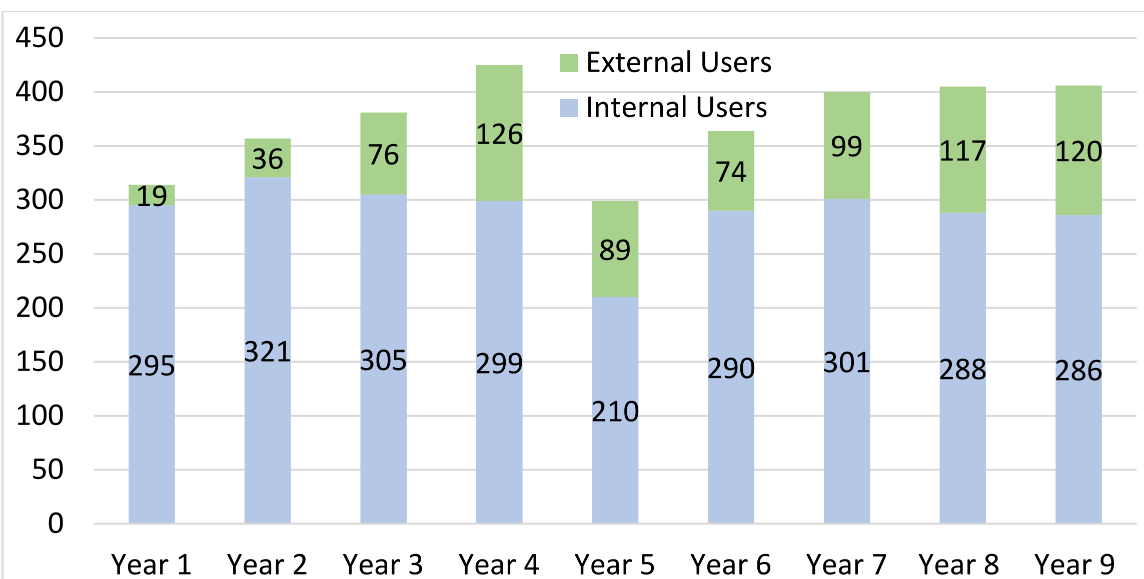
Innovation and Entrepreneurship Activities

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 a 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.

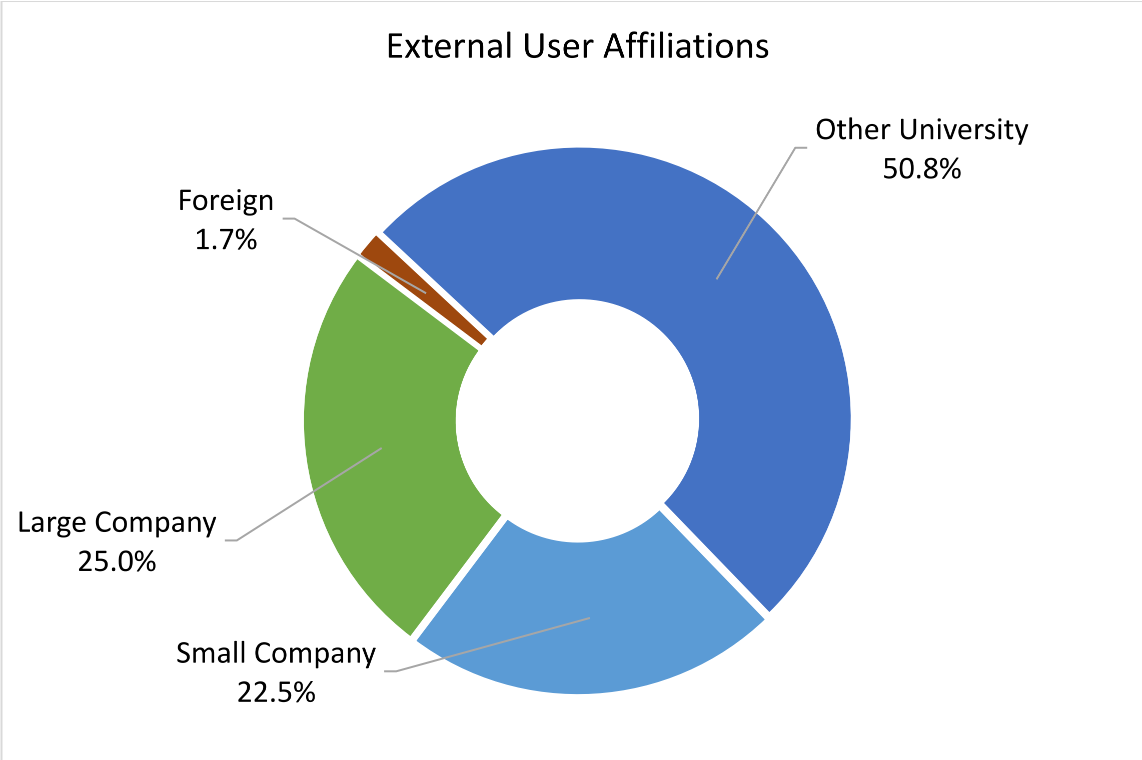
Vajra Instruments is a regular user of NNF facilities. Access to the NNF Nanofabrication Cleanroom facility is critical for the success and operations of the small startup company, Vajra Instruments. The NNF Nanofabrication Cleanroom facility is providing Vajra Instruments high quality electrochemical 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.

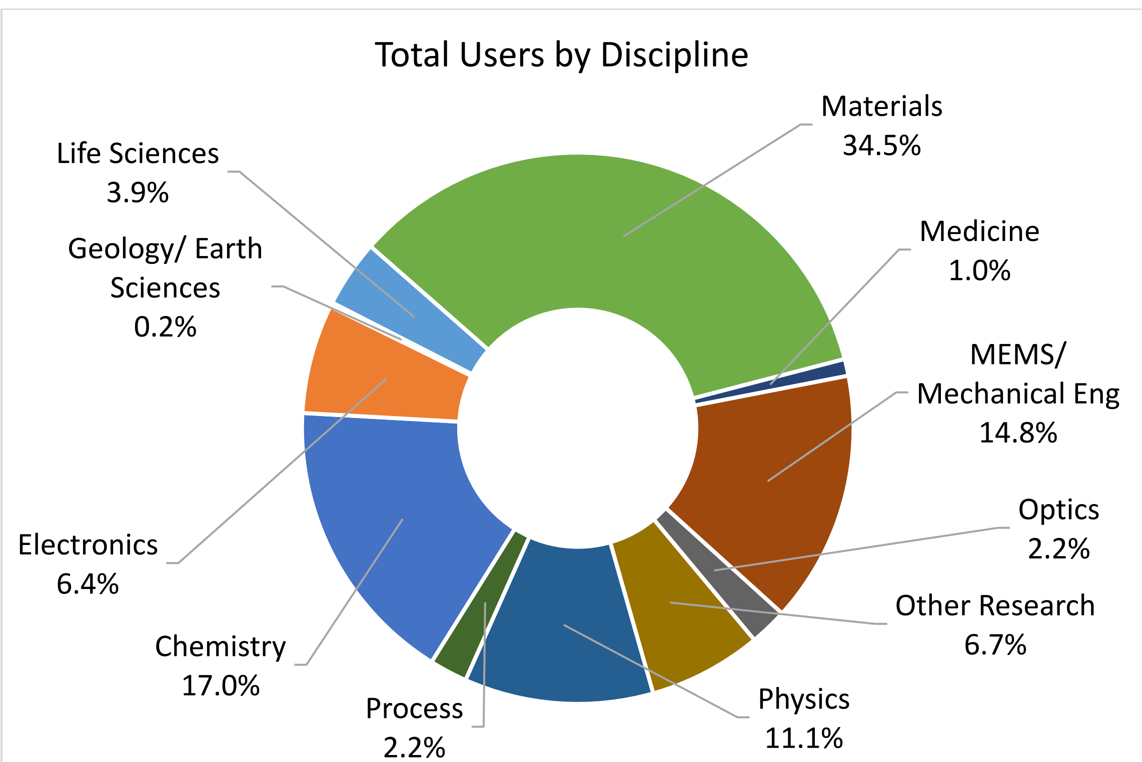
NNF Site Statistics

Yearly User Data Comparison	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Total Cumulative Users	314	357	381	425	299	364	400	405	406
Internal Cumulative Users	295	321	305	299	210	290	301	288	286
External Cumulative Users	19 (6%)	36 (10%)	76 (20%)	126 (30%)	89 (30%)	74 (20%)	99 (25%)	117 (29%)	120 (30%)
Total Hours	23,445	20,102	24,008	31,037	24,002	23,422	27,262	23,297	18,833
Internal Hours	23,123	19,278	22,260	27,468	20,809	20,382	23,388	19,779	15,462
External Hours	322 (1%)	824 (4%)	1,748 (7%)	3,569 (11%)	3,192 (13%)	3,040 (13%)	3,874 (14%)	3,518 (15%)	3,371 (18%)
Average Monthly Users	40	120	132	137	90	120	134	128	129
Average External Monthly Users	3 (8%)	7 (6%)	19 (15%)	18 (13%)	14 (15%)	15 (12%)	17 (13%)	18 (14%)	18 (14%)
New Users Trained	47	54	124	98	150	215	278	211	245
New External Users Trained	0 (0%)	1 (2%)	6 (5%)	7 (7%)	5 (3%)	16 (7%)	26 (9%)	14 (7%)	5 (2%)
Hours/User (Internal)	78	60	73	92	99	70	78	69	54
Hours/User (External)	17	23	23	28	36	41	39	30	28



NNF Year 9 User Distribution





12.9. NNCI Site @ 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 and external users from academic, industrial, and government labs. nano@stanford seeks to develop and propagate a national model for educational practices that will help learners at all levels become knowledgeable about the nanoscale and, when appropriate, proficient users of the facilities. nano@stanford has a robust entrepreneurial ecosystem, facilitated by auxiliary laboratories with less stringent particle count requirements that can function as flexible maker spaces and entrepreneurial resources available on campus. Another unique strength of nano@stanford is its high-impact, scalable, education and outreach (E&O) programs: a community college internship program and a middle school teacher professional development program.

nano@stanford facilities include Stanford Nano Shared Facilities (SNSF), Stanford Nanofabrication Facility (SNF), Stanford Mineral Analysis Facility (MAF) and Stanford Isotope and Geochemical Measurement & Analysis (SIGMA) Facility. The facilities offer an extensive suite of nanofabrication and characterization tools, including capabilities rarely found at shared facilities (e.g., MOCVD, two Raith EBPG 5200 electron-beam lithography systems, a diamond deposition system, and a nanoSIMS). The four facilities occupy ~30,000 sqft of space and are located in convenient proximity on Stanford's campus. Not only do the facilities offer access to state-of-the-art equipment, but they also provide the expertise of ~42 technical staff members (including 18 Ph.D.s) who support the lab community's research endeavors.

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

During year 9, nano@stanford added ***five new capabilities*** and two infrastructure-related items:

1) Helios 5 Hydra CS DualBeam System with Secondary Ion Mass Spectrometry
2) Bruker Dimension IconIR
3) Hitachi TM4000PlusE Tabletop SEM (for user research and E&O programs)
4) Heidelberg MicroMLA Direct Write System
5) Tystar Titan Mini 4600 Series Furnaces
6) Hydrogen generation system
7) NEMO lab management system (at SNF)

SNSF is making swift progress on its expansion that will include an additional 10,000 sqft of facility space and new characterization capabilities thanks to an investment from the Vice Provost and Dean of Research, including $30M for construction and ~$20M for new instrumentation. Construction has started with a grand opening planned for spring 2026.

In year 9, nano@stanford ***increased staffing with 4 new positions**** ***(demonstrating growth) and*** **hired** ***an outstanding successor for a recently vacated position***. New staff include Rachelle Salmani (Process Operations Associate*, SNF), Neel Mehta (Process Engineer, SNF), Dr. Nadia Makarova (SPM Support Scientist*, SNSF), Christopher Lung (Lab Operations Engineer*, SNSF), and Dr. Kathleen Akbar (Laboratory Research Scientist*, SIGMA).

<u>User Base</u>

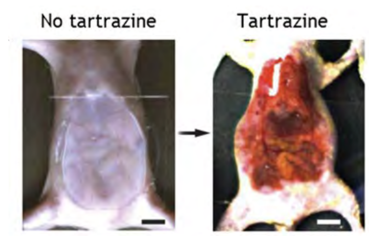
The nano@stanford marketing efforts have undergone significant growth since hiring a new Program Communicator in year 8. To raise awareness of our facilities and programs we utilize five communications channels: a new quarterly newsletter, social media, the nano@stanford website, digital/print media (e.g., printed flyers and digital media displayed on campus TVs), and targeted email campaigns. We have 3600 YouTube subscribers, 2400 newsletter subscribers, 130 Instagram followers, and 330 LinkedIn followers (19.8K people have viewed our posts). Our interns also host their own Instagram to share about the intern experience with 348 followers.

To augment the user experience, we continue to send "nano@stanford Weekly Update" emails to the lab community to keep them informed of news, events, and opportunities. We also continue to support the nano@stanford Lab Member Collaborative (nano-LMC, a user advisory group), which strives to provide a direct line of communication between users and nano@stanford leadership and to create an improved sense of inclusiveness and community. In year 9, the nano-LMC's initiatives included safety, societal and ethical implications (SEI), gender minority resources, and process sharing. Their safety survey resulted in numerous facility improvements. The group also organized an interactive Town Hall to collect user feedback, a Trivia Night, monthly happy hours, and SEI lunch n' learns.

In year 9, nano@stanford served ***1449 users, the highest number of cumulative annual users*** for the duration of the award (versus 1445 in year 8). The user base includes 276 users from 125 small companies, which exemplifies the strong entrepreneurial ecosystem in the area.

<u>Research Highlights and Impact</u>

The following are three research highlights from two internal users and one external user. During 2023, we captured 215 published journal articles from internal users, 55 articles from external users, 26 conference presentations, and 3 patents.



In-vivo imaging of gut motility in a mouse.

Research by **Stanford Professors Mark Brongersma, Guosong Hong**, demonstrated that strongly absorbing molecules, like tartrazine, can make biological tissue optically transparent. ***The publication gained national attention*** by being featured on NPR News, The Late Show with Stephen Colbert (1.76M viewers), USA Today, and other outlets. The work demonstrated that dyes with sharp absorption resonances in the near-UV and blue spectral regions can minimize the refractive index contrast between water and lipids to achieve optical transparency. In-vivo imaging was performed on mice coated in highly concentrated tartrazine to visualize gut motility, cerebral blood vessels, and muscle sarcomeres. Deep tissue optical imaging through mm of scattering medium was possible with micrometer scale spatial resolution. This discovery will enable non-invasive visualization of deep tissues and organs, allowing observation of structure, activity, and function without surgery or transparent windows. The research was published in *Science.*

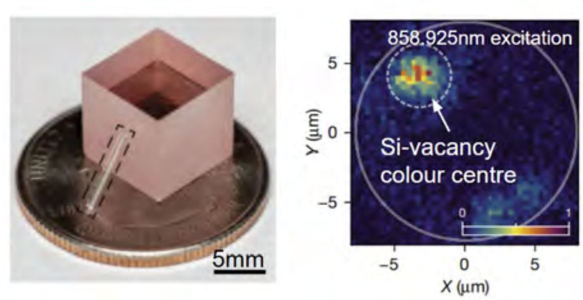
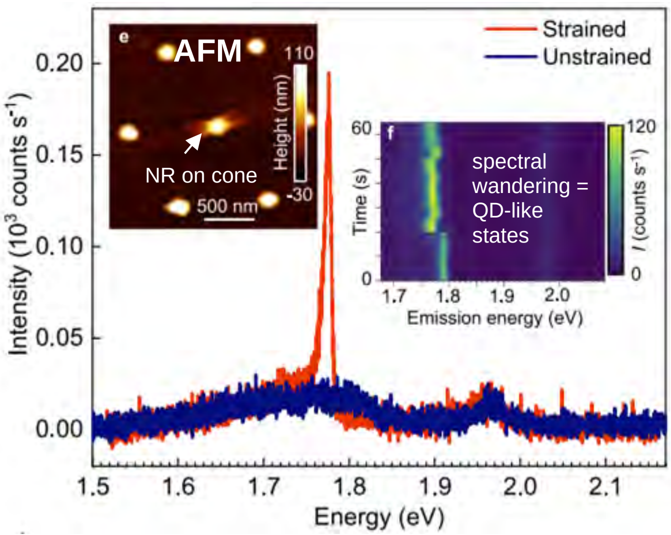


Photo of a Ti:SaOI laser system and photoluminescence detection of a colour centre.

To democratize Ti:sapphire technology, research from **Stanford Professor Vučković's group** developed chip-integrated, broadband tunable Ti:sapphire laser systems that are 10,000x smaller and 1,000x cheaper than the existing tabletop systems and can be pumped with a cheap, green laser pointer. ***The work won 2nd place in the NNCI NTEC competition and catalyzed the formation of a new startup company, Brightlight Photonics***. Fabrication entailed thinning bulk Ti:sapphire on SiO_2 on sapphire crystal (Ti:SaOI) and patterning onto it a spiral waveguide, platinum microheater for tuning, and a microring resonator. As a proof-of-concept, the authors used Ti:SaOI laser systems for a cavity quantum electrodynamics (QED) experiment. They demonstrated the ability to detect and distinguish silicon vacancy colour centres and parasitic fluorescence by tuning the system to different excitation wavelengths. The research was published in *Nature*.

Dr. Xufan Li and his coworkers from the Honda Research Institute developed a direct growth method for single-crystal transition-metal dichalcogenide (TMC) nanoribbons (NRs). First, Na-Mo-Ni-O seed nanoparticles (NPs) were deposited on (001) fluorophlogopite mica by evaporating a mixture of MoO_2, Ni, and NaBr, in the presence of moisture. Then, the NPs were exposed to a chalcogen vapor atmosphere. The authors adjusted the NP diameter distribution and chalcogen vapor pressure to control the dimensions of MoS_2 and WSe_2 NRs and consequently tune their optical properties. The MoS_2 and WSe_2 NRs exhibited width-dependent photoluminescence and strain-induced quantum emission signatures. This research may lead to new quantum dot light sources and advancements in quantum optoelectronics. The research was published in *Nature*.



PL spectra of strained & unstrained NRs. Insets: AFM of NR over Au nanocone. Time-series of PL spectra.

<u>Education and Outreach Activities</u>

Our year-round, **community college internship program** is a paid, hands-on experience for students from local colleges to work in a class 100 cleanroom. While the interns learn transferable technical and professional/durable skills, the lab benefits from extra staff and user support. The interns stock supplies, run process monitors, perform equipment maintenance, give lab tours, train users, and collaborate on lab support projects. These projects are distinct from the REU program because the activities are not research-based but directly benefit the facilities. For example, the interns fabricated 125 pocket wafers which are now an inventory item available for users doing chip-scale processing. Two highlights include: (1) one intern experienced his 2nd REU at Harvard (CNS) and transferred to UCSD (SDNI) this fall, and (2) eight interns attended TechConnect with support from MNT-EC and one of them shared about her intern experience at a White House meeting.

Intern Lillian Ngo at the White House.

In Year 9, we ***trained 25 students*** from 11 local community colleges. Out of the 35 interns since 2018, 19 transferred to 4-year institutions, 2 accepted full-time jobs at startups, 1 interned at Intel, 1 was a summer research assistant in a Stanford professor's lab, 1 was hired as full-time staff at

SNF,1 is now an MSE Masters student at Stanford, and 1 is a Ph.D. candidate at MIT. We intentionally target minority serving institutions (MSIs) when recruiting interns and 76% have been from underrepresented groups and 60% have been female.

NanoSIMST is a middle school teacher professional development workshop, led by nano@stanford, during which participants learn about nanoscience and prepare classroom lessons. In year 9, ***52 teachers were trained*** nationwide with 12 NNCI sites participating by either running an in-person program or sponsoring virtual teachers from their areas. Based on historic NanoSIMST implementation data, we estimate these teachers will impact 3900 students with nanoscience lessons this year, and that ***over 13.8K students have been impacted since 2017***. Additional program growth was possible this year because the Microelectronics Commons NW-AI-Hub supported 11 virtual teachers and one extra teacher facilitator. For the 2nd consecutive year, we hosted a field trip for ~150 eighth graders from Sacramentos' Sutter Middle School (a Title 1 school), where a NanoSIMST alumna teaches.

Sutter Middle School visited for a 2nd year. The field trip, led by a NanoSIMST alumna, 150 8th graders.

Other E&O activities (e.g., tours, demos, workshops, curriculum support, etc.) reached ~7000 participants in year 9. This included 12 Stanford classes which used the facilities to supplement classroom content with experiential learning for ~240 students. We continue to create content for our edX courses, reaching ~12,000 learners from 143 countries since 2019.

<u>Societal and Ethical Implications Activities</u>

nano@stanford staff continue to serve as guides and proponents for a SEI Student Working Group, composed of alumni from NNCI's Science Outside of the Lab (SOtL) program and SEI-interested lab members. In year 9, the group continued to co-host an SEI-focused book club and discussed its second book: "The New Climate War" by Michael Mann. The SEI group also organized quarterly SEI Lunch n' Learns, featuring topics like ethical considerations for choosing data sets to train AI, the culture and pressure of publishing in academia, and ethical responsibilities around scientific communication.

<u>Innovation and Entrepreneurship Activities</u>

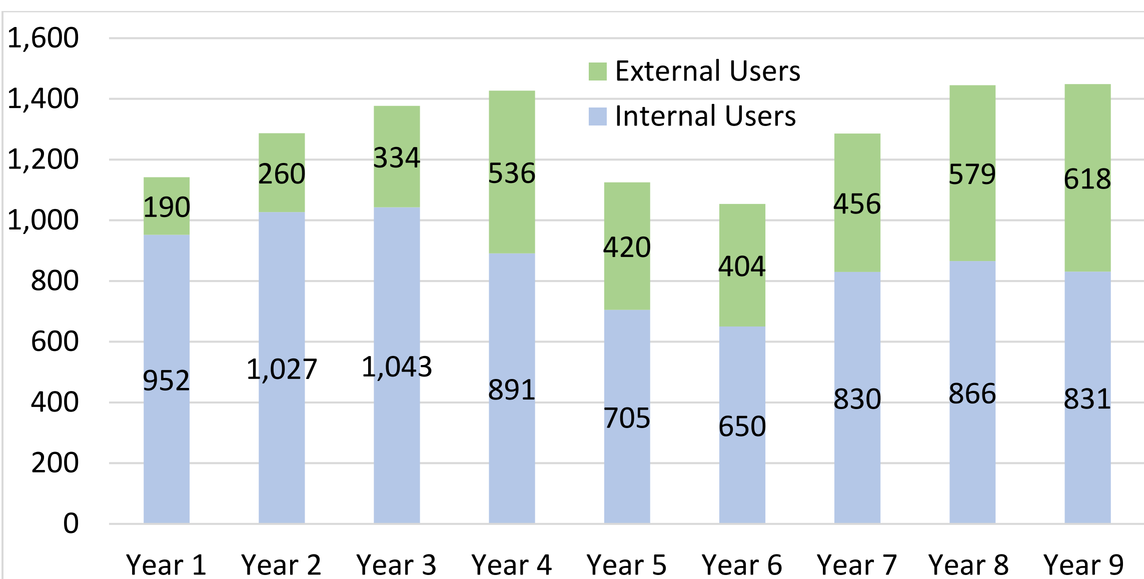
nano@stanford collaborated with the I&E working group chair to design the special topic session for the 2023 NNCI Annual Conference, called "Translating from R&D to Market" and to organize the NNCI Webinar "From Lab to Launch: Stanford's Entrepreneurial Ecosystem". This year, 3 nano@stanford students were accepted into the NNCI NTEC program. Stanford's Joshua Yang won 2nd place for his Laser on Chip project and his startup company, Brightlight Photonics, is now underway.

2nd place NTEC winner, Joshua Yang, and mentor, Lavendra Mandyam.

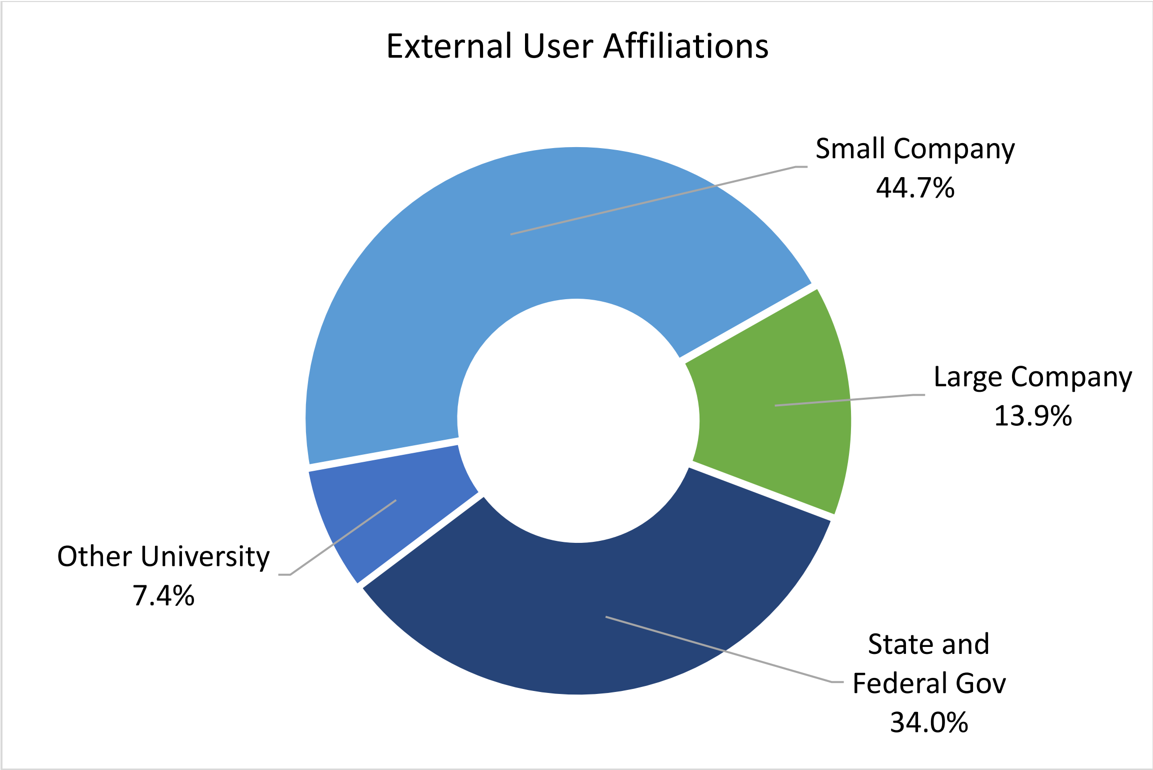
nano@stanford Site Statistics

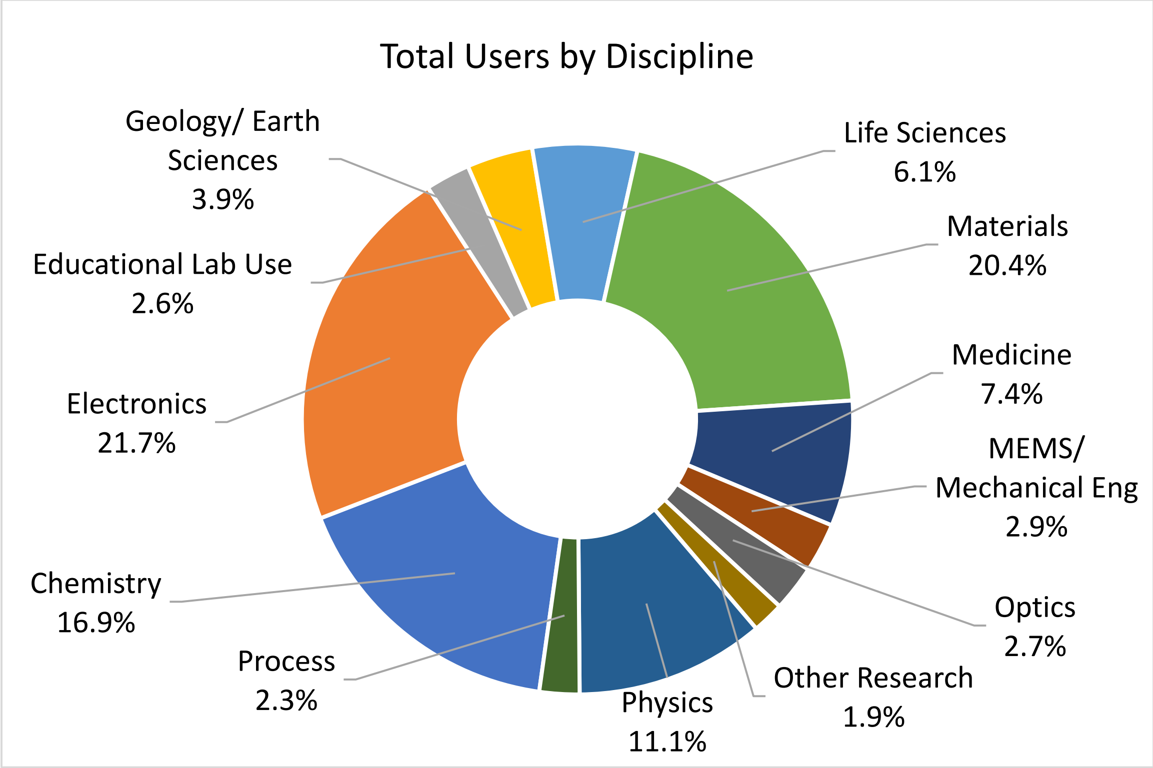
Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4***	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	1,142	1,287	1,377	1,427	1,125	1,054	1,286	1,445	1,449
Internal Cumulative Users	952	1,027	1,043	891	705	650	830	866	831
External Cumulative Users	190 (17%)	260 (20%)	334 (24%)	536 (38%)	420 (37%)	404 (38%)	456 (35%)	579 (40%)	618 (43%)
Total Hours	113,089	113,193	135,054	119,877	78,663	104,536	108,702	109,649	122,538
Internal Hours	94,996	91,248	105,083	72,408	47,856	63,013	69,230	66,599	66,365
External Hours	18,093 (16%)	21,944 (19%)	29,971 (22%)	47,469 (40%)	30,807 (39%)	41,523 (40%)	39,472 (36%)	43,050 (39%)	56,173 (46%)
Avg. Monthly Users	520	572	601	615	405	470	548	589	600
Avg. External Monthly Users	74 (14%)	92 (16%)	115 (19%)	213 (35%)	136 (34%)	162 (34%)	176 (32%)	198 (34%)	247 (41%)
New Users Trained	550	579	584	596	359	491	581	579	572
New External Users Trained	97 (18%)	143 (25%)	194 (33%)	262 (44%)	159 (44%)	186 (38%)	197 (34%)	212 (37%)	175 (31%)
Hours/User (Internal)	100	89	101	81	68	97	83	77	80
Hours/User (External)	95	84	90	89	73	103	87	74	91

*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 9 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, photonic and quantum devices, advanced energy materials and devices, and bio-nano interfaces.

Facility, Tools, and Staff Updates

Infrastructure Investments: In recent years, the NNI site undertook major infrastructure expansions and upgrades, including a complete renovation of the WNF cleanroom and a new Nano Engineering & Sciences building on the UW campus, as well as an expansion of the MaSC facility, a renovation of the ATAMI business development space, and completion of the new Johnson Hall on the OSU campus. The renovation of Graf Hall at OSU has been completed, and dedicated laboratory space is available for Oregon Process Innovation Center (OPIC) research equipment. Significant efforts are underway at OSU on the new Collaborative Innovation Complex (CIC) building, and on putting together a 10-year plan for renovating several engineering buildings. Major upgrades to UW's shared nanofabrication and quantum technology infrastructure are in progress, enabled by recent congressional earmarks supporting the Washington Nanofabrication Facility, the Molecular Analysis Facility, as well as the affiliated Quantum Technologies Training & Testbed (QT3) lab.

Major New Tools and Capabilities:

Washington Nanofabrication Facility (UW)

- SAMCO REI-10NR etch tool
- Oxford PlasmaPro 100 Cobra 300 ICP-RIE (Cl/ALE)
- Goniometer (donation from industrial partner)
- Oxford ICP 380 fluorine etcher upgrade with two additional gases, CH_4 and H_2
- Angstrom Engineering electron beam evaporator
- IntlVac IBE (donation from industrial partner)
- SPTS fluorine etcher (donation from industrial partner)
- Raith Voyager electron beam lithography (donation from industrial partner)
- Heidelberg MLA 150 direct-write laser lithography (Murdock Charitable Trust)
- AFM Bruker FastScan (Murdock Charitable Trust)
- New SEM, PECVD, and lithography tools (bonder, aligner, track)

Molecular Analysis Facility (UW)

- ThermoFisher Apreo 2 S LoVac SEM
  - Gatan EDAX Pegasus integrated EDS-EBSD with Clarity super detector
- Molecular Vista PiFM upgraded scan head
- 3 Nikon stereo microscopes, 1 digital camera
- CrystalMaker software
- Focused Ion Beam
- XPS

ATAMI (OSU)

- Agilent liquid chromatography / mass spectrometry
- Ocean Insight UV/VIS
- Corning Nebula flow reactor
- The Jen-Hsun & Lori Huang Collaborative Innovation Complex ($200M, 150,000 ft^2) will include new cleanroom / nanofabrication facilities and the fastest supercomputer on the West Coast. Construction is scheduled to be completed in 2025.

MaSC, APSCL, OPIC (OSU)

- Stanford Research Systems SR865A lock-in amplifier
- 2 Laurell WS-650MZ-23NPPB spin coaters
- Memmert HCP SD humidity chamber
- Ultimaker 3D printer
- Shimadzu UV-2600 UV-vis spectrometer
- Ossila UV ozone cleaner
- Keysight B2985A electrometer

Staff Update: Greg Herman, NNI lead at OSU since 2015, has taken on a new position as Division Director of Chemical Sciences and Engineering at Argonne National Labs. Joe Baio, Associate Professor of Chemical, Biological, & Environmental Engineering, has taken over the NNI leadership at OSU.

This reporting period saw few changes in facility staff, however, the WNF is planning to hire at least one additional engineer in response to the significant number of new tools and increased workforce development commitments. Operations manager Sharon Li is now supporting the WNF 100% of her time. At the MAF, Research Scientist Ellen Lavoie was promoted; her duties have expanded to oversee lab safety and tours/outreach activities. At the Advanced Technology and Manufacturing Institute (ATAMI) at OSU, Maille Daley was hired as administrative assistant and Erik Carlson was hired as a second chemist supporting newly expanded flow chemistry capabilities.

<u>User Base</u>

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.

During Year 9, NNI facilities have seen an increase around 5 to 10 percent in total users, external users, total new users, and new external users, with stronger growth in the external user metrics. External users constitute about one-third of our user base and more than half of our user hours. Almost two-thirds of external users are employed by small companies.

Research Highlights and Impact

NNI is honored to have David Baker, winner of the 2024 Nobel Prize in Chemistry, among our users. Attendees of the 2018 NNCI Annual Conference will remember his keynote presentation on *De Novo Design of Protein Nanomaterials*.

We chose work led by co-PI Mo Li (*Nature* 620, 316-322, 2023) for this year's research highlight, which demonstrates non-mechanical beam steering for next-generation LiDAR. Current systems are generally too bulky, fragile and expensive for applications in autonomous vehicles and robotics. Li's team reports an on-chip, acousto-optic beam-steering technique that uses only a single gigahertz acoustic transducer to steer light beams into free space. Exploiting the physics of Brillouin scattering, in which beams steered at different angles are labelled with unique frequency shifts, this technique uses a single coherent receiver to resolve the angular position of an object in the frequency domain and enables frequency-angular resolving LiDAR. The system achieves frequency-modulated continuous-wave ranging with an 18° field of view, 0.12° angular resolution and a ranging distance up to 115 m. The demonstration can be scaled up to an array realizing miniature, low-cost frequency-angular resolving LiDAR imaging systems with a wide two-dimensional field of view. This development represents a step towards the widespread use of LiDAR in automation, navigation and robotics.

Broadening Visibility and Support for NNI Facilities: Renewed efforts have been launched to increase the facility budgets for much-needed acquisitions, upgrades, and staff support.

- At the university level, a provost initiative invests $2M annually for 5 years in infrastructure supporting quantum science and technology.
- A congressionally directed appropriations request (CDAR) approved in 2023 is supporting the UW Quantum Technology Training & Testbed (QT3), and two 2024 CDARs provide $5.3M for upgrading workhorse tools in the WNF and the MAF.
- A request to the Washington state legislature is currently pending.
- The M. J. Murdock Charitable Trust approved $1.2M to purchase a new direct-write laser lithography system and high-speed atomic force microscope (AFM) for the WNF.
- WNF director Maria Huffman has received funding specifically targeted at workforce development and broadening access to the WNF via the CA-Pacific NW AI Hardware ME Commons HUB led by Stanford.
- Huffman has also received additional funding from both Intel and Micron to continue offering short courses to URM and Community College students.
- Huffman was chosen by the Washington State Commerce Department as a member of a working group that coordinates a comprehensive, statewide approach to securing current and future grant opportunities enabled by the CHIPS and Science Act.

Education and Outreach Activities

NNI has fostered public understanding and appreciation of nanotechnology through diverse educational and outreach initiatives targeting K-gray audiences across Washington and Oregon. Key goals include workforce development, promoting underrepresented populations' transition to 4-year degrees, and engaging Regional First Nation Tribes. NNI has reached over 40,000 participants in its first five years under NNCI support. Despite challenges in organizing large events post-pandemic, NNI has strengthened partnerships with underserved schools to encourage pathways to careers in nanotechnology and diversify the workforce.

Engineering Discovery Days: After a hiatus since 2019, NNI collaborated with the UW College of Engineering to revive Engineering Discovery Days in May 2024. This event welcomed 8,000 4^{th} to 8^{th} grade students to explore STEM and nanotechnology through 118 exhibits. Plans for 2025 aim to expand attendance to 15,000 students, emphasizing inclusivity and exposure to STEM careers.

High School and Community Engagement: The Summer Experience in Science and Engineering for Youth (SESEY) program at OSU offers diverse high school students a week-long campus experience, emphasizing hands-on engineering research. NNI faculty facilitated projects illustrating nanotechnology's applications and career opportunities. Additionally, NNI's Student Laboratory Assistant Program has supported undergraduates and community college students, including veterans and students from tribal schools, providing valuable nanofabrication training and workforce readiness.

Workforce Development Initiatives: NNI supports skilled workforce development through training programs and collaboration with industry. Key initiatives include:

- Nanofabrication workshops funded by the Micron Foundation and Intel, enabling students to fabricate and test wafer-scale devices. These workshops target underserved students, supporting career discernment and recruitment into STEM fields.
- Nanofabrication short courses for UW Pathways for Inclusive Excellence (PIE) and Bellevue College students, focusing on semiconductor fabrication.
- Student assistant programs at the Washington Nanofabrication Facility (WNF) and Materials Analysis Facility (MAF), employing diverse undergraduates and offering hands-on lab experience.
- Partnerships with programs like the Engineering Dean's Scholars and STEM Leaders to increase representation in nanotechnology fields.

College Transition Support: The College Transition Program, in collaboration with UW's Office of Admissions, supports underserved students through the Engineering Dean's Scholars initiative. Participants receive academic support and community building opportunities. Retention rates into engineering majors for the program's first cohorts (2021-2022) have exceeded 85%, surpassing historical averages for similar populations.

First Nations Engagement: NNI is dedicated to expanding nanotechnology access and addressing community-identified needs in diverse First Nations communities. NNI has engaged local tribal nations in its cleanroom internship program, recruiting three American Indian students, including two from a Puyallup Indian Tribe-affiliated school. One participant has since earned a Bachelor's degree from UW. Research shows that hands-on teacher research experiences enhance student science achievement. NNI co-director Joe Baio collaborated with Chemawa Indian School, hosting a teacher in the Educators-in-Residence program. Together, they developed teaching modules on 3D printing to visualize molecular structures and chemical bonds.

Curriculum Integration and Academic Courses: NNI-affiliated courses at UW and OSU integrate hands-on training in nanotechnology, ranging from undergraduate to graduate levels. Key courses include EE 527 (Nanofabrication Techniques), EE/ME/MSE 504 (MEMS), and CHE 544 (Thin Film Processing). Specialized programs, such as the Graduate Certificate in Quantum Information Science and Engineering and the UPWARDS semiconductor workforce development initiative, leverage NNI facilities for experiential learning.

Innovation and Entrepreneurship Activities

The University of Washington was recently named the "#1 most innovative public university in the world" by Reuters Top 100. Milken Institute's report on "Concept to Commercialization" lists UW as the "#7 Best University for Technology Transfer," and AUTM identified UW as "#2 in the U.S. for number of licenses granted by a university." At Oregon State University, spin-off Inpria Corporation, whose metal oxide EUV photoresists are used in microchip fabrication, attracted investors such as Intel and Samsung. It was acquired in September 2021 by the Japanese firm JSR for $514 million. Currently we are aware of at least ten small businesses with active SBIR/STTR grants performing part or all of their R&D work at NNI facilities.

Working Group and Seminar on Innovation & Entrepreneurship: The NNI site has renewed its efforts in innovation and entrepreneurship activities on several fronts. We are actively participating in the I&E working group. An I&E seminar series continues approximately quarterly with leaders in I&E. The NNCI Nanotechnology Entrepreneurship Challenge (NTEC) is a program created by Matthew Hull (NanoEarth) to support student entrepreneurs interested in translating nano-enabled innovations from the lab to society. PI Böhringer has served as a panelist for the NNCI virtual NTEC Showcase. The most recent NTEC Showcase took part on April 30, 2024, and included a team from NNI on a "Durable double perovskite ($SrCoIrO_3$) electrocatalyst for acidic media water electrolyzer".

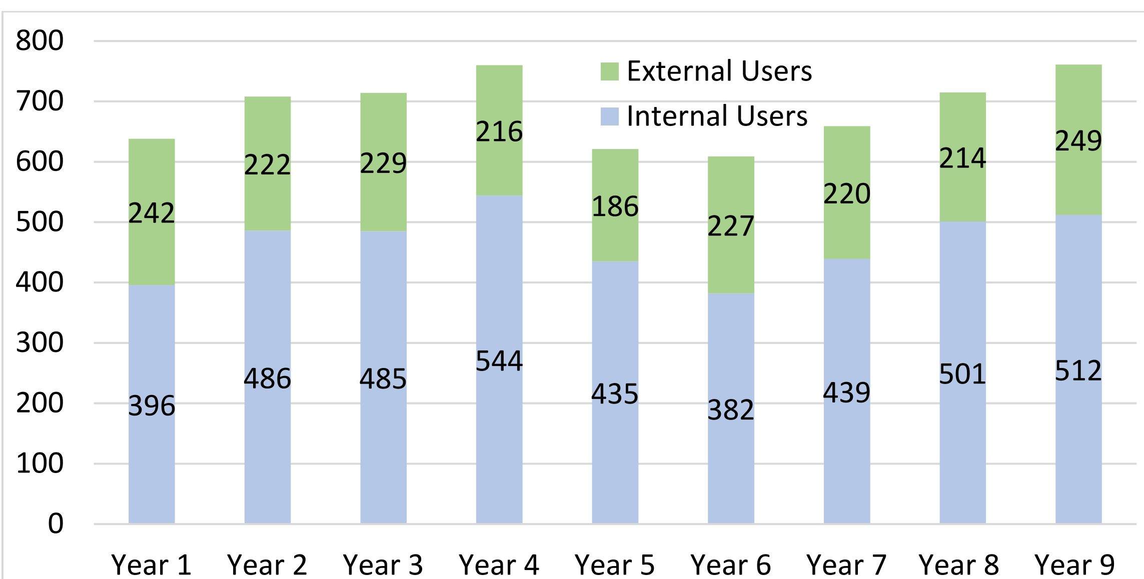
NNCI Seed Grants: With the renewal of the NNCI program in 2020, we obtained funding for seed grants with the goal to recruit new users with innovative applications of nanotechnology to the NNI facilities. COVID prevented us from conferring any awards in Year 6, however, in Years 7 through 9 we were able to fund a total of 10 seed grants, which were further supplemented with resources from the UW Institute for Nano-engineered Systems and the College of Engineering.

Regional Technology and Innovation Hubs (Tech Hubs): UW is collaborating with Montana State University in a new NSF Accelerating Research Translation award. This program seeks to speed and scale translational research and jumpstart economic development in geographically isolated and historically under-resourced innovation ecosystems. With its established, robust entrepreneurial ecosystem centered at CoMotion, its campus-wide technology transfer division, UW will act as a "mentor" for Montana State University.

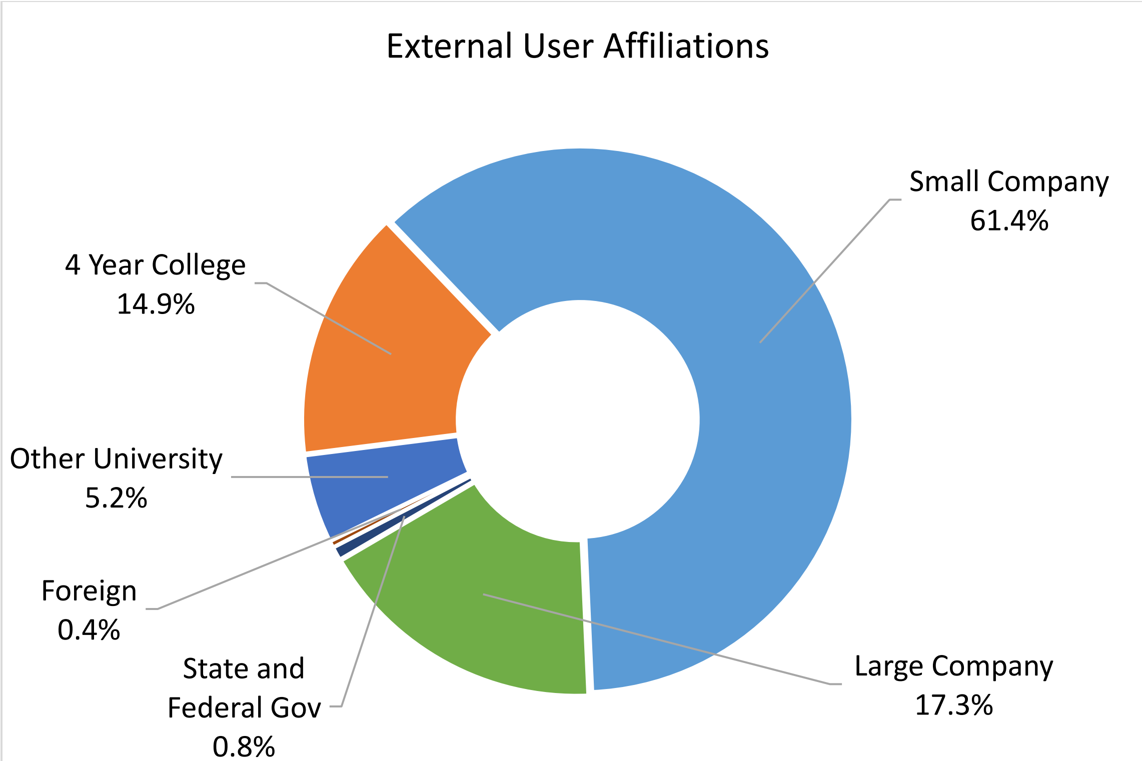
The Corvallis Microfluidics Tech Hub and the Pacific Northwest Mass Timber Tech Hub aim to establish global leadership, respectively, in microfluidics for semiconductor cooling and in mass timber design and manufacturing.

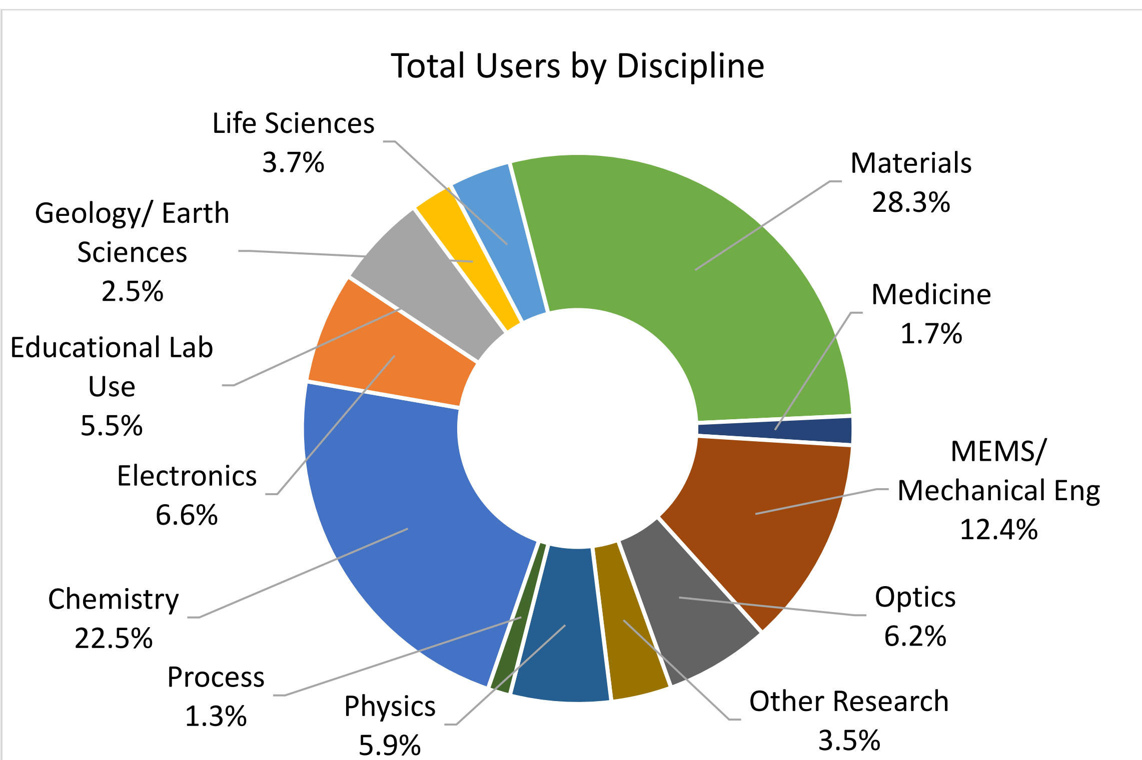
NNI Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	638	708	714	760	621	609	659	715	761
Internal Cumulative Users	396	486	485	544	435	382	439	501	512
External Cumulative Users	242 (38%)	222 (31%)	229 (32%)	216 (28%)	186 (30%)	227 (37%)	220 (33%)	214 (30%)	249 (33%)
Total Hours	38,350	46,562	55,925	65,032	55,939	72,122	60,027	52,784	51,854
Internal Hours	21,822	30,600	27,695	35,564	22,262	26,740	29,379	26,864	25,441
External Hours	16,528 (43%)	15,962 (34%)	28,230 (50%)	29,468 (45%)	33,677 (60%)	45,382 (63%)	30,648 (51%)	25,920 (49%)	26,413 (51%)
Average Monthly Users	267	277	266	304	226	252	265	282	321
Average External Monthly Users	103 (39%)	98 (35%)	93 (35%)	93 (31%)	77 (34%)	88 (35%)	85 (32%)	87 (31%)	113 (35%)
New Users Trained	126	159	206	134	64	115	186	170	153
New External Users Trained	41 (33%)	37 (23%)	57 (28%)	31 (23%)	18 (28%)	31 (27%)	56 (30%)	45 (26%)	16 (10%)
Hours/User (Internal)	55	63	57	65	51	70	67	54	50
Hours/User (External)	68	72	123	136	181	200	139	121	106



NNI Year 9 User Distribution





12.11. Research Triangle Nanotechnology Network (RTNN)

Facility, Tools, and Staff Updates

Tools: In Year 9, 12 new instruments valued at >$9.7 million were acquired or ordered, including a Durham Magneto Optics ML3 Pro Direct Write Lithography (DWL) tool, a JEOL JEM-ARM300F2 High Resolution Scanning Transmission Electron Microscope (S/TEM), a Thermo Fisher Scios 2 HiVac Gallium Ion Focused Ion Beam (Ga-ion FIB), a ThermoFisher Helios 5 CX FIB, a Nu (AMETEK) Sapphire Multi-Collector Isotope Ratio Mass Spectrometer (MC-ICP-MS), a Trion Minilock III Inductively Coupled Plasma Reactive Ion Etcher (ICP-RIE), a Glow Research Autoglow 200 plasma etcher, a Tepla Gigabatch 310M plasma etcher, a ThermoFisher RaptIR + is50 Fourier Transform Infrared (FTIR) Spectrometer, a Malvern Panalytical Zetasizer Ultra Dynamic Light Scattering instrument, a Rame-Hart Model 290 Goniometer/Tensiometer, a Labconco Free Zone 2.5 Lyophilizer for benchtop freeze drying, and a Disco DAD3240 Dicing Saw.

Techniques: An RTNN facility added an EDS detector to their Hitachi FlexSEM 1000II to allow elemental analysis along with SEM imaging. We've also developed two new processes, including a methane/hydrogen-based diamond-like carbon deposition process, as well as a new process to obtain heteroepitaxial deposition of Ni on sapphire substrates using high temperature (300°C) sputtering.

Staff: Renata Garces was hired as an Engineer at SMIF to primarily offer user training and support in the newly formed Soft Materials Lab. Cynthia Corley joined CHANL as a Laboratory Manager and will provide methods development and technical support to the research community as well as manage and maintain the newly acquired instrumentation. NNF hired two new Research Engineers, Erik Vick and Borys Kolasa, who will both support operations and training in the cleanroom, as well as two undergraduate assistants (Will Allion and Adam Davis). Four of these individuals are represented in the photos at right.

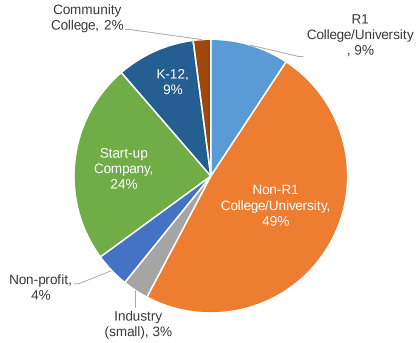
New RTNN staff/personnel, from left to right: Renata Garces (SMIF Engineer), Cynthia Corley (CHANL Laboratory Manager), Borys Kalasa and Erik Vick (NNF Research Engineers).

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.

Satisfaction: RTNN continually assesses its facility users and programs. The RTNN Assessment team is associated with PCOST (Public Communication of Science and Technology) at NC State. Unique surveys are used for collecting demographic and user satisfaction data from various RTNN programs. Surveys are hosted on Qualtrics, the analysis was done on SPSS with some original SAS coding, and all surveys are IRB-approved. Overall, facility users who responded to the survey were very satisfied with their experiences in the facility they used in Year 9 (6.30 ± 1.01 on a 7-point Likert scale where 7=very satisfied, n=272). This level of satisfaction was consistent with responses from previous RTNN years (Year 8: 6.31 ± 1.13, n=238). 99.6% of users (n=274) indicated that they would return to the lab they utilized if further work was necessary.

RTNN Kickstarter Program: This program supports use of the facilities by new, non-traditional users by providing free initial access. To date, 105 projects have been awarded (Year 9: 7 projects). The figure below shows the affiliations of the program participants. Most participants are from non-R1 colleges/universities (49%), start-ups (24%), while K-12 students/classrooms make up about 9%. 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 >$337,500 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 reveal 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.

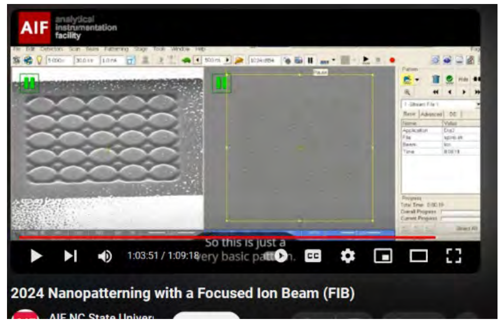


Affiliations of participants in the Kickstarter program (n=105).

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. Figure 3 shows a representative screenshot of a laboratory video. **Since the course launch, over 327,000 (Y9: >26,300) people have visited the course website, more than 68,100 enrolled (>6,100 in Year 9), >43,100 engaged with a part of the course (>4,200 in Year 9), and >13,700 completed all course components (>1,600 in Year 9).** Several participants have engaged with RTNN outside the course (e.g., Kickstarter program, workshops, newsletter subscription). *Assessment:* Coursera also collects reviews and learner stories. One example review in the present reporting year stated: "*WOW, Thanks a lot for making this course, we learned a bit of the material in my class -but how the information and relationships between concepts are structured in this course are something else. Truly, thanks!*" To supplement the data analytics procured by the Coursera platform, we developed a survey instrument that is sent to learners upon completion of the course. The data were collected from March 12, 2023 – March 29, 2024. We received 422 completed surveys. (Note: Only students who completed the course received the survey). On a Likert scale with 7=Very Satisfied, the mean of each question was consistently >6. Overall, students were very satisfied with the course with measures for course materials, multimedia content, and instruction. >89% of respondents noted that they were likely or very likely to recommend the course to others. 71% of respondents noted that they had a better knowledge of the capabilities of this NNCI Site (RTNN).

Screenshot of a video filmed for "Nanotechnology, A Maker's Course" with a demonstration of TEM sample preparation.

Workshops, short courses, symposia: In Year 9, the RTNN held 14 short courses (mostly in-person or with hybrid virtual components) with over 140 participants. Instrument-focused short courses introduce tools and techniques to provide a foundation for subsequent training on a specific tool, e.g., as in figure at right. Workshop topics are selected based on user input as well as unique and new capabilities at our site, which results in events that are relevant, useful, and well-attended. We continue to develop new workshops and short courses designed to familiarize users with new equipment and state-of-the-art techniques. For example, in response to user input, AIF began hosting Rietveld Refinement Workshops for XRD analysis (led by PI Jones) in Year 9.



Screenshot of a short course by Nicky Cates, from Smart Material Solutions, on nanopatterning with focused ion beams that is also uploaded to YouTube.

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 2023 (Year 9), this in-person event drew over 104 participants (see photo).

Students from all across NC present and discuss their work in a poster session at Carolina Science Symposium 2023.

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. We also maintain two subscription lists to share information and opportunities: one to principal faculty (>260 PIs) and one to other stakeholders (>3,800 subscribers). The RTNN actively promotes activities, events, and opportunities on multiple social media platforms including X (formerly Twitter), Facebook, and LinkedIn.

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 and interfaces: metamaterials, nanomaterial and nanostructure interfaces. Research Highlights are provided as supplementary slides. Scholarly and Economic Impact: Work performed in the RTNN led to >206 publications in 2023 by our users (163 of which cited the NNCI award number). 40 of these publications were authored by external users (30 cited the NNCI award). Work performed in the facilities led to >180 patents filed and >43 patents awarded in 2023.

Education and Outreach Activities

The 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 several RTNN educational and outreach activities and the numbers of participants reached by those programs in Year 9.

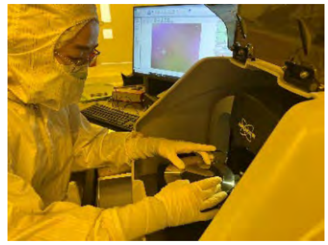
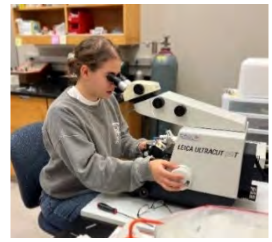
Based on growing societal needs for workforce development in high technology areas including but not limited to semiconductors and microelectronics, in Year 9, we intentionally started to differentiate between "*outreach*" in the conventional definition and "*early workforce development*." We define **early workforce development programs** as those that go beyond exposure to concepts and include learning or training modules over *multiple* interactions. An example of an early workforce development program in Year 9 is the Engineering for US All (e4usa) program that engages rural students in a 1-year, project-oriented engineering class at a local university (in our case, an RTNN nanotechnology facility embedded within the university).

Year 9 Education & Outreach Events. Evaluated programs are highlighted.

	Participants
Kickstarter Program	6
Engaged learners in Coursera course on nanotechnology	>4,200
In-Person Outreach Events	>4,600
Remote outreach events (e.g., SEM demonstrations in classrooms)	>300
Short courses, workshops	>140
Conferences	104
Total	>9,350

In-Person Programs: Year 9 maintained strong momentum for in-person outreach programs and events. One program to highlight is Girl Scouts STEM Day @ Duke, which developed through a cultivated relationship with youth organizations in our state to expand our reach to K-12 students outside the Research Triangle and into rural areas. The RTNN collaborates on this program, in partnership with the Triangle Women in STEM, Duke's Pratt School of Engineering and Trinity College of Arts and Sciences, Credit Suisse, and IBM, to host North Carolina girls as well as Girl Scouts and their families at the annual Girl Scouts STEM Day @ Duke. At this event, girls experience hands-on SEM sessions. There are also concurrent sessions where parents learn how to support their daughters in the pursuit of STEM degrees and careers. This event continues to offer a virtual event alternative called "Girl Scouts STEM Power Hour". This virtual component enables us to engage with more rural participants than our traditional on-campus event, including participants from across the country and members from two NC Native American tribes. As a result of the success of the virtual format, we continue offering a virtual event to complement the in-person activities. The most recent in-person Girl Scouts STEM Day in May 2024 drew 311 participants and volunteers.

Education and Experiential Learning: RTNN staff and facilities are a powerful enhancement to courses available in our network including Class-Based Explorations, Advanced Physics Laboratory Experiences, and the availability of staff and facility access to supplement topical courses like Wide Bandgap Semiconductor Device Fabrication/Technology or Biological Electron Microscopy techniques. A concerted effort is also made to maintain a strong connection to local community colleges in the Triangle ecosystem: Dr. Phil Barletta, NNF Director of Operations, continues to engage in a program with Durham Technical Community College, where he lectures

RTNN CC Interns Angelina Yang analyzing samples on a profilometer (top) and Izzy Smith preparing biological samples for TEM via ultramicrotomy (bottom).

on micro- and nanofabrication to rotating cohorts (10-15 participants) of processing and equipment technicians from Wolfspeed/Cree, Inc. In Year 9, the first group of students completed RTNN Community College (CC) Internships, and new program participants started their internships. The CC Internship program supports students actively enrolled at local community colleges to work in an RTNN core facility with professional staff during the academic year, with the goal to facilitate their subsequent transfer and matriculation at a major research university. This year, Angelina Yang, who is currently pursuing her Associate of Engineering degree from Wake Technical Community College (WTCC) and Isabella "Izzy" Smith, also a student at WTCC pursuing her Associate of Science, are the new CC interns. The photos above show the interns working in the laboratories. RTNN staff and facilities are also leveraged considerably in other NSF programs, including a collaborative Research Experience for Undergraduates (REU) site focused on hybrid perovskites that welcomed 12 new participants and a Research Experience for Teachers program that hosted 8 teachers in Year 8. All 12 REU students from the Summer 2023 cohort attended the NNCI REU Convocation at the Montana Nanotechnology Facility (MONT).

RTNN representatives receive the Opal Mann Green Engagement and Scholarship Award from NC State, the university's highest honor for community engagement.

In Year 9, the RTNN's engagement and outreach activities were recognized at the university level. The RTNN was awarded the Opal Mann Green Engagement and Scholarship Award from NC State University, the university's highest honor for community engagement (photo at left). The recognition is awarded to a team of individuals whose significant accomplishments have demonstrated excellence and who practice collaborative democratic strategies of responsiveness, respect for partners, academic neutrality, accessibility, integration, coordination, and resource partnerships.

<u>SEI Activities</u>

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 is currently engaged with the NNCI Research Community on Convergence Research to determine how nanoscience and availability of lab support contributes to some facets of geoengineering that may be able to impact concerns regarding climate change (presented at meetings of the Society for Risk Analysis and Sustainable Nanotechnology Organization).

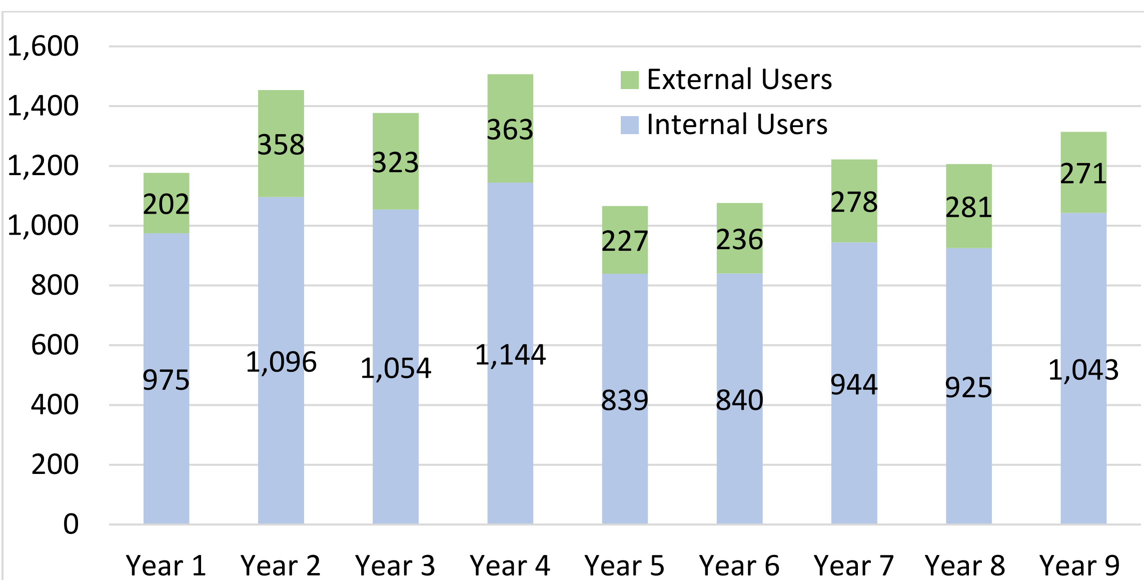
<u>Innovation and Entrepreneurship Activities</u>

The RTNN serves a critical role in innovation and entrepreneurship through facilities, expertise, and programs. The majority (52%) of companies in Year 9 that used 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 27% of all Kickstarter recipients are either start-up/small companies. The RTNN is also in connection with local start-up incubators including Alexandria LaunchLabs, American Underground, Innovate Raleigh, First Flight Venture Center, and North Carolina Small Business and Technology Development Center. RTNN also sponsored two different student teams in the 2024 NNCI Nanotechnology Entrepreneurship Challenge (NTEC) lead by NanoEarth: Apex Analytics (lead by a senior in Industrial Systems Engineering) and OneOK (lead by a postdoc in Materials Science and Engineering).

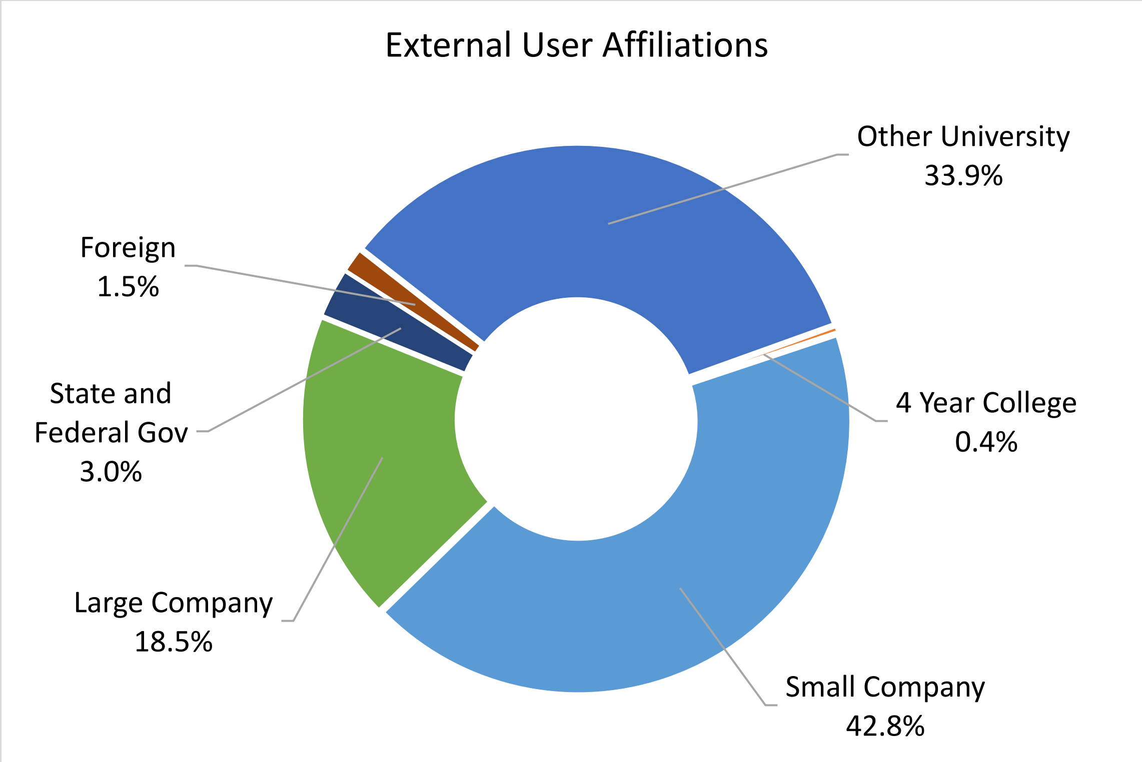
Many start-up companies spin out of RTNN universities and continue to use our facilities in their operation, with notable ongoing success stories including: Qatch Technologies, Smart Material Solutions, Adroit Materials, Cell Microsystems, Third Floor Materials, Voxel Innovations, IonQ, InSomaBio, Isolere Bio, Tyrata, and many more. Codetta Bioscience is a spin-out that has raised >$17M in the past 2 years in Series A funding (among other sources). These companies alone have received >$75 million altogether in SBIR/STTR and other funding.

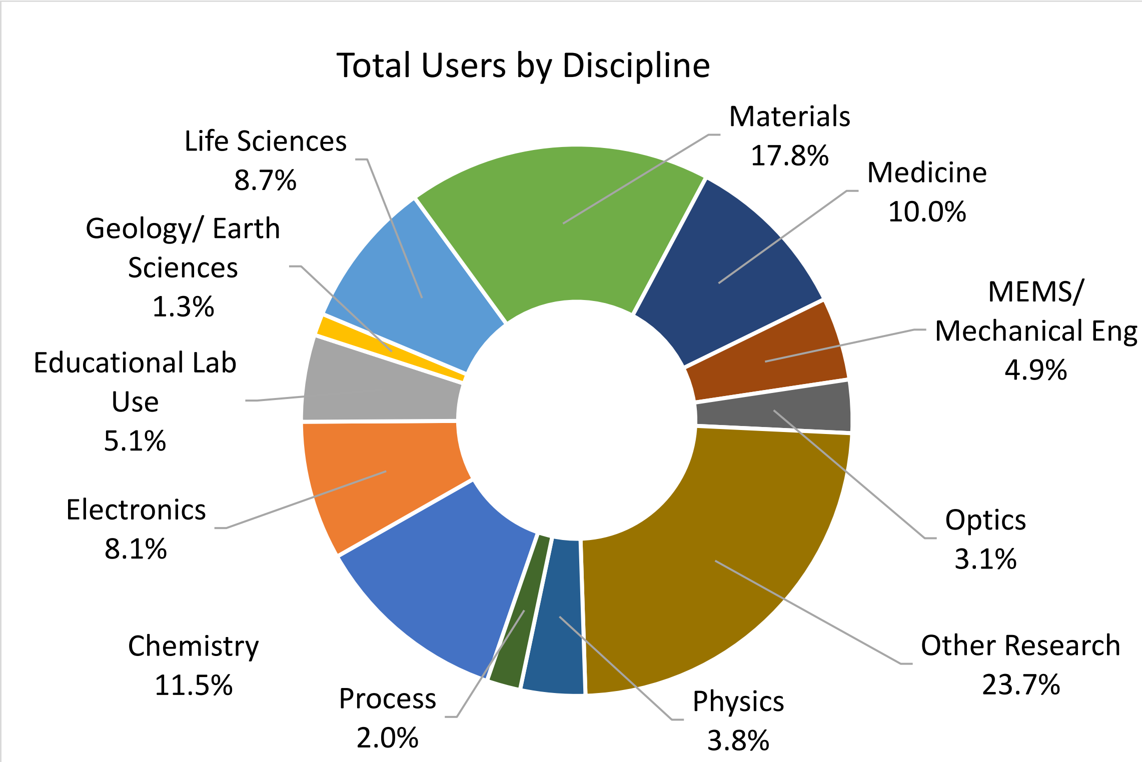
RTNN Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	1,177	1,454	1,377	1,507	1,066	1,076	1,222	1,206	1,314
Internal Cumulative Users	975	1,096	1,054	1,144	839	840	944	925	1,043
External Cumulative Users	202 (17%)	358 (25%)	323 (23%)	363 (24%)	227 (21%)	236 (22%)	278 (23%)	281 (23%)	271 (21%)
Total Hours	53,044	51,747	55,684	61,404	43,099	53,491	51,211	50,150	58,905
Internal Hours	46,908	43,053	46,422	49,685	33,636	43,209	40,837	40,958	49,963
External Hours	6,136 (12%)	9,694 (17%)	9,263 (17%)	11,719 (19%)	9,463 (22%)	10,282 (19%)	10,374 (20%)	9,192 (18%)	8,943 (15%)
Average Monthly Users	395	422	420	445	308	352	396	397	450
Average External Monthly Users	50 (13%)	63 (15%)	71 (17%)	74 (17%)	53 (17%)	67 (19%)	78 (20%)	80 (20%)	76 (17%)
New Users Trained	433	527	695	627	288	435	492	449	564
New External Users Trained	71 (16%)	69 (13%)	82 (12%)	102 (12%)	54 (19%)	74 (17%)	60 (12%)	75 (17%)	75 (13%)
Hours/User (Internal)	48	39	44	43	40	51	43	44	48
Hours/User (External)	30	24	29	32	42	44	37	33	33



RTNN Year 9 User Distribution





12.12. San Diego Nanotechnology Infrastructure (SDNI)

Facility, Tools, and Staff Updates

Facility: The San Diego Nanotechnology Infrastructure (SDNI) offers technical strengths in the areas of Nano/Meso/Metamaterials, NanoBioMedicine, NanoPhotonics, and NanoMagnetics. SDNI's strategic goals are to (1) provide infrastructure that enables transformative research and leverages San Diego's innovation ecosystem, which includes major research institutes (UCSD, Salk, Scripps, Craig Venter, etc.) and over 2,000 companies employing more than 60,000 scientists and engineers; (2) accelerate the translation of discoveries and new nanotechnologies to the marketplace and support entrepreneurship and innovations; (3) support and advance the nation's nanotechnology infrastructure; and (4) collaborate with the California Board of Education and local school districts to develop education and outreach programs which promote STEM efforts in high school and community colleges, especially at schools with high populations of underrepresented minority (URM) students.

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 operation of all the SDNI facilities is managed by the Facility Online Manager (FOM) system, which streamlines the operation, record keeping, and accounting processes.

In 2023-2024, SDNI has made two bold initiatives that are unique to a university nanofabrication facility: (a) working with an industrial partner (PDF Solutions) to **apply AI/ML to analyze the processing data and optimize the operation of the tools** and (b) establishing the **first GMP (Good Manufacturing Practices) facility for FDA approved medical devices within a university environment.**

Tools: SDNI invested $1.1M to upgrade chemical fume hoods in the Nano3 cleanroom facility. The new fume hoods are built with fire safe material FM-4910 CPVC and have many new features such as quick dump rinse tanks and cup sink to the dual-carboy waste collection system.

Through a loan issued by the Qualcomm Institute, SDNI invested $750,000 to acquire an advanced new tool: Oxford PlasmaPro 100 Cobra 300 plasma dry etch system. This new equipment is designed and configured for deep silicon etch using Bosch and Pseudo Bosch processes with high etch rate and selectivity to silicon oxides and photoresists. It also offers a cryo-silicon etching capability to achieve a sidewall roughness of less than 5nm. In addition, the new system is configured to have the capability of atomic layer etch (ALE) for fluorine-based chemistries. The ALE capability can satisfy new research needs, expanding SDNI's user base and impacts. In addition, many existing tools have been upgraded or replaced with newer models to improve the overall performance and efficiency.

Staff Update: In September 2023, SDNI hired Dr. Fubo Rao as the new technical director of the Nano3 facility after a one-year candidate search. Before joining SDNI, Dr. Fubo Rao was the cleanroom manager of the Center for Nanoscale Materials (CNM) at Argonne National Laboratory. At CNM, Dr. Rao managed the 18,000 sq. ft. class-100 nanofabrication cleanroom facility which is a hub for more than 600 academic and industrial users.

SDNI also hired a lead processing engineer, Dr. Kin Wong, to develop advanced processes and improve customer support. Before joining SDNI, Dr. Wong was a research staff scientist at UCLA for over 10 years, specializing in nanofabrication for quantum materials and devices. With additional funding from the Microelectronics Commons program, funded by the CHIPS and Science Act, SNDI hired an equipment engineer, Tim Watson, and a postdoc Jeongho Ma. Mr. Watson has 30 years of professional experience in semiconductor equipment and process and has been a business owner to serve clients in semiconductor industry. Dr. Ma is specialized in advanced process for nanophotonics and biomedical devices. He helps train and mentor student interns, develop and characterize new materials and processes for sensors, MEMS, and packaging.

User Base

In the last 12 months, SDNI facilities have had more than 58,000 hours of facility usage by 780 users from various universities, academic institutions, as well as local and national businesses. 25% of the users are from companies. **37% of the users have used our remote services.** In the last 12 months, more than 200 new users were trained by SDNI facility staff. The work that used SDNI facilities has resulted in 140 publications and 8 patents. In 2023, **SDNI supported 167 students to receive their degrees, including 78 Ph.D. degrees and 61 M.S. degrees.**

SDNI facilities have been valuable resources for local and national business. Users from 69 companies used the SDNI facilities. Among them are large companies such as Apple, Qualcomm, Illumina, ASML, Northrop Grumman, Raytheon, Teledyne Technologies, General Atomics, etc., and many start-up companies such as Fabric8labs, Roswell Biotechnologies, Obsidian Sensors, Armonica Technologies, Avery Digital Data, etc.

The total number of usage hours in Year 9 is 6.5% higher than Year 8. The increase is mainly contributed by internal users. There is a decrease in the external users largely due to transfer of activities from SDNI to users' own newly established facilities for scaling up. Although the situations tentatively impacted our usage, we considered them a success since it demonstrated how SDNI has contributed to the growth of the new businesses and economy.

One notable achievement in terms of user recruiting is to admit Apple as a user of the facility. UCSD, SDNI and Apple have worked diligently for several months to finalize the service agreement terms and conditions. This is one of few cases that Apple uses external user facilities for corporate R&D, and we are happy to share our experience with other NNCI sites, if interested.

Overall, the number of external users continued to be high, which shows the value of providing well-maintained tools and fabrication expertise for businesses in Southern California and across the nation.

Research Highlights and Impact

SDNI offers unique tool sets, skills, technical support, mentorship, and services to produce innovative materials and devices that will help the nation to gain competitive advantages in the areas of next generation semiconductor technologies, artificial intelligence (AI), advanced manufacturing, semiconductor packaging, quantum information science (QIS), and 5G/6G communications. The SDNI facility plays a pivotal role in research pursuits that align with NSF's "10 Big Ideas" for the future and semiconductor research as the nation's new initiative under the CHIPS and Science Act. Discoveries made by users of the SDNI have the potential to create transformative changes in fields critical to the future of human society and national interests. In the past 12 months, the SDNI facilities have supported over 140 scientific publications and 8 patents from over 130 groups from academic institutes, government labs, and companies.

Here we highlight fundamental and applied research, cutting-edge technology development, and translational research that has demonstrated significant impact and is in alignment with the nation's initiative in semiconductors and NSF Big Ideas, particularly in the areas of convergence research, understanding the rules of life, and laying the foundation for the midscale infrastructure to support science beyond 2026.

SDNI has supported the development of an intracranial electroencephalogram (iEEG) microdisplay (published in Science Translational Medicine, doi: 10.1126/scitranslmed.adj7257) to **overcome limitations in current functional brain mapping**. The iEEG consists of free-standing arrays of 2048 GaN light-emitting diodes (μLEDs) laminated on the back of micro-electrocorticography (μECoG) electrode grids to enable real-time iEEG recordings and optical display of cortical activities.

SDNI also supported the **breakthrough in solid-state batteries through the discovery of a new cathode material, $S_{9.3}I$.** The research team demonstrated a new cathode material (published in Nature, https://doi.org/10.1038/s41586-024-07101-z) for solid-state lithium-sulfur batteries that is both electrically conductive and structurally healable—features that overcome the limitations of these batteries' current cathodes. This discovery has the potential to store up to twice as much energy per kilogram as conventional lithium-ion batteries to double the range of electric vehicles without increasing the battery pack's weight. Additionally, the use of abundant, easily sourced materials offers an economically viable and environmentally friendlier choice.

SDNI also plays a crucial role in the demonstration of three-dimensional (3D) bioprinting techniques that have emerged as the most popular methods to fabricate 3D engineered tissues to help scientists discover the rules of life, the complex biological ecosystems, and fundamentals in disease development and progression. In the work published in Science Advances (doi/10.1126/sciadv.ade79230), scientists have found ways to address the challenges of simultaneously satisfying the requirements of high cell density (HCD), high cell viability, and fine fabrication resolution by including iodixanol in the bioink. The 3D bioprinting technology has been successfully commercialized and its application has been extended to studies of the ecology of coral reef and living organisms-on-a-chip, helping scientists to understand the rules of life.

In addition to advancing sciences, SDNI has been a great asset to help industries commercialize cutting edge technologies, producing high economic impact. The prominent examples in 2023 include SDNI's assistance of a biotech startup company, Armonica, and a large company, Qualcomm, to overcome key technology hurdles. With its state-of-the-art e-beam lithography and nanofluidic technologies, SDNI engineers helped Armonica develop the third generation DNA sequencing technology, which uses metamaterial enhanced Raman signal to read ultralong (over 100,000 bases/run) DNA without labelling or amplification, a breakthrough from the current sequencing technique. SDNI engineers also fabricated optical metamaterial structures for Qualcomm to demonstrate silicon metalenses capable of supporting fully silicon integrated SWIR sensing.

SDNI has also contributed significantly to the CHIPS and Science Act. Under the CHIPS Act ME Commons program, UCSD has become a key member of CA DREAMS, a technology hub in southern California. The SDNI facility is one of the designated facilities to support semiconductor technologies for 5G/6G communications and electromagnetic warfare. The SDNI facility also participated in the CHIPS Act National Advanced Packaging Manufacturing Program (NAPMP) to produce advanced substrates and substrate materials for 3D heterogeneous integration. Above all, the success in the production of high-density, wirelessly controlled neural probes manufactured at the SDNI facility has led to the construction of **the nation's first GMP facility in medical devices within a university environment.** In the same vein, several key nanofabrication technologies have succeeded or in the path of success in transitioning from university laboratories to manufacturing. This includes successful back-end-of-line (BEOL) integration of disordered materials (a-Si) into SiGe BiCMOS process by Tower Semiconductor and ongoing effort of integrating novel RRAM process with CMOS.

Education and Outreach Activities

We have been working diligently to **integrate nanotechnology contents to K-12 NGSS-aligned science curricula** as well as community college programs in California. In 2023, we carried out strong workforce development programs that included: 1) training and retaining 20 interns at SDNI and assigning them to nanofabrication and characterization tasks, 2) providing hands-on nanofabrication and characterization training to 2 cohorts of veterans who successfully graduated. This effort is part of a collaboration between Southwestern College and Penn State University, 3) joining forces with Southwestern College to help SWC start a nanotechnology program targeting the general STEM student population. This pilot effort, partially supported by an NSF ATE grant, will train 36 students within the next 3 years. Finally, being a member of the Southern California hub (CA DREAMS) under the CHIPS Act Microelectronics Commons program, SDNI facilities have been used to develop workforce for the domestic semiconductor industry.

K-12 Education and Outreach: SDNI's education and outreach efforts include tours and presentations for K-12 students, nanotechnology lesson development for middle and high school science classes, live scanning electron microscopy sessions for remote high school science classes, nanotechnology summer institute for middle and high school teachers, and REU programs.

Students from the Carlsbad School District (California) attending presentations given by young scientists who shared their life journey as a scientist and provided guidance to students regarding STEM education and career possibilities.

Since 2021, SDNI has maintained its position of **top performer of the nationwide RAIN** (Remotely Accessible Instruments for Nanotechnology) network that includes 28 institutions across the nation. In 2023, we continued to perform remote scanning electron microscopy (SEM) sessions with K-12 and community college students as well as on-site sessions. During these sessions, students were introduced to the basic principles of microscopy and the difference between optical and electron microscopy. A large library of specimens including nanoparticles, nanophotonics, semiconductor chips, MEMS, metallic/ceramic structures, and a large variety of biological samples including pollen, phytoplankton and zooplankton from deep sea sediments, butterfly wings, and gecko feet were studied. When performing outreach SEM sessions, we also suggest follow-up assignments and thought-provoking questions about image analyses and feature/function correlations.

SDNI hosted educational visits by middle and high school students: The students visited SDNI nanotechnology facility and learnt the functions of multiple nanotechnology instruments including

E-Beam lithography, photolithography, atomic layer deposition, dry and wet etching, metrology, and electron microscopy. Students also attended presentations on the basics of nanotechnology and its multiple applications (see photo above). As invited speakers, scientists present their research and share their academic and personal journey with the students, encouraging them to enter the STEM fields.

SDNI's Summer Institute for Middle and High School Teachers: It is a week-long program that aims to introduce nanotechnologies to the teachers so that they can teach nanotechnologies in their science classes. SDNI followed through and provided continued support to these teachers during the school year after the training. Since 2021, SDNI has admitted 97 teachers to the Summer Institute, including 30 teachers in the 2024 cohort.

Research Experience for Undergraduates (REU): Since 2020, SDNI's REU summer program has provided a diverse population of 34 undergraduate students with the opportunity to experience nanotechnology related research in state-of-the-art laboratories under the supervision of UC San Diego faculty. Our 2024 REU cohort participated in the NNCI REU Convocation in Nebraska. SDNI will be hosting the 2025 NNCI REU Convocation.

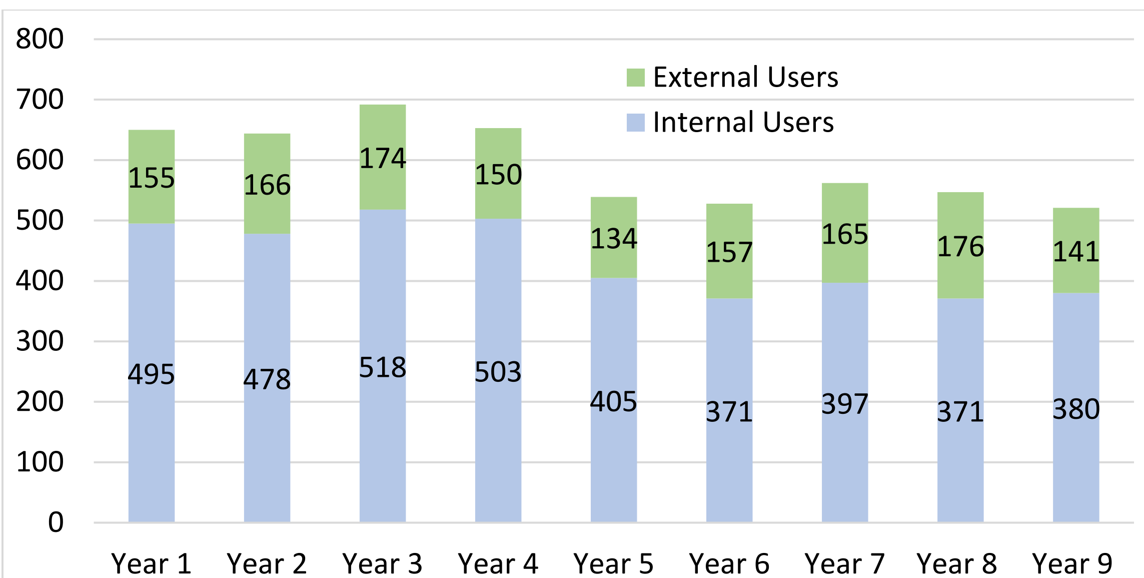
Hands-on Kit for Nanophotonic Education: Silicon photonics is evolving into a multibillion-dollar commercial market and has been identified as a national priority through legislation such as the CHIPS and Science Act. There is an acute lack of photonics workforce and an imminent need to increase the photonics education and training capacity. However, the availability of education in the field of silicon photonics is extremely limited due to the high cost of and difficulties in photonics packaging and the expensive test equipment needed for characterization.

Integrated Photonic Education Kit (IPEK) is a plug & play didactic toolkit that enables hands-on experimental integrated photonics for education institutions.

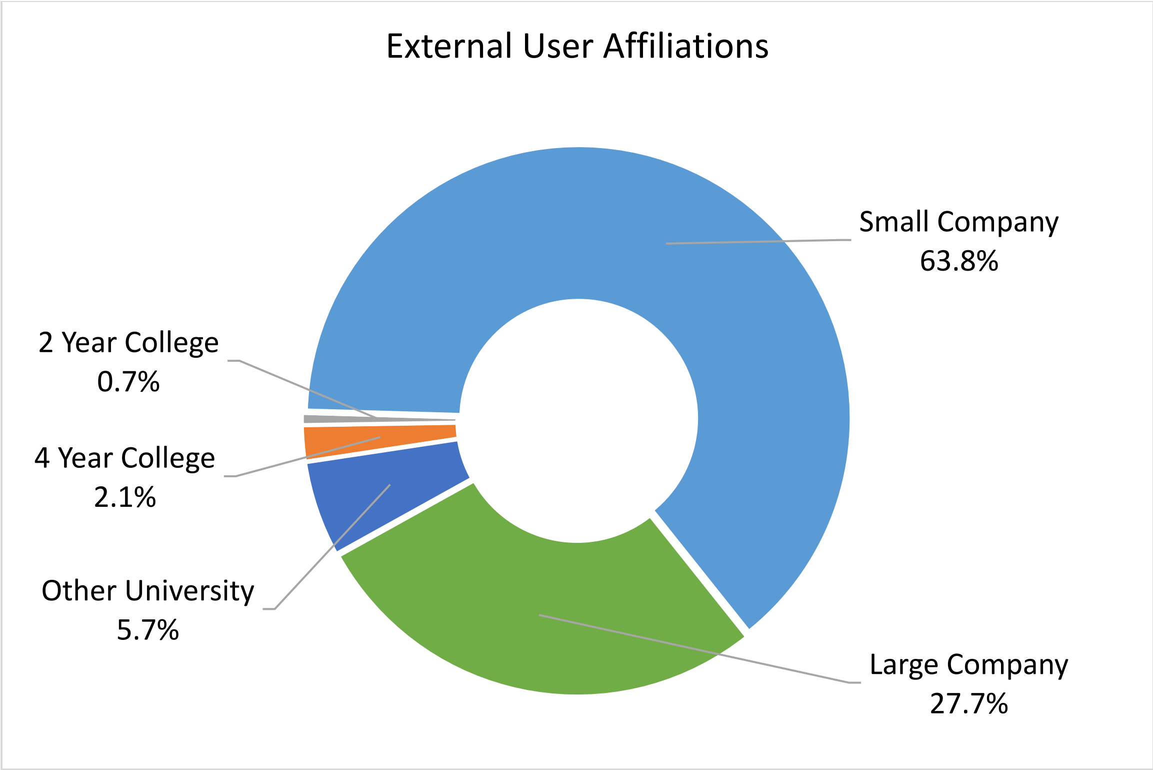
To address this urgent need, a prototype educational toolkit has been developed by the SDNI Chip-Scale Photonics Testing Facility (CSPTF). The **Integrated Photonic Educational Kit (IPEK)** bridges the learning gap by offering a user-friendly and cost-effective solution in the form of a fully packaged photonic educational toolkit. It allows students to experimentally analyze the key building blocks and concepts that form the foundation of all integrated photonics devices, circuits, and systems. SDNI has also delivered several IPEKs to technical schools (Bridgewater State University, Rose Hulman Institute of Technology), universities, and industry, and the demands have increased rapidly. More production runs are being scheduled to provide more prototypes to interested institutions.

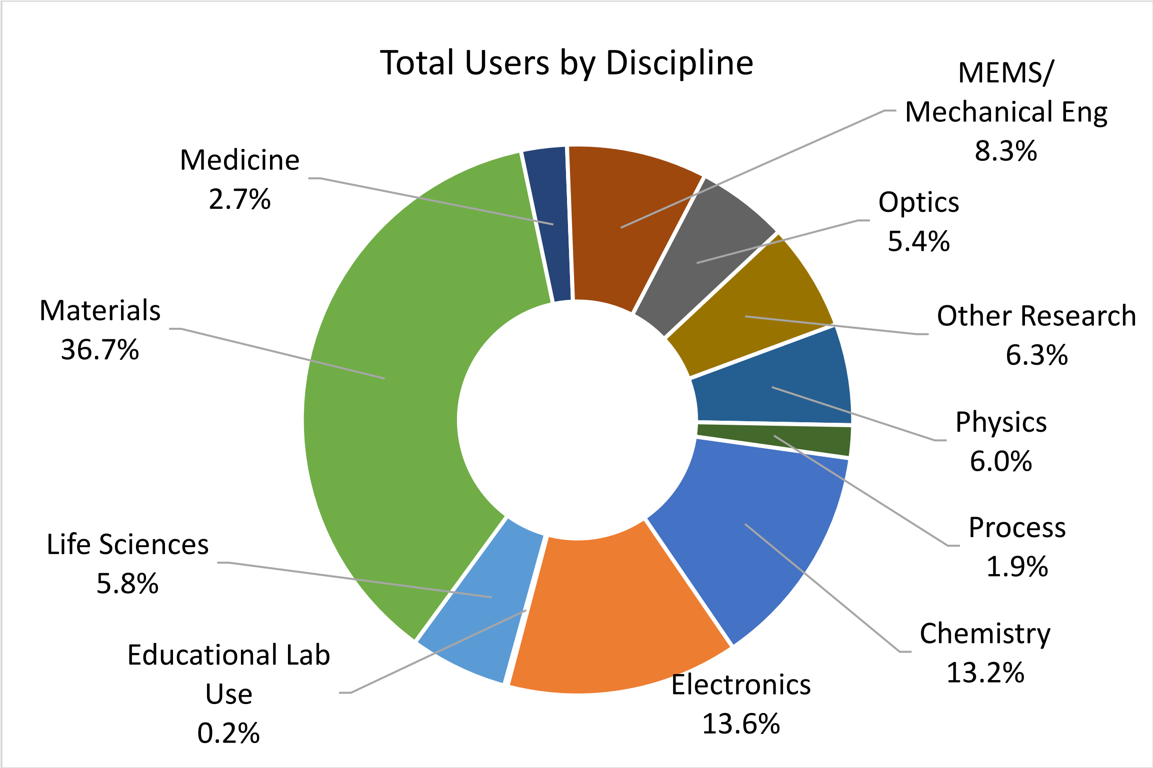
SDNI Site Statistics

Yearly User Data Comparison									
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Total Cumulative Users	650	644	692	653	539	528	562	547	521
Internal Cumulative Users	495	478	518	503	405	371	397	371	380
External Cumulative Users	155 (24%)	166 (26%)	174 (25%)	150 (23%)	134 (25%)	157 (30%)	165 (29%)	176 (32%)	141 (27%)
Total Hours	47,893	50,497	49,519	69,367	53,667	61,111	65,051	58,521	58,240
Internal Hours	40,890	38,890	39,372	56,393	41,316	44,969	45,279	38,781	43,498
External Hours	7,003 (15%)	11,607 (23%)	10,147 (20%)	12,974 (19%)	12,352 (23%)	16,142 (26%)	19,773 (30%)	19,740 (34%)	14,742 (25%)
Average Monthly Users	290	285	300	296	229	234	260	248	238
Average External Monthly Users	49 (17%)	56 (20%)	54 (18%)	50 (17%)	46 (20%)	53 (23%)	63 (24%)	68 (28%)	55 (23%)
New Users Trained	183	210	225	202	169	152	152	152	152
New External Users Trained	34 (19%)	50 (24%)	46 (20%)	40 (20%)	36 (21%)	18 (12%)	18 (12%)	18 (12%)	18 (12%)
Hours/User (Internal)	83	81	76	112	102	121	114	105	114
Hours/User (External)	45	70	58	86	92	103	120	112	105



SDNI Year 9 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 tools, characterization instruments, 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*, CRN (formerly SQI), NUFAB, IMSERC, NUCAPT, JB Cohen XRD, PLD) and the University of Chicago (PNF).

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

SHyNE facilities are actively engaged in acquiring and upgrading key equipment within the facilities through a combination of internal and external funding mechanisms. More than 20 new instruments and tool upgrades valued at over $10M were installed in Year-9. **NUFAB**: AJA Niobium Sputtering system; Plassys Tilt-Angle Evaporator system; SAMCO Deep RIE system; SAMCO PECVD system; Osiris Acid Bench; Air Control Acid Bench; Toho FLX 2320-S Thin Film Stress Measurement System; Keysight Semiconductor Device Parameter Analyzer. **NU*ANCE***: Gatan liquid Helium TEM holder; Thermo/FEI Helios 5 Hydra Plasma FIB; Cryo Industries Cryogenic Stage for TERS-AFM system; Protochips Cathodoluminescence (CL) TEM holder; Thermo NEXSA G2 XPS UV source upgrade; Malvern Zetasizer Advance Series - Ultra (Blue Label); Oxford EDS for FEI Helios FIB; JEOL 3200FS "in-lens filter" TEM; **IMSERC**: Electron single crystal diffractometer, Mass spectrometry for liquids, Electron Paramagnetic Resonance (X, Q-band) Spectrometer; **Cohen XRD**: Xenocs SAXS system upgrade, Rigaku Ultima 3; **NUCAPT**: Advance computer workstations, Leica glove box module, precision polishing system; **PLD**: Annealing Furnace for substrate preparation. **CRN** (formerly SQI): Tunable Resistive Pulse Sensing Nanoparticle Analyzer, Peptide Synthesizer, Flash Chromatography System; **PNF**: new high-speed direct-write optical lithography installed, with plans for two new instruments.

Maintaining an active and engaged user base for SHyNE facilities is contingent upon the successful recruitment and retention of high-quality staff. SHyNE supports over 60 staff members annually, and several new staff joined the SHyNE team in Year-9, two of whom are in newly created positions. **NUFAB**: Diego De La Vega, Core Engineer; Nathan Dvorak, Research Associate; **NU*ANCE***: Dr. Kunmo Koo, EPIC-TEM Research Associate; Dr. Yu Wen, EPIC-FIB Research Associate; Liam Foley, Program Assistant, Marie Taherzadeh-Malmiri, Program Coordinator; **CRN** (formerly SQI): Joe Grzybek, Tessa Lusis; **IMSERC**: Jinlei Cui, Research Associate Professor; **PNF**: Dr Aamer Mahmood, executive director; Dr Alexander Anferov, process engineer; Joseph Chamberlain, process engineer.

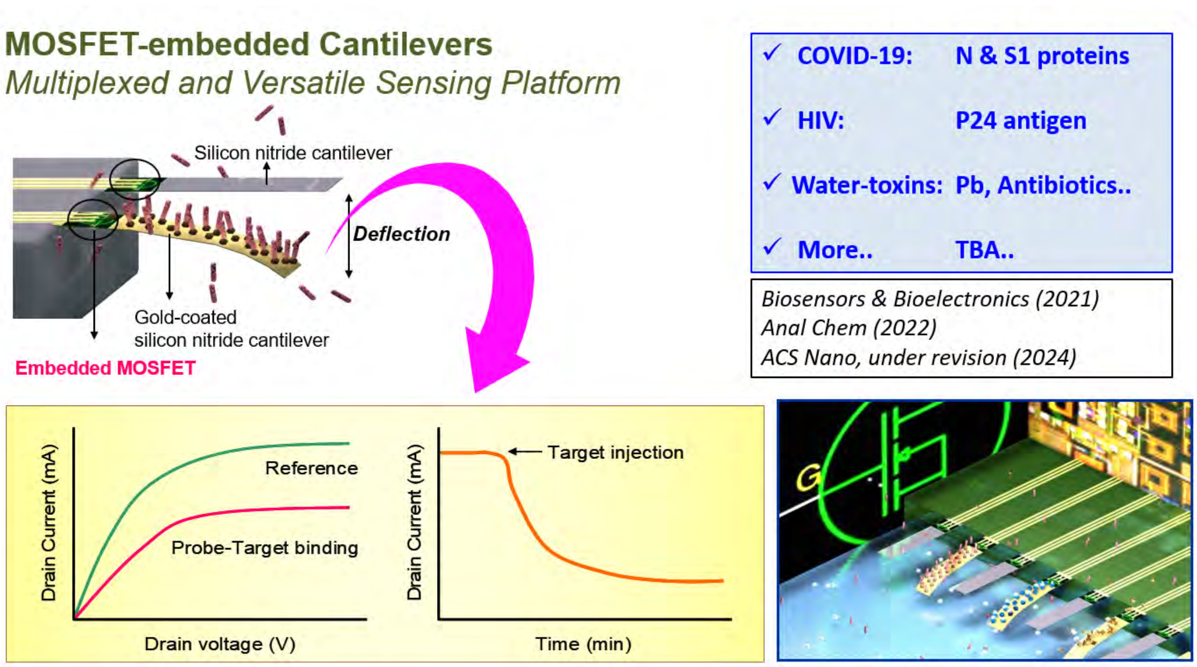
<u>User Base</u>

SHyNE facilities in Year-9 served 1,866 unique users who logged over 225,000 hours of instrument time generating $6.7M in revenue. Northwestern and UChicago shut down in the spring of 2020 for nearly 3 months in response to COVID-19, and utilization gradually rose in subsequent years; in Year-9 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, which began operations in Year-1, had 45 external users in Year-9.

SHyNE actively engages local and regional companies, colleges, universities, non-profit research organizations and governmental agencies to recruit new external users. To this end, several communication strategies are deployed, including exhibitions at conferences and trade shows, production of web portals, highlight 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-9, 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 faculty users (Achinivu, Mathew, Sharma) from University of Illinois at Chicago, federally designated as MSI, AANAPISI, and HSI. In Years 9-10, SHyNE will continue to focus on recruiting additional external academic, industry, and government users through an active engagement campaign including our SEED program.

<u>Research Highlights and Impact</u>

Soft-Hard interfaces have become ubiquitous in many emerging technologies, especially those connecting microelectronics with biology. Physically transient forms of electronics enable unique classes of technologies, ranging from biomedical implants that disappear through processes of bioresorption after serving a clinical need to internet-of-things devices that harmlessly dissolve into the environment following a relevant period of use. John Roger's group developed a

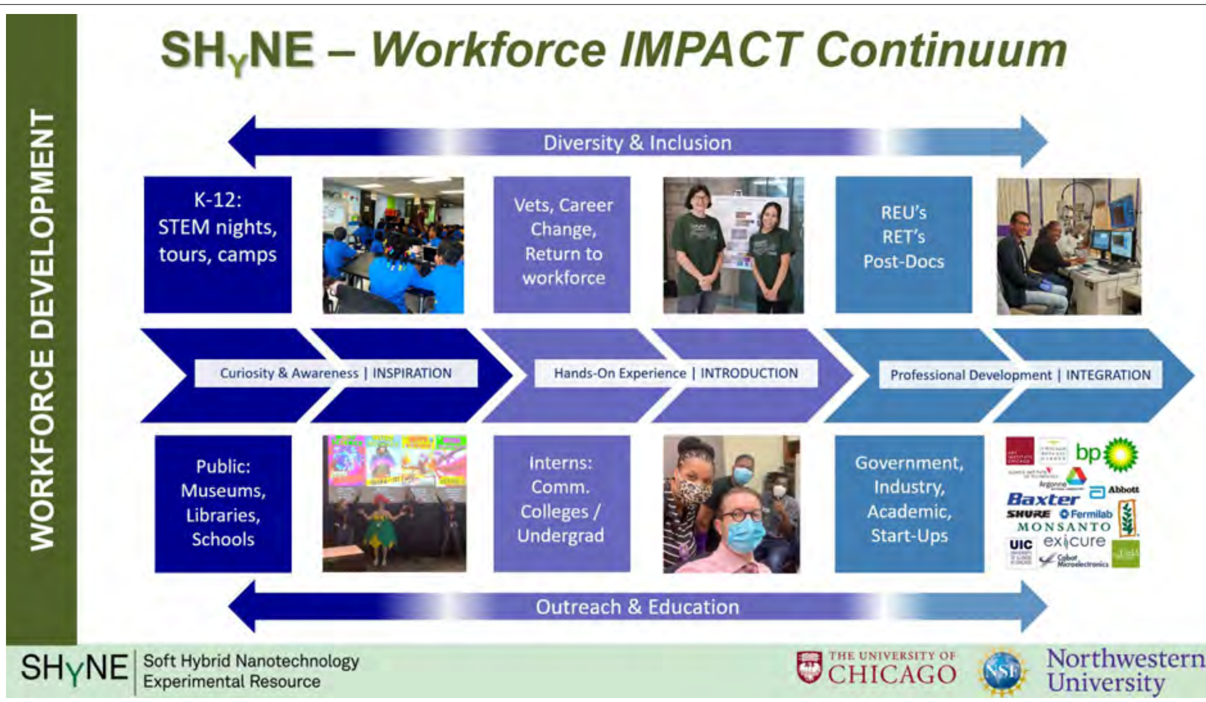


"Multiplexed Antigen-Based Detection of SARS-CoV-2 and Other Diseases Using Nanomechanical Sensors" introduces a novel diagnostic platform that employs nanomechanical sensors for the simultaneous detection of multiple antigens, including those from SARS-CoV-2. These sensors operate by measuring minute mechanical changes upon antigen binding, enabling high sensitivity and specificity in identifying various pathogens. The multiplexing capability allows for the concurrent detection of different diseases, streamlining diagnostics and facilitating rapid, point-of-care testing. This technology holds promise for enhancing diagnostic efficiency, particularly in scenarios requiring the differentiation between pathogens with overlapping clinical symptoms. Provisional Patent number: 702581.02469.NU2023-243.

sustainable manufacturing pathway, based on ultrafast pulsed laser ablation, that can support high-volume, cost-effective manipulation of a diverse collection of organic and inorganic materials, each designed to degrade by hydrolysis or enzymatic activity, into patterned, multi-layered architectures with high resolution and accurate overlay registration. The technology can operate in patterning, thinning and/or cutting modes with (ultra)thin eco/bioresorbable materials of different types of semiconductors, dielectrics, and conductors on flexible substrates. Component-level demonstrations span passive and active devices, including diodes and field-effect transistors. Patterning these devices into interconnected layouts yields functional systems, illustrated in examples that range from wireless implants as monitors of neural and cardiac activity, to thermal probes of microvascular flow, and multi-electrode arrays for biopotential sensing. These advances create important processing options for eco/bioresorbable materials and associated electronic systems, with immediate applicability across nearly all types of bioelectronic studies. This work introduced a new manufacturing process for biomedical devices based on the laser ablation technique utilizing LPKF laser cutting tool in NUFAB. The device performance was evaluated with electrical test probe station, also in NUFAB cleanroom. This new pathway has immediate applications across nearly all types of bioelectronic studies.

Education and Outreach Activities

Educations and Outreach are a 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 video, web and social media communications. In Year-9 we held several major workshops and lectures, assisted with 25 courses, hosted 30+ seminars and exhibitions and provided tours for academic, international, government, and industry participants. SHyNE sponsored eight REU students in a unique, facilities oriented REU program that exposed undergraduates to advanced instrumentation as a key component of their projects. SHyNE also



Schematic of SHyNE approach to workforce development across the K through 'Gray' education spectrum.

participated in the Summer Research Program at US-NNCI Institutions, a cooperative program between the National Nanotechnology Coordinated Infrastructure (U.S.) and the Advanced Research Infrastructure for Materials and Nanotechnology (ARIM)-Japan, hosting a Japanese graduate student for 10 weeks. Over 30 workshops and demos were held, including a SEM workshop with Oxford Instruments and Hitachi, Horiba Seminar and Demo on Cross-correlated SPM and TERS/TEPL Characterization and workshop and demo with Keysight Technologies in collaboration with SHyNE's NUFAB facility on Keysight RF Vector Network Analyzer. 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, high-impact science learning opportunities for underserved youth. Other K-12 outreach included participation in Northwestern's *Career Day for Girls* program and *STEM Shadow Day*. SHyNE also hosted the Midwest Microscopy & Microanalysis Society Spring meeting and the 4th 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 500 registrants from 37 different countries.

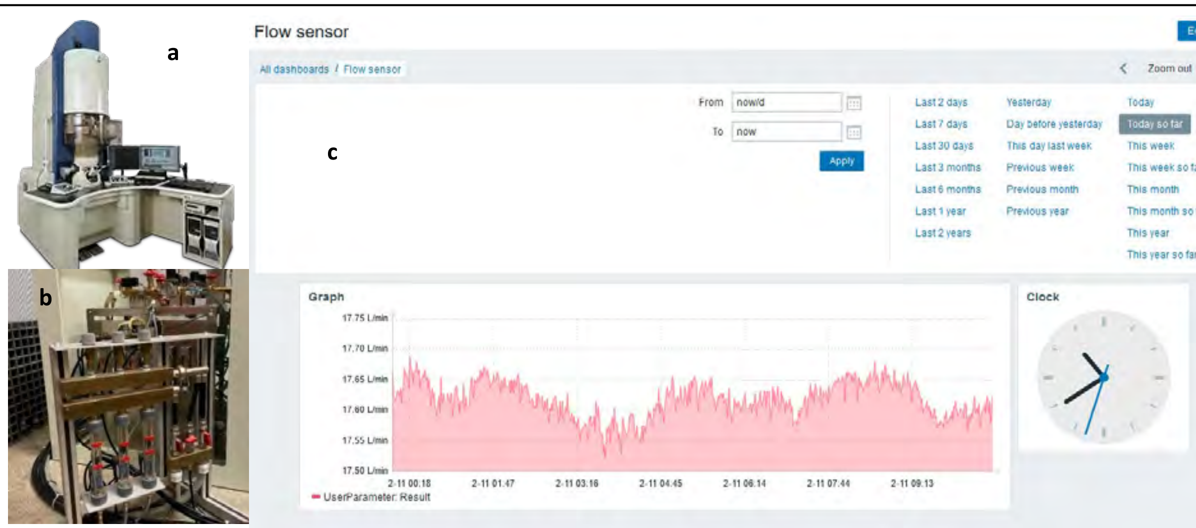
SHyNE Resource, collaborating with Northwestern's Medill School of Journalism and the School of Communication, has established a novel Nano-Journalism focus within the existing Health, Environment and Science Journalism program. Mohammad Behroozian, a PhD student in NU School of Communication's "Children, Media and Human Development Lab" studies educational media productions to inform children living in warzones. He is SHyNE nanoscience journalist and content producer, responsible for creating educational content to engage youth in areas of nanoscience and nanotechnology. SHyNE leadership in the Global and Regional Interactions (GRI) sub-committee is underscored by its emphasis on international and intra-network staff exchange, as well as workforce development initiatives on both a global and local scale. To this end, SHyNE hosted an undergraduate intern from Chicago State University, an HBCU, and is working with Oakton Community College to establish an internship program for their Nanotechnology Certificate students.

Computation Activities

Computational Imaging Efforts at NU*ANCE:* A component of SHyNE data management includes computational imaging efforts and equipment and facility predictive maintenance. SHyNE collaborates with the Center for Hierarchical Materials Design (CHiMaD) at Northwestern University; this has been instrumental in the design of automated data workflows, adding efficiency in maintaining FAIR data principles. The acquisition of high-speed direct electron detectors at SHyNE facilities has introduced the need to improve the network infrastructure to accommodate the massive amount of data produced. Recognizing this challenge, SHyNE and CHiMaD have worked together to successfully implement a state-of-the-art LIMS as a pilot program. This implementation integrates with pre-existing systems and provides a platform to optimize and modernize lab workflows, ultimately boosting efficiency and productivity for researchers. This proactive approach has positioned SHyNE to maintain a competitive edge and ensure research agility, while guaranteeing the security and reliability of the generated data. In summary, SHyNE/NUANCE 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.

Predictive Maintenance is a program allowing facility managers to detect equipment/facility problems before the failure occurs and prescribe remedies. The current characterization and fabrication systems employ many sensors and monitor their readings in real-time. The predictive maintenance project was initially focused on capital equipment such as PECVD and deep-RIE. These systems are usually equipped with dozens of sensors and operation software that logs the sensor data automatically. By analyzing the log data, we were able to review the history process, evaluate the current condition, and predict the possible future failure. However, most lab instruments don't have the complete sensor-and-log system. Many of them serve critical roles in facility operation, for example, the chillers. Any anomaly in the flow and temperature of the cooling water could cause failure or even damage to the associated instrument.

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 Dr. 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.



Predictive maintenance implemented on cooling water system of JEOL ARM200CF AC-S/TEM. We implemented the cooling water of JEOL ARM200CF AC-S/TEM (Fig a). Fig b shows the mechanical flowmeters in use before the project. The flow rate reading was totally relied on staff observation. A commercial turbine flow sensor was used to replace the mechanical one. The sensor output was read by a raspberry Pi and converted to the flow rate. The microprocessor also sent the real-time reading to a cloud server for data logging. Fig. c shows the dashboard hosted on the server displaying the flow rate as a function of time. The server was also configured to send email alerts to equipment managers once an anomaly was detected. This automatic monitoring system can prevent equipment damage caused by long-time inefficient cooling power and reduce the equipment manager's workload.

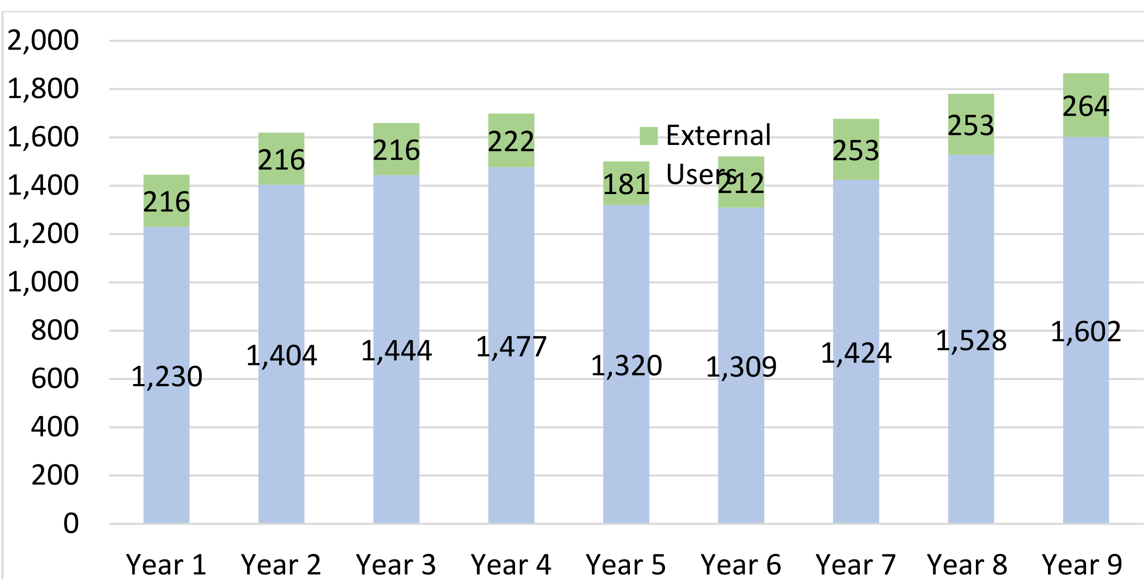
Innovation and Entrepreneurship Activities

A number of the industrial users are based on technology and entrepreneurs who developed their key technology using SHyNE facilities. SHyNE member facilities partner with UChicago's Polsky Center for Entrepreneurship and Northwestern's Corporate Liaison Network, INVOHub, and InQbation Lab to support start-up ventures that need fabrication, synthesis, characterization, and analysis capabilities as part of their entrepreneurship activities.

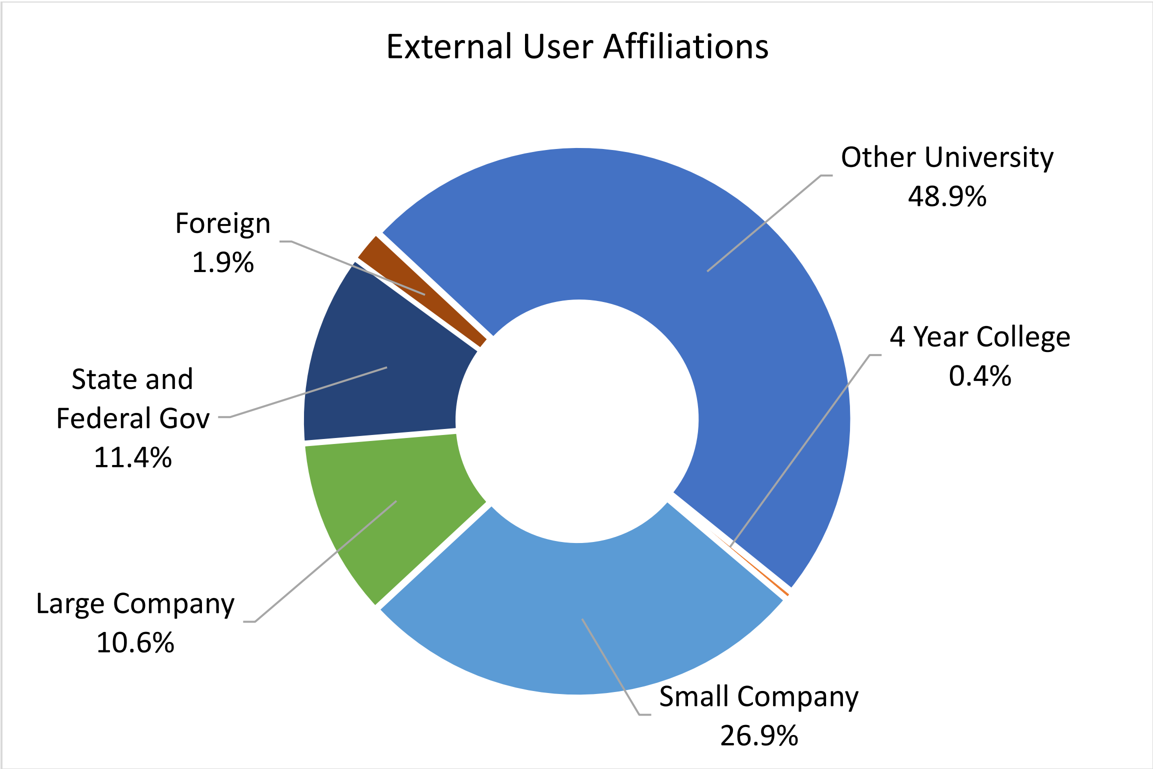
In summary, SHyNE/NUANCE implementations are synchronized with the rise of artificial intelligence ecosystems and associated machine learning algorithms to accelerate innovation in a wide variety of scientific disciplines. We expect that in the coming years, the latest data analysis tools and techniques will gain a greater foothold into facility environment and revolutionize this environment in ways that leave it better positioned to address major scientific challenges.

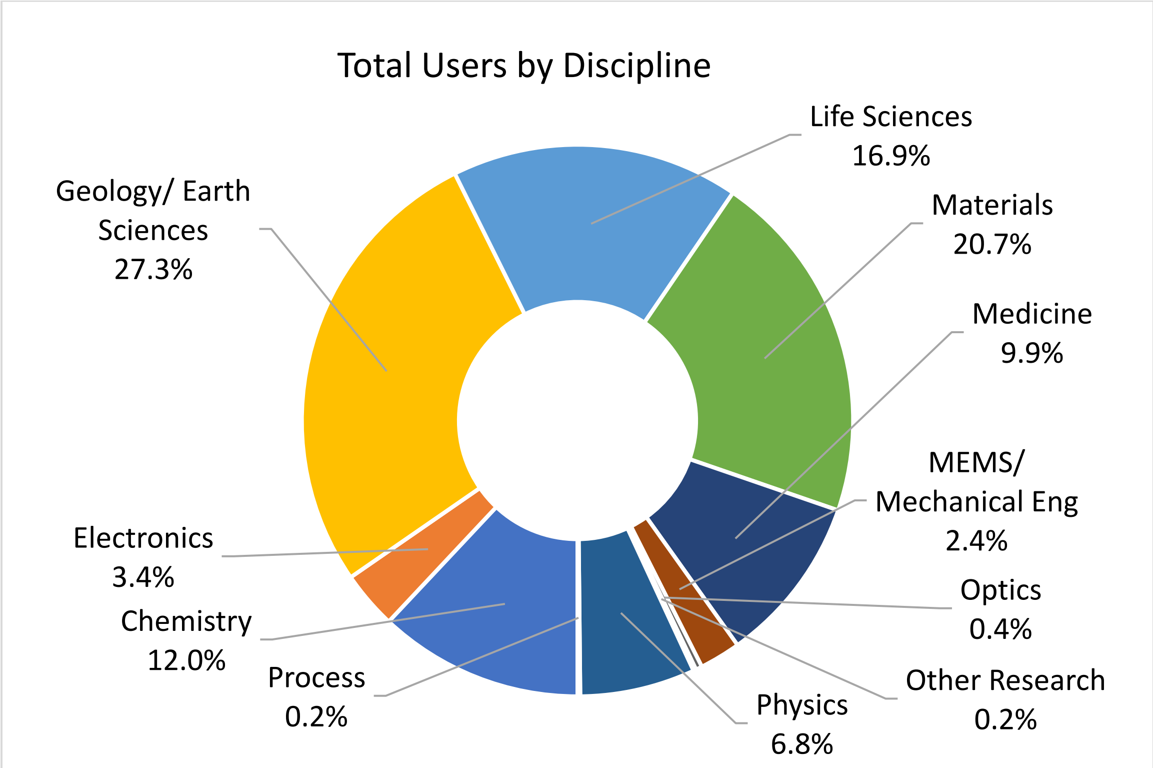
SHyNE Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	1,446	1,620	1,660	1,699	1,501	1,521	1,677	1,781	1,866
Internal Cumulative Users	1,230	1,404	1,444	1,477	1,320	1,309	1,424	1,528	1,602
External Cumulative Users	216 (15%)	216 (13%)	216 (13%)	222 (13%)	181 (12%)	212 (14%)	253 (15%)	253 (14%)	264 (14%)
Total Hours	138,000	132,673	137,375	202,844	139,175	159,720	179,802	200,070	225,932
Internal Hours	128,838	127,127	131,206	192,434	132,177	150,425	167,794	185,264	212,423
External Hours	9,162 (7%)	5,545 (4%)	6,169 (4%)	10,410 (5%)	6,998 (5%)	9,294 (6%)	12,008 (7%)	14,806 (7%)	13,509 (6%)
Avg. Monthly Users	679	802	797	829	606	693	759	815	858
Avg. External Monthly Users	54 (8%)	54 (7%)	52 (7%)	61 (7%)	41 (7%)	54 (8%)	61 (8%)	72 (9%)	77 (9%)
New Users Trained	699	698	605	649	340	597	649	653	698
New External Users Trained	152 (22%)	140 (20%)	86 (14%)	120 (18%)	66 (19%)	121 (20%)	137 (21%)	132 (20%)	124 (18%)
Hours/User (Internal)	105	91	91	130	100	115	118	121	133
Hours/User (External)	42	26	29	47	39	44	47	58	51



SHyNE Year 9 User Distribution





12.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Facility, Tools, and Staff Updates

In July 2024, the Georgia Tech Institute for Electronics and Nanotechnology (IEN) merged with the Institute for Materials (IMat) to create the new Institute for Matter and Systems (IMS). IMS continues to be the home of both the Micro/Nano Fabrication Facility and the Materials Characterization Facility (MCF) at Georgia Tech, so this merger did not result in any substantial changes for SENIC. Georgia Tech personnel that were previously employed by IEN or IMat are now IMS staff members. This new institute has appointed a Facility Advisory Committee and an Employee Advisory Committee.

SENIC continues to facilitate the "3 universities, 2 locations, 1 site" mindset and partnership between IMS and Joint School of Nanoscience and Nanoengineering (JSNN). Our strategic goals, as developed with the help of our advisory board and stated in our NSF renewal proposal, 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 SENIC Year 9, the IEN/IMS Micro/Nano Fabrication Facility expanded its workforce with seven new staff positions. These positions include a Research-Equipment Specialist I, a Process Equipment Engineer, and a Laboratory Technician, whose primary responsibilities are operation of the cleanrooms, facilitating equipment installations, and equipment maintenance. Additionally, the facility hired an IT Support Engineer and a Systems Support Engineer to support the functionality and maintenance of the SUMS user management, scheduling, and billing system and other IT operations. A Lab & Facility Coordinator was hired to enhance operational efficiency, provide user support, and oversee equipment maintenance. Finally, a Process Engineer was added to support the operation and maintenance of the packaging research equipment. The Georgia Tech Materials Characterization Facility (MCF) hired a new Research Scientist to manage the setup and operation of a characterization lab that will be a part of Georgia Tech's Manufacturing Institute which is due to start in FY 2026.

New waste collection systems and gas cabinets have been ordered for both the Pettit and Marcus facilities. The Callaway building cleanroom was shut down and equipment relocated to the Pettit cleanroom. The relocation and renovation of the Marcus staff office into a new cleanroom area has been approved and is currently in the planning stage.

As in previous years, JSNN has continued to maintain a strong Facility and Technical Support team with facility and lab managers for different core labs, including for the Micro and Nanofabrication (cleanroom) core, Analytical Chemistry core, and Advanced Microscopy core in an effort to streamline operations and remote services. To further support the Facility and Technical team, in 2023-2024 JSNN recruited 10 paid Core Facility Assistants, experienced JSNN graduate students who report to and assist the lab managers primarily in user training, consultation, and support services.

During the past year, SENIC has continued to add new tools/upgrade existing tools at both Georgia Tech and JSNN. Decisions regarding tool purchases/upgrades are informed by the annual NNCI user survey, dedicated equipment need surveys and questionnaires, as well as input from facility advisory boards. 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. This past year, many tools at JSNN were purchased/replaced/upgraded with university or State of North Carolina funds as part of Engineering NC's Future Capital Improvement Funds to establish the Interdisciplinary Bioengineering Core (IBEC) Lab.

New Tools/Upgrades:

<u>Georgia Tech IMS Facilities</u>
Lesker PVD200 Sputtering System (2)
Suss ACS200 Coating System
KLA SPTS Rapier Bosch Etch System
Suss LabSpin6 Coater (2)
Disco DAG810 Surface Grinder
Bruker Tribolab CMP System (2)
Qualilab Elite V10 Chemical Analyzer
ClassOne Solstice S8 Electroplating System (Ordered)
Disco DAS8930 Surface Planer (Ordered)
Gatan Monarc Cathodoluminescence Detector

<u>JSNN Facilities</u>
BMF MicroArch S230 3D Printer
Leica CPD300 Critical Point Dryer
NS CNC Elara Mini CNC Mill
TA Instruments HR20 Rheometer/DMA
Cytation 5 Multimode Reader
Malvern Zetasizer Ultra
Evident SZX2 Custom Polarized Microscope
532nm Laser Upgrade for Horiba XPlora Confocal Raman
Laser/detector Upgrade for Beckman Flow Cytometer
Leica EM FC7 Cryo Upgrade for Leica FC7 Ultramicrotome
Abbelight SAFe 360 Super Resolution Microscope Upgrade
Diffuse Reflectance Accessory Upgrade for UV-Vis-NIR Spectrometer

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. 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 SENIC Undergraduate Internship in Nanotechnology, 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 nano- related fields across the US, the SENIC Catalyst Program provides researchers with 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 education. During Year 9, new Catalyst awards were made to researchers from Davidson College, Morehouse College, Gwinnett School of Mathematics, Science, and Technology, Chattahoochee High School, and Morrow High School. Since the start of the program in 2019, 45 projects have been awarded, most of them to HBCUs, PUIs, and high schools.

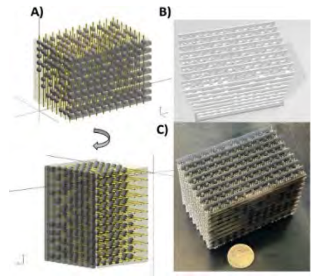
As stated in our renewal proposal, SENIC expanded its relationship with the Center for Nanophase Material Science (CNMS) at Oak Ridge National Lab (ORNL). In particular, we have developed a pathway for joint user/project support, where a SENIC user can obtain expedited access to ONRL resources not available in SENIC facilities, and this mechanism has now been used for 2 projects. After a period of inactivity, SENIC has revived the Southeastern Nano Facility Network (SENFN). A reaffirming meeting was held in December 2023 that drew facility staff from 10 institutions, and SENFN now convenes as a regularly scheduled monthly virtual meeting.

During this past year of the NNCI (Oct. 2023 - Sept. 2024), SENIC facilities have served 1,489 individual users, including 309 external users (49% growth since Year 5) representing 77 companies, 29 colleges/universities, and 8 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 167 users obtained services remotely, and some users were served both on-site and remote. Monthly users averaged 656 (a 76% increase compared to Year 5), and on average 49 new users/month were trained (589 total during the reporting period).

Research Highlights and Impact

Notable new academic users of the SENIC facilities this past year come from Binghamton University, Delaware State University, Lehigh University, and University of Texas – Tyler, while new industry users include Cognition Medical, Jung Engineering Enterprises, Oxos Medical, and Method Aeronautics to name a few. Some example research highlights include:

Programmed Internal Reconfigurations in a 3D-Printed Mechanical Metamaterial Enable Fluidic Control for a Vertically Stacked Valve Array (E. Josephs, UNCG and J. Alston, NC A&T)



Researchers in this work addressed control of fluids within 3D structures by incorporating mechanical metamaterials that exhibit spatially adjustable mechanical properties. A systematic computational and experimental characterization of a modified re-entrant honeycomb structure was performed to generate a modular metamaterial for an active device that allowed for direct regulation of flow through integrated, multiplexed fluidic channels "one-at-a-time," in a manner that is highly scalable. It is expected that mechanical metamaterials in 3D fluidic systems will enable new biotechnological and biomedical applications for 3D printed devices. The work was funded by the National Institute of Health and the National Science Foundation and published in *Advanced Functional Materials*.

Printing Nanoscale Metal Structures with Light (S. K. Saha, Georgia Tech)

Researchers at the Georgia Tech School of Mechanical Engineering have developed a method for printing nanoscale metal structures, using light activation, that is faster and less expensive than previous technologies. This breakthrough was enabled by invention of a clear ink solution containing metal salt and light absorbers. Light converts the dissolved salt into solid metal nanoparticles which adhere to the surface of a glass substrate. Funding for this work was provided by grants from the School of Mechanical Engineering and the EVPR's office at the Georgia Institute of Technology. Publication occurred in *Advanced Materials*.

Wireless Monitoring Patch for Detection of Sleep Apnea (W. H. Yeo, Georgia Tech)

Georgia Tech researchers have created a wearable device to accurately measure obstructive sleep apnea and quality of sleep for use in the home. The wearable sleep monitor patch was developed by a team of researchers and clinicians and is made of silicone and fits over the forehead, with a second, smaller silicone attachment that molds to the chin. Funding was provided by the Alzheimer's Association and the National Institutes of Health, as well as a Center Grant from the Georgia Tech Institute for Electronics and Nanotechnology. The work was published in *Science Advances*.

Photocatalytic Hydrogen Evolution Using Mesoporous Honeycomb Iron Titanate (B. Bastakoti, NC A&T)

Researchers in this work synthesized a mesostructured honeycomb photocatalyst with a high surface area and partial crystallinity. The photocatalyst was efficient in hydrogen evolution through water splitting in the presence of light. The porous nature of the catalyst ensures sufficient active sites and, coupled with enhanced charge transfer, increases photocatalytic activity towards water splitting. The work was funded by the National Science Foundation and published in *Small*.

Scholarly impact can be measured indirectly with more than 580 publications, presentations, and patents benefiting from SENIC facilities in CY 2023. Using a Google Scholar search, 200 of these 2023 publications (and more than 1200 publications 2015-2023) 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.

SENIC facilities supported multiple lab courses from Fall 2023 to Summer 2024. GT teaching cleanroom and Materials Characterization Facility supported 7 courses from 5 academic schools in the College of Engineering. JSNN facilities supported an additional 11 courses for graduate students in Nanoscience and Nanoengineering. These courses had more than 450 students enrolled. Over the academic year from Fall 2023 to Summer 2024, more than 350 degrees were awarded to current/former SENIC users at GT and JSNN including 76 Bachelors, 142 Masters, 129 Doctorates.

Additional impact of SENIC is indicated by centers and other large programs that are enabled by the supported core facilities. In 2024, NC A&T State University received funding from state and national sources to create the new Interdisciplinary Biomedical and Engineering Core (IBEC), located at JSNN and other locations. In 2023, Georgia Tech was part of the renewal award for the Atlanta Center for Microsystems-Engineered Point-of-Care Technologies, a partnership with Emory University and Children's Healthcare of Atlanta. This center is a node in the NIH's Point-of-Care Technology Research Network (POCTRN).

While economic impact can be difficult to quantify, select examples from Year 9 indicate that SENIC-supported companies are achieving success:

- **Absolics, Inc.** will receive up to $75 million in funding under the CHIPS and Science Act to support the construction of a 120,000 square-foot facility in Covington, Georgia and the development of substrates technology for use in semiconductor advanced packaging.
- Medical device company **Artelon**, which develops soft tissue fixation products for foot and ankle and sports medicine procedures, was acquired by Stryker**.**
- **Kepley Biosystems** was awarded an NSF SBIR Phase II grant to continue product development in sepsis diagnosis and management.

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 10,000 individuals from young children to adults.

JSNN is a participating institution in the NIH Maximizing Access to Research Careers (MARC) Undergraduate Fellowship program. It annually offers two students underrepresented in biomedical sciences a research opportunity, focused workshops, and courses to prepare them for graduate school. With the passing of the CHIPS Acts and support from Intel, JSNN offered its annual microelectronics training programs IN-RELPS (Intel-NCA&T Partnership in Broadening Research and Experiential Learning Pathways in Semiconductors) and CLAWS (Commercial Leap Ahead for Wide Bandgap Semiconductors), an 8-week summer internship to 17 undergraduate students. Participants demographics are as follows: two community college students (Forsyth Tech) and fifteen undergraduate students (NC A&T, UNCG, WSSU, Delaware State, and NC State). JSNN provided research experiences 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. IMS has established a strong relationship with the Technical College System of Georgia and has hosted visits by faculty and students. IMS's summer internship program had students from two Georgia colleges, Kennesaw State University (R2 institution) and Georgia State University (R1 institution). IMS also hosted 5 high school interns (from metro Atlanta, Virginia, and Connecticut) who worked with the lab operations team during the summer. IMS also hosted five REU students and one Japanese graduate student in 2024. In addition to internships, SENIC also provided opportunities for high school students and undergraduates to work in the facilities as student assistants.

Each academic year, JSNN hosts a weekly seminar, and IEN hosted a bimonthly seminar called Nano@Tech. This seminar was held in person and live steamed on YouTube, but this series has been replaced by the Systems Matter Seminar beginning in September 2024. 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 2023 ("Bio-Microfluidics") but is currently on pause.

SENIC has been active in providing outreach to K-12 students, educators, and the general public. SENIC at Georgia Tech was the lead site of the NSF-supported Research Experiences for Teachers across the National Nanotechnology Coordinated Infrastructure collaborative program, which ended in 2023. Using SENIC funds, we hosted a cohort of 5 teachers from the metro Atlanta area in 2024. This program provided high school and community college faculty with an opportunity to engage in hands-on research for six weeks, implement lesson plans they created in the classroom, and travel to the Georgia Science Teachers Association annual meeting (January 2025) to share their results and experience with the broader teaching community. A renewal proposal was submitted to NSF in January 2024 and funded to start October 2024. The summer 2024 Nanotechnology Summer Institute for Middle School Teachers (NanoSIMST) program was held in-person at Georgia Tech with a cohort of 11 teachers from Georgia. Teachers participated in a week of instruction that introduced them to nanotechnology and learned about classroom lessons that meet Georgia state standards. The teachers also participated in cleanroom and lab tours, used the portable SEM, and participated in a careers panel.

Throughout the year, JSNN partnered with schools in the Piedmont Triad to educate students, teachers, and community members on nanoscience concepts through classroom visits and community events. JSNN connected graduate students with middle school students within the Guildford County School System for mentorship and educational experiences. As a collaboration with Core Technology Molding, JSNN provided hands-on science demonstrations and tours to over 250 elementary and middle school students and teachers from local school districts.

The Explorers Program is an annual week-long summer program that involves interactive, hands-on experiences with nanoscale technology, nanotechnology applications, 3D printing, agriculture, and ethics, emphasizing phosphorus sustainability. In July 2024, JSNN welcomed 16 high school students from underrepresented groups to learn about phosphorus sustainability and propose solutions to phosphorus-related environmental issues. In the summer of 2024, JSNN also hosted the Draelos Science Scholars Program, which provided mentored lab experiences in chemistry, nanoscience, biology, and bioengineering to 19 high school students for six weeks.

IMS continues to offer virtual class trips to schools throughout Georgia. The virtual program covers similar information as the original "Intro to Nano." IMS staff ship kits to schools so students can continue to do hands-on activities while being guided through a virtual visit. In June 2024, Georgia Tech hosted 70+ middle and high school students from Muscogee county in Georgia. Students were able to tour the cleanroom facility (window tour) and the Materials Characterization Facility and attend the Introduction to Nanotechnology presentation. Finally, IMS held several short courses during this past year for "Microelectronics Fabrication" and "Microfluidics". IMS also held four one-day workshops covering topics in characterization, laser micromachining, and photolithography.

Societal and Ethical Implications Activities

The aim of SENIC's SEI activity 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 replicability across the NNCI network by forming the basis for toolkits that other sites or facilities can use to replicate this work. During SENIC Year 9, Prof. Diana Hicks and graduate student Sergio Pelaez examined the societal orientation of nanotechnology inventions, identifying statements promising societal or commercial benefits from an innovation in patent text.

Why it Matters: Science and technology policy has become increasingly concerned with broader impacts, coupled with a proliferation of ethical language for scientists to demonstrate their commitment to societal benefits. This manifests in various ways: through broader impact statements in grant applications, value-laden language in papers, Ethical, Legal, and Social Implications (ELSI) studies within technology initiatives, and ethical guidelines to govern disruptive technologies. However, a critical question has arisen: are these claims of societal benefit genuine or merely rhetorical? This has significant implications for how we evaluate and develop technologies - are we steering innovation toward social good, or are we just talking about it?

Our Approach: We developed a new method combining large language models with patent analysis to investigate this question. Using both generative (GPT-4o) and discriminative (RoBERTa Large) models, we analyzed 61,000 USPTO patents in the fields of nanotechnology to identify and classify value expressions - statements about societal or commercial implications (N=~2.9m). We then correlated these expressions with the patents' technological orientation, determined through their mapping from technology classes to the UN Sustainable Development Goals (SDGs). Our findings reveal that patents containing societal benefit promises are more likely to be oriented toward addressing social challenges based on their objective technological features. This suggests that such promises go beyond mere rhetoric, reflecting an underlying capacity to address societal issues.

The figure displays the share of nanotechnology patents that relate to an SDG, relate to SDG 9 (industry & innovation), or that have no relation to an SDG. Within each SDG type, the share of patents that express public values and/or private values is displayed. Patents related to SDGs other than industry & innovation are much more likely to promise to contribute to solving societal problems, i.e. contain a public value expression. A paper on this analysis has been submitted to a leading innovation policy journal, and it has also been presented at several social science conferences.

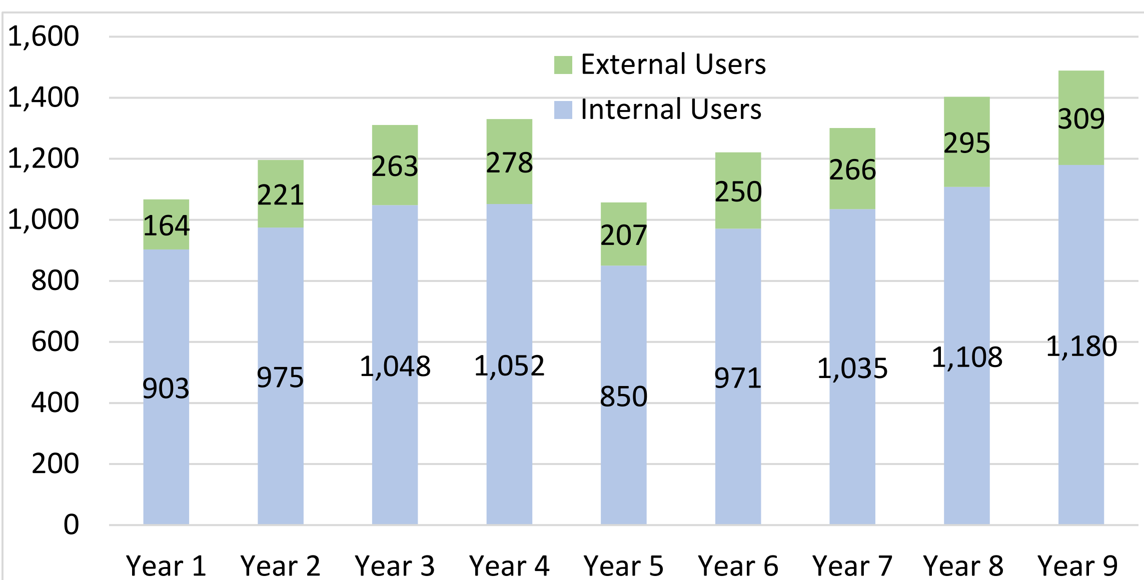
Innovation and Entrepreneurship Activities

In 2024, four teams from SENIC (JSNN) led by Sindhu Yalavarthi (Mentor: Kerui Wu), Yusif Abdul-Rashid (Mentor: Kerui Wu), Evan McDowell (Mentor: Jeff Alston), and Keshan Lighty (Mentor: Lifeng Zhang) were selected to participate in the NNCI NTEC cohort. The team led by Keshan Lighty won the third-place award at the virtual NNCI NTEC Showcase. SENIC representative Sherine Obare (JSNN) participated in the NNCI I&E Working Group quarterly meetings.

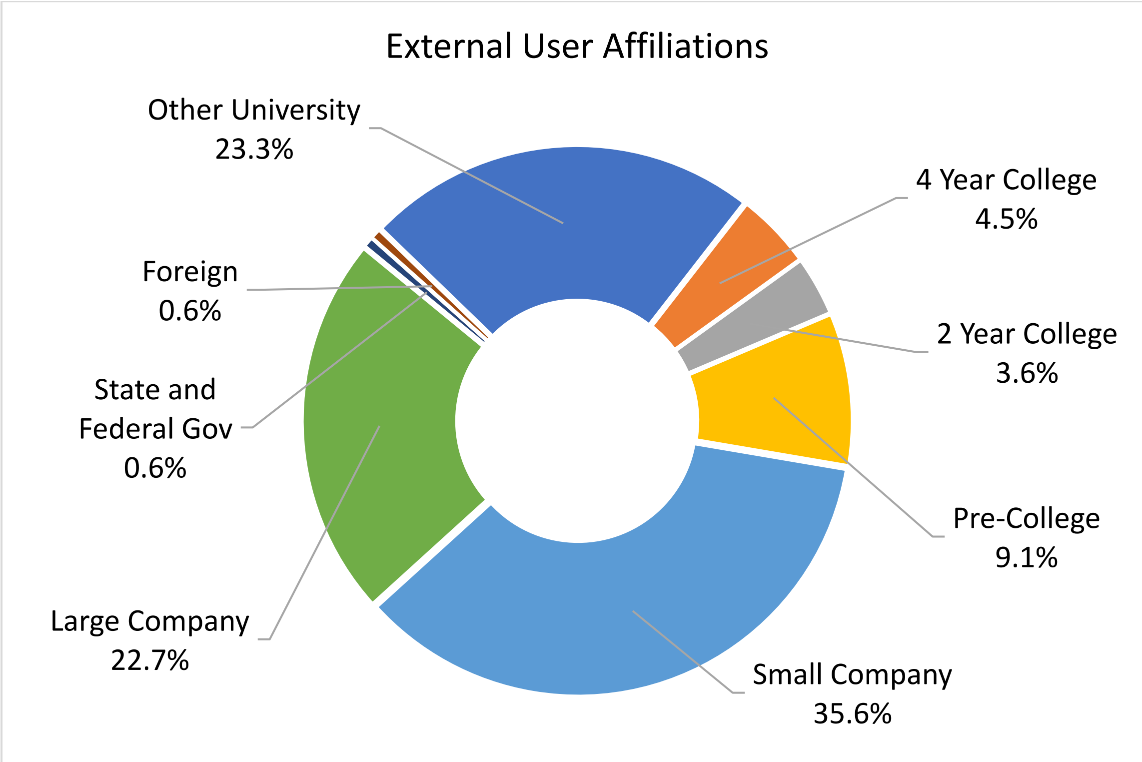
SENIC Site Statistics

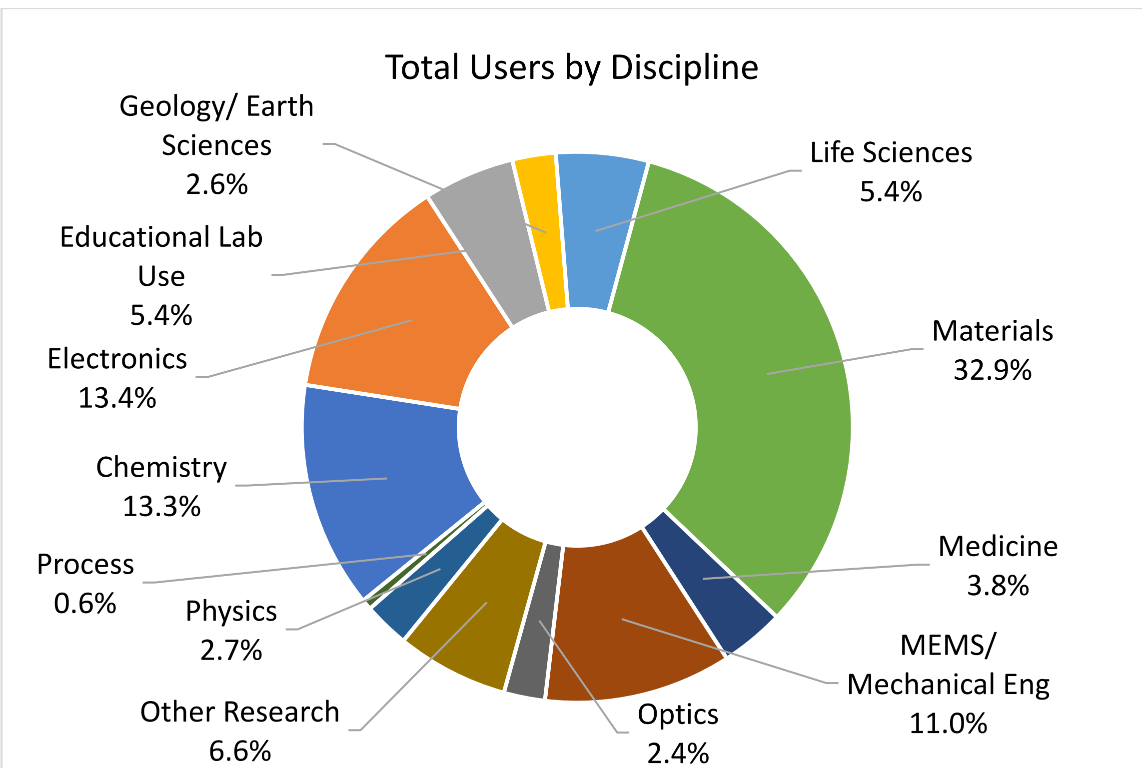
Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	1,067	1,196	1,311	1,330	1,057	1,221	1,301	1,403	1,489
Internal Cumulative Users	903	975	1,048	1,052	850	971	1,035	1,108	1,180
External Cumulative Users	164 (15%)	221 (18%)	263 (20%)	278 (21%)	207 (20%)	250 (20%)	266 (20%)	295 (21%)	309 (21%)
Total Hours	79,581	85,275	99,118	101,571	66,611	92,998	109,049	127,584	136,945
Internal Hours	71,659	73,499	85,730	88,282	58,620	80,751	96,276	112,755	118,809
External Hours	7,922 (10%)	11,733 (14%)	13,388 (14%)	13,289 (13%)	7,991 (12%)	12,247 (13%)	12,773 (12%)	14,829 (12%)	18,136 (13%)
Avg. Monthly Users	447	498	546	576	373	499	563	603	656
Avg. External Monthly Users	60 (13%)	63 (13%)	83 (15%)	89 (15%)	51 (14%)	75 (15%)	73 (13%)	83 (14%)	87 (13%)
New Users Trained	313	313	386	502*	248	453	505	571	589
New External Users Trained	67 (21%)	110 (35%)	123 (32%)	132 (26%)	45 (18%)	80 (18%)	124 (25%)	142 (25%)	180 (31%)
Hours/User (Internal)	79	75	82	84	69	83	93	102	101
Hours/User (External)	48	53	51	48	39	49	48	50	59

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



SENIC Year 9 User Distribution





12.15. Texas Nanofabrication Facility (TNF)

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

The Texas Nanofabrication Facility (TNF) at the University of Texas at Austin (UT) is composed of the Microelectronics Research Center (MRC) which has been part of the NSF NNIN program since 2004, the Texas Materials Institute (TMI), and nanomanufacturing fab (nm-Fab). NNCI-TNF (composed of MRC, TMI and nm-Fab facilities) has 22,000 sq. ft. cleanroom space (class 100 and 1000) and 20,000 sq. ft. of labs. We partner with Austin Community College (ACC).

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 meet annually with the external advisory committee and also seek advice periodically on an *ad hoc* basis.

Major Tool Acquisitions and Upgrades: We have recently received $550M from the State of Texas in response to the CHIPS and Science Act. We are using this to expand the cleanroom by 10,000SF and add 8” nanofabrication tools, and equipment for Heterogeneous Integration. The nano fabrication and characterization equipment that are being installed at a price tag of $27M will be completed by end of 2024. Texas won the $840M DARPA NGMM grant for establishing a shared-use 3D Heterogeneous Integration facility by 2026.

Staff: NNCI TNF at UT Austin provide shared equipment access for users to conduct their research. Research users have access to equipment after face-to-face training and certification sessions. The highly skilled training staff also provide user support for both standard and advanced fabrication or characterization techniques. They propose innovative and unique solutions to solve user’s complex scientific challenges. With the constantly evolving cohort of users utilizing the shared facilities each year, training sessions are organized every weekday. There are 25 technical and administrative staff members in TNF. TNF has a total of 19 full-time technical staff at MRC (3 Ph.D. s, and 7 technicians and engineers), TMI (5 Ph.D. s and 1 technician) and NASCENT nm-Fab (3 Ph.D. s). Six of these are funded by NNCI, while the rest are funded by the University. To keep up with the training demands for new users and current users who want to expand their equipment usage capabilities, for the last eight and a half years, we have also used undergrad and graduate students as part-time lab technicians.

The Site Director, Sanjay Banerjee, reports to the Associate Dean for Research, and is assisted by an Executive Committee (comprised of Profs. Ram Manthiram, and S.V. Sreenivasan, who direct the two other components of TNF), and an External Advisory Board (EAB) which includes three Outside Users of NNCI-TNF, and two faculty members from Universities of Texas at Austin and Dallas. The Executive Committee, advised by the EAB, provides overall leadership and management, set the technical priorities and decide on resource allocation. This committee meets annually to discuss any operational and external user access issues. The committee also provides guidance about staffing and new equipment acquisition during the year on an ad hoc basis. The SEI program is under the direction of Prof. Lee Ann Kahlor. The effort on Computation is led by Prof. Frank Register.

James Hitzfelder is the Site Coordinator of the main cleanroom at the Microelectronics Research Center and Dr. Raluca Gearba is the Site Coordinator of the Texas Materials Institute which houses advanced metrology tools. The coordinators dispatch training requests to technical trainers, discussing project proposals with new users, supporting existing users by organizing specific in-depth training, prioritizing equipment repair and maintenance, and reporting.

User Base

In Year 9, TNF hosted over 1,100 unique users and 50,000 total laboratory usage hours. Average laboratory hours and user fee revenue has increased from Year 8. The external user percentage share of total laboratory hours has remained approximately constant year over year. As in Year 8, a slim majority of external users were affiliated with small companies.

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 (27%), Electronics (13%), or Chemistry (16%) disciplines. The number of cumulative users has increased, reflecting recovery from the pandemic. The number of new users per month has returned to pre-pandemic levels.

TNF had 13% average outside users at the end of the ninth year, and it has been around 23% during the first 6 years. The percentage drop is mainly due to increase of number of internal users. More than half of the current companies which benefit from the TNF shared facilities were already users at TNF in past years. This shows that a good and lasting relationship between TNF and their users has been established and demonstrates the usefulness of the NNCI financial and scientific model. TNF will continue to organize activities such as technical workshops that are known to attract users from within and outside the University. The NASCENT nmFab Industrial Liaison Officer (Dr. Larry Dunn) works closely with TNF to promote the shared facilities to industrial partners.

Research Highlights and Impact

Work done at TNF has led to multi-institution, and multi-NNCI site high impact papers. TNF has also enabled technology development by small companies, many supported by SBIR and STTR grants from NSF, DoD, etc. Some of these examples from the past year are described below. Several of these address the NSF Big 10 Ideas, or other federal initiatives.

a) **Small Company User (2010 - present), Nanohmics,** Mark Lucente, Chris Mann, Steve Savoy, and Karun Vijay

This company is illustrative of the wide range of programs that small companies run through TNF, funded by various government SBIR and STTR programs.

Polarization Metasurface Detection Device for Food Safety. FDA SBIR Phase II. Contract *#2R44FD006910-02. Sept 2022 – Aug 2024. $1.2MM. PI: Mark Lucente, PhD*

Nanohmics is developing a highly sensitive washless "bind and detect" assay with rapid testing, high-throughput multiplexing, and portability to ports of entry and food processing plants for detection of foodborne pathogens. A microfabricated multifunction metasurface operates as a high-efficiency waveplate sensitive to binding of specific pathogens. The metasurface is functionalized through silanization with an array of different antibodies. The metasurface-based MetaDotTM bind-and-detect biosensor will provide portable, low-cost, rapid, highly sensitive multiplex screening of foodborne pathogens. Nanohmics' MetaDot reader will measure pathogen binding on a custom optical metasurface coated with an array of bioreceptor regions (dots), each functionalized for direct covalent receptor binding using aminated antibodies or DNA aptamers (Figure 1). Each single-use functionalized biosensor chip is mounted in a custom ergonometric cassette to facilitate easy handling and precise insertion into a port in the side of the MetaDot reader. Nanohmics has demonstrated a scalable fabrication process that can reduce chip cost and produce a $3 biosensor chip to simultaneously test for 36 different pathogens – enough to test for the presence and concentration of the 31 identified foodborne pathogens, such as Listeria, Salmonella enterica, various E. coli strains, Shiga toxin-producing Escherichia coli (STEC), and foodborne viruses such as Enteroviruses.

b) Small Company User (2011-present), Applied Novel Devices (AND), Leo Mathew and Rajesh Rao

Previously, we had reported a new class of Si power MOSFET technology (ANDFET) with sub-30um substrate developed by AND partly using the NNCI facilities at UT-Austin. We have further advanced the technology using the UT-Austin NNCI labs to develop a polyimide passivation module. This polyimide passivation scheme has been integrated into the ANDFET technology and is compatible with pick and place die level packaging approaches as well wafer level chip scale packages such as ANDPACK. In addition, two different dicing approaches to device singulation have been developed – both conventional dicing processes as well as a novel integration that eliminates dicing of dissimilar materials (Si on thick metal stack) have been demonstrated.

c) External Company user (Magic Leap)

With the help of the UT-MRC fabrication facility Magic Leap was able to prototype, test and optimize nanopatterns for waveguides and other optical components such as Anti-Reflective structures into Master Templates which once replicated through Nanoimprint in High Volume (>10,000's) can give >99.9% Tr% at targeted wavelengths with ability to modulate this at different wavelengths.

d) Internal Academic user with another NNCI site (NCI-SW)

Quantum Conductance in Vertical HBN Memristors with Graphene-Edge Contacts

Prof. Deji Akinwande, Univ. of Texas and Prof. Ivan Esqueda, Arizona State University

Two-dimensional materials (2DMs) have gained significant interest for resistive-switching memory toward neuro-morphic and in-memory computing (IMC). To achieve atomic-level miniaturization, the researchers introduced vertical hexagonal boron nitride (h-BN) memristors with graphene edge contacts. In addition to enabling three-dimensional (3D) integration (i.e., vertical stacking) for ultimate scalability, the proposed structure delivers ultralow power by isolating single conductive nanofilaments (CNFs) in ultrasmall active areas with negligible leakage thanks to atomically thin (~0.3 nm) graphene edge contacts. Moreover, it facilitates studying fundamental resistive-switching behavior of single CNFs in CVD-grown 2DMs that was previously unattainable with planar devices. They studied their programming characteristics and observed a consistent single quantum step in conductance attributed to unique atomically constrained nanofilament behavior in CVD-grown 2DMs. This resistive-switching property was previously suggested for h-BN memristors and linked to potential improvements in stability (robustness of CNFs). This study shows experimental evidence of this, including superior retention of quantized conductance.

e) Internal Academic User (TNF)

Monolithic Barium Titanate Modulators on Silicon-on-Insulator Substrates

Prof. Dan Wasserman (ECE) and Alex Demkov (Physics), Univ. of Texas (TNF)

The linear electro-optic (Pockels) effect provides a mechanism for the rapid (and ideally lossless) modulation of a material's refractive index. Barium titanate (BTO), a complex oxide with a large Pockels coefficient and low optical loss, is thus of significant interest for devices essential to integrated silicon photonics (modulators, phased arrays, tunable resonators), offering decreased operating voltages and/or footprints, low-loss operation, and compatibility with existing CMOS fabrication infrastructure. However, fabrication and growth challenges have limited the direct integration of monolithic BTO-based optoelectrics on silicon substrates. Here Wasserman and Demkov demonstrate a low loss, monolithic BTO device architecture fabricated in thin film epitaxial BTO integrated on silicon-on-insulator substrates by using off-axis RF-sputtering. Mach−Zehnder interferometer modulators are fabricated in the as-grown BTO and characterized spectrally and as a function of DC and AC applied biases. The electro-optical modulators show low losses and competitive VπL values compared to state-of-the-art lithium niobate modulators, in a monolithic architecture compatible with CMOS electronics and silicon integrated photonic circuitry.

f) Internal + External National Lab User

Radiation Response of Domain-Wall Magnetic Tunnel Junction Logic Devices

Prof. Incorvia (Univ. Texas) with Sandia National Labs

Domain-wall magnetic tunnel junctions are a new spintronic device family that may be exploited in resilient edge logic processors or neuromorphic edge accelerators in the future. Here, domain-wall magnetic tunnel junction logic devices were exposed to large total ionizing doses, heavy ion displacement damage, or both. The parts demonstrated complete resilience to the ionizing radiation, but ion-irradiated parts followed a similar degradation curve to previously tested tunnel junction parts in response to heavy ion irradiation. Microscopy and spectroscopy methods confirmed significant damage in some devices.

<u>Education and Outreach Activities</u>

We have a paid internship opportunity at TNF for students from the Engineering Technology department at ACC which gives them 3 college credit hours for the internship. We are also starting a regular REU program for undergraduates from Summer 2024.

Outreach activities that TNF engaged in.

1. Vandgerift High School visit TMI
2. Texas School for the Blind and Visually Impaired (TSBVI) STEM Day
3. Edison Lecture Series
4. STEM Girl Day
5. Bowie Elementary field trip to UT

<u>Societal and Ethical Implications Activities</u>

Prof. Lee Ann Kahlor manages an SEI program where an SEI Training Module was developed and tested. Over the past year, Kahlor has implemented several improvements to enhance the user interface and navigability of the SEI@TNF Website (http://sites.utexas.edu/nnci-sei/).

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 at NNCI-TNF for the last nine years. This past year, the SEI @ TNF team focused on a new project to explore ethical leadership within scientific organizations, the recognition of scientists' contributions to societal impact, and the importance of knowledge-sharing initiatives. The project involved 1) carefully compiling a sampling frame of 600 people from publicly available NNCI node directories, 2) drafting a 10-minute quantitative survey that builds on the extant research on organizational communication, societal impacts of technology, and ethical leadership, 3) piloting and revising the survey, 4) fielding the survey and managing communication and responses, and preliminary data analysis. The team will continue to work with the data for the rest of the year. Dr. Looi (UT PhD 2023) is now an assistant professor of communication at Hong Kong Baptist University and continues to study nanotechnology among other topics. Greg Song is joining the faculty at St. Thomas University in Minneapolis in Fall 2024. A video module developed on this topic has been viewed more than 1000 times. https://youtu.be/4wz8Kifsd4U?si=mFClPj-xn_HbV5tR

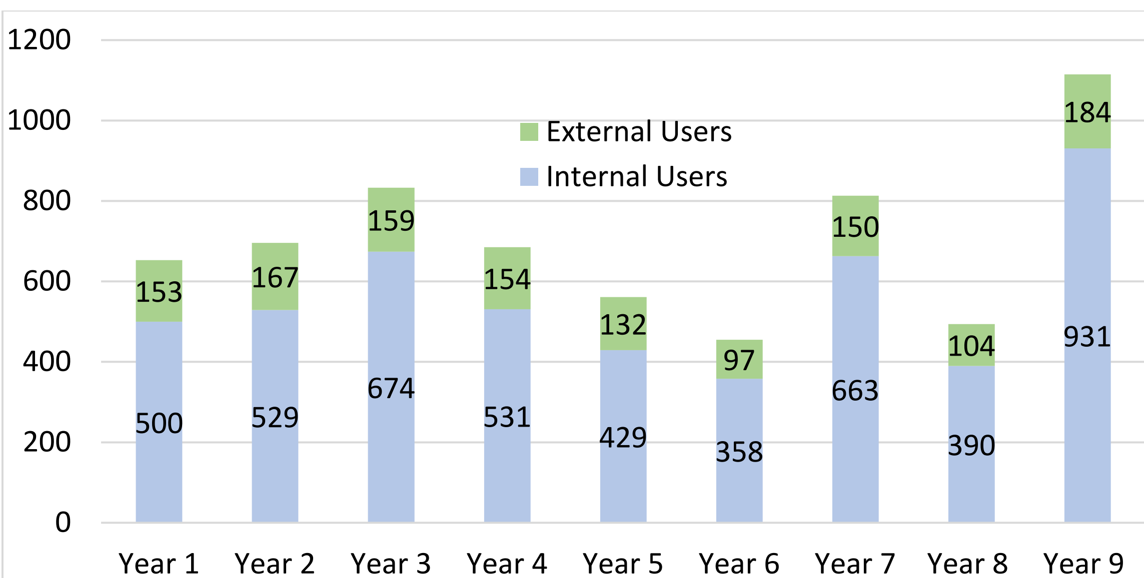
Organizational Leadership Project: Anonymous online survey of employees and affiliates of NNCI nodes helps to identify factors at the individual & organizational level (organizations=NNCI nodes) that shape communication within and outside the organization about the societal impacts of nanotechnology (both positive and negative impacts).

Computation Activities

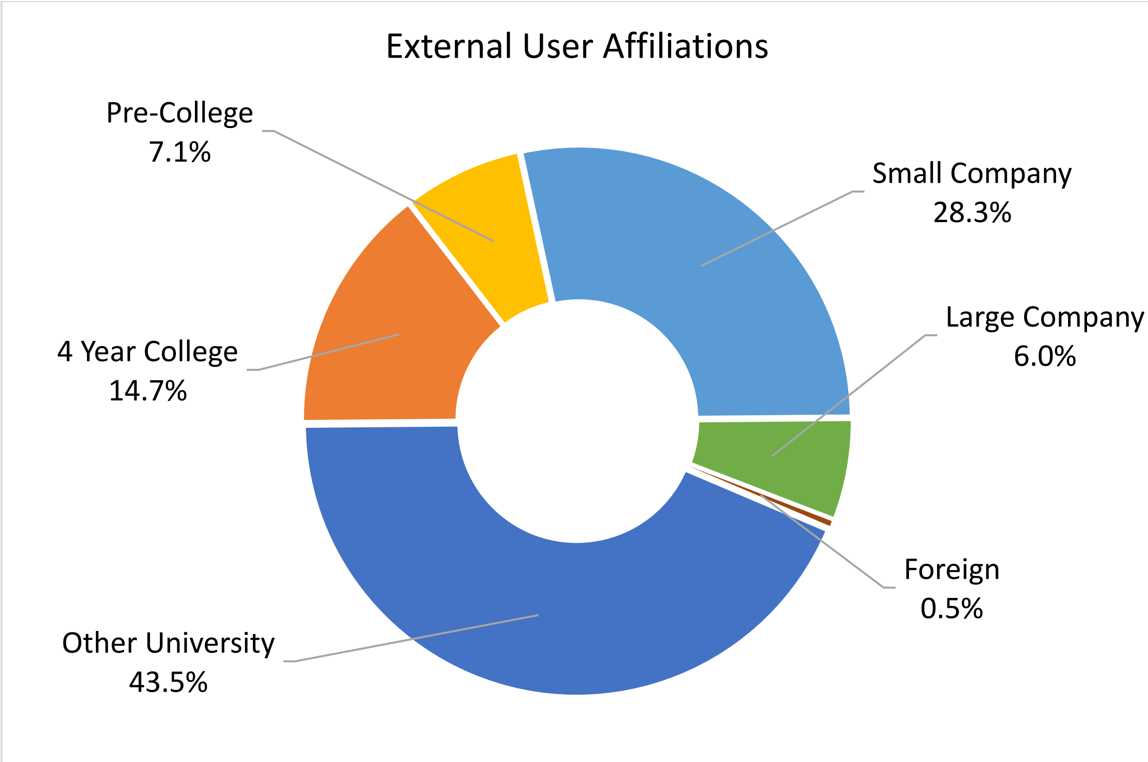
Professor Frank Register directs computational projects and tool development, which are chosen based on the needs of the experimentalists in TNF. The effects of tensile strain and contact transmissivity on the performance limits of monolayer molybdenum disulfide (MoS_2) nanoscale n-channel MOSFETs are studied using a semi-classical Monte Carlo method. Density functional theory calculations were performed to parametrize the electronic band structure of MoS_2 subject to tensile and shear strain. The second activity involved developing a phase-field model using COMSOL to accurately capture multi-domain textures in ferroelectric layers. Through coupled solutions, it analyzes the impact of domain dynamics on device electrostatics and transport, guiding the optimization of performance metrics like ON/OFF ratio and switching speed.

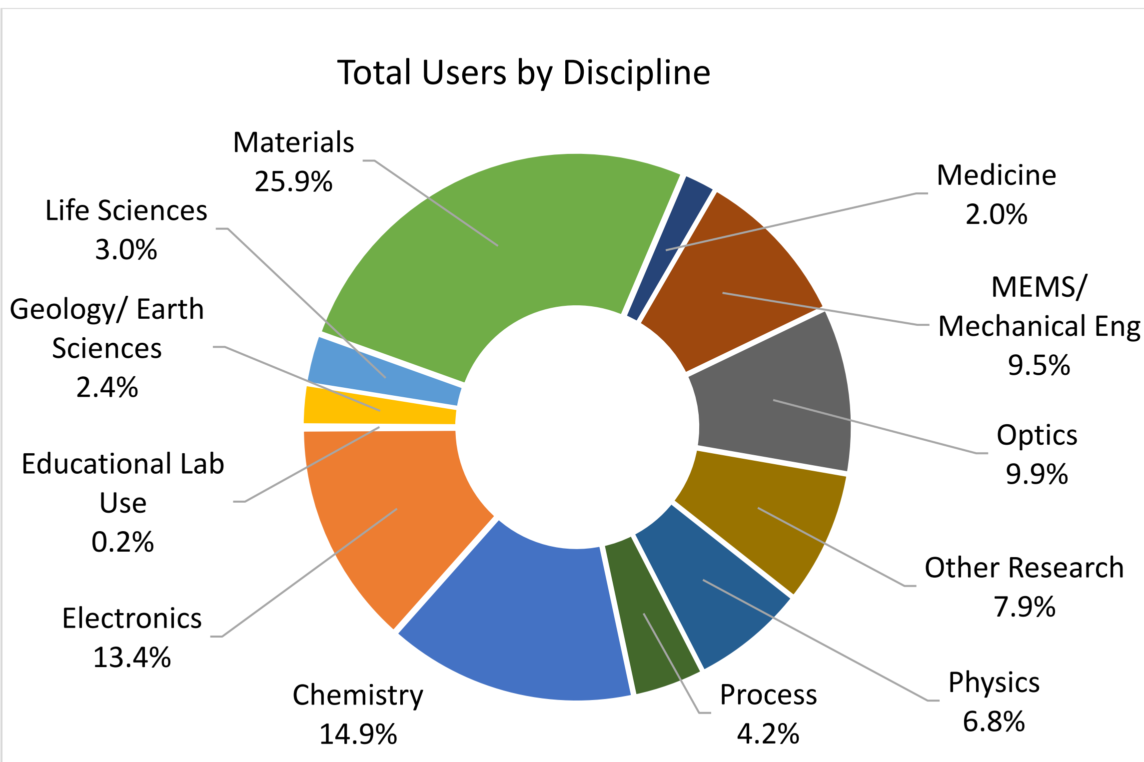
TNF Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	653	696	833	685	581	455	813	494	1,115
Internal Cumulative Users	500	529	674	531	429	358	663	390	931
External Cumulative Users	153 (23%)	167 (24%)	159 (19%)	154 (22%)	132 (24%)	97 (21%)	150 (18%)	104 (21%)	184 (17%)
Total Hours	67,570	58,354	63,645	65,166	38,229	53,901	65,193	41,445	50,922
Internal Hours	53,484	45,952	46,464	48,254	28,263	41,159	51,438	30,537	38,102
External Hours	14,084 (21%)	12,402 (21%)	17,181 (27%)	16,912 (26%)	9,966 (26%)	12,742 (24%)	13,755 (21%)	10,908 (26%)	12,820 (25%)
Average Monthly Users	244	272	287	315	216	246	337	245	352
Average External Monthly Users	45 (18%)	50 (19%)	59 (21%)	65 (21%)	45 (21%)	53 (22%)	66 (20%)	51 (21%)	68 (19%)
New Users Trained	99	193	80	62	34	38	54	12	67
New External Users Trained	48 (48%)	45 (23%)	33 (41%)	29 (47%)	16 (47%)	10 (26%)	18 (33%)	5 (42%)	9 (13%)
Hours/User (Internal)	107	87	69	91	66	115	78	78	41
Hours/User (External)	92	74	108	110	76	131	92	105	70



TNF Year 9 User Distribution





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

Facility, Tools, and Staff Updates

Facility & Tools: After significant facility upgrades, the JEOL JEM-ARM200F NEOARM Atomic Resolution Analytical Electron Microscope was installed. The Panalytical Empyrean NanoEdition x-ray scattering platform was upgraded with a TTK-600 variable temperature stage.

Staff: The facility welcomed two new instrumentation specialists this year. Hongyu Wang joined as the TEM Instrumentation Laboratory Manager after completing his Ph.D. in Mechanical Engineering at NC State University. Jarret Wright joined as a FIB/SEM Laboratory Manager after more than a decade in the materials analysis industry.

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. Our Earth and environmental users have included those in the fields of chemistry, mechanical engineering, civil engineering, medicine, materials, and physics.

Our Multicultural and Underserved Nanoscience Initiative (MUNI) continues to support diverse populations through research support and educational opportunities. The reach of MUNI is greatly expanded due to our collaboration with VT's Institute for Critical Technology and Applied Science (ICTAS) Diversity and Inclusion Seed Investment program, the VT Office of Recruitment and Diversity Initiatives HBCU/MSI Research Summit, and the VT Chapter of Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS).

Research Highlights and Impact

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

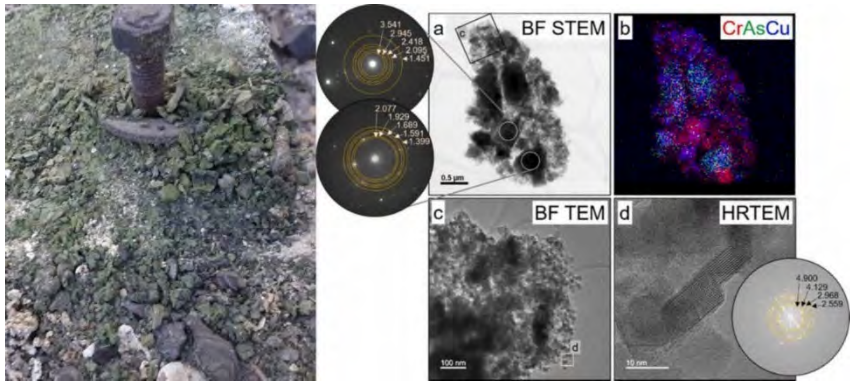
Academic Highlight – Wildland-urban interface fire ashes as a major source of incidental nanomaterials: Fires generate numerous combustion products; however, the nature of the material consumed can have important implications for the environment as well as human health. Wildland fires tend to consume organic material, whereas urban fires consume a wide variety of substances from building materials to household items to industrial solvents and more. However, the nature of the products of wildland-urban interface fires has not been investigated in detail. The focus of this research is the identification and characterization of metal-based incidental nanomaterials (INMs) present in fire ash from the wildland-urban interface (WUI). Ti, Cu, Fe, Zn, Mn, Pb, and Cr-bearing INMs were detected in WUI fire ash with sizes varying from <50 nm to a few hundred nm in the initial work. Further work detected original and transformed Cr, Cu, and As INMs in WUI fire ash and studied their concentrations and compositions. The source of Cr, Cu, and As-bearing INMs in WUI fire ashes is treated wood.

In addition to NanoEarth, this work was supported by the NSF (2101983 and 1828055), and by the U.S. Geological Survey (USGS) Toxic Substances Hydrology Program, Minerals Integrated Science Team, under the Environmental Health Program of the USGS Ecosystem Mission Area.

Publications:

- Alam et al. (2023). Identification and quantification of Cr, Cu, and As incidental nanomaterials derived from CCA-treated wood in wildland-urban interface fire ashes. *Journal of Hazardous Materials*, 445, 130608. https://doi.org/10.1016/j.jhazmat.2022.130608

- Alshehri, et al. (2023). Wildland-urban interface fire ashes as a major source of incidental nanomaterials. *Journal of Hazardous Materials*, 443, 130311. https://doi.org/10.1016/j.jhazmat.2022.130311



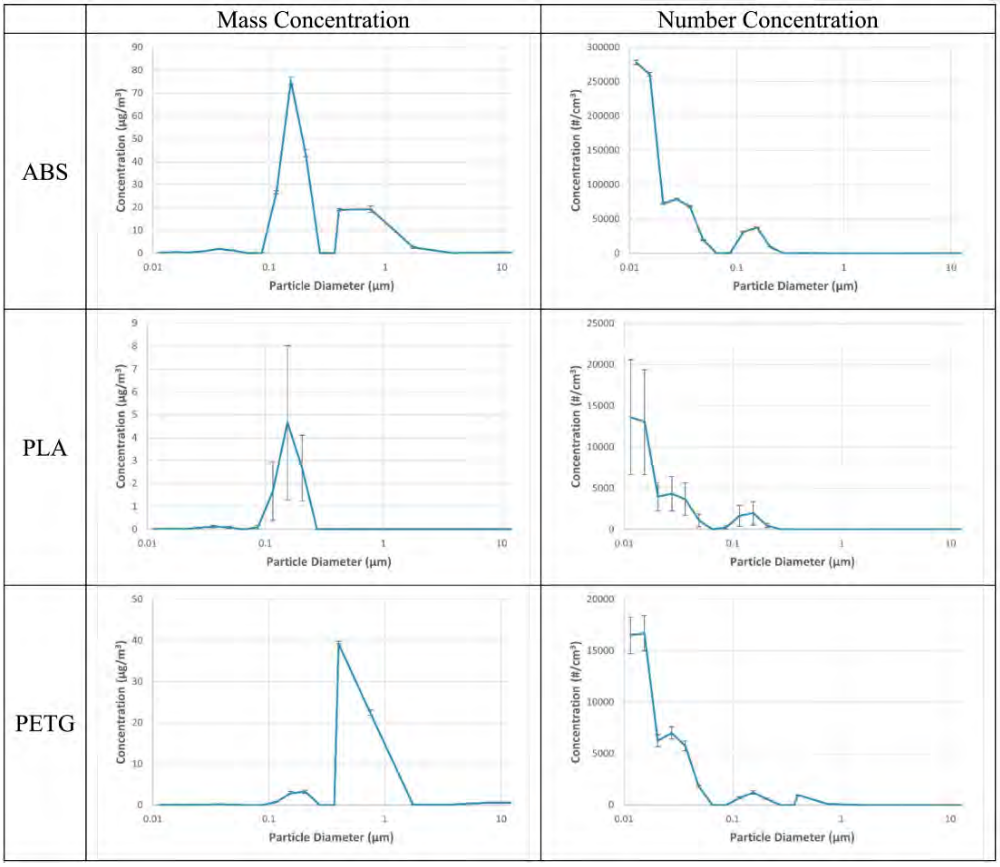
(left) Wildland-urban interface fire ashes. (right) Transmission electron microscopy (TEM) images, energy dispersive spectroscopy (EDS) map, and electron diffraction from Cr-, Cu-, and As-bearing nanomaterials in an aggregate from ash A125. (a) shows the aggregate's overall morphology and two electron diffraction patterns collected from a Cr-bearing (top) and an As-bearing (bottom) suggesting possible phases are CrO_3 *(top) and* AsO_2, As_2O_3, As_2O_5, *or* As_4O_6 *(bottom). Compositional information is presented in (b) as an EDS composite. Magnified view of the aggregates in (a) is shown in (c) and (d). The d-spacings obtained from (d) match to that of* CrO_3.

Industry Highlight – Estimating lung carcinogenicity of 3D printer emissions (Chemistry & Industrial Hygiene, Inc., Lakewood, CO): Use of 3D printing is expanding, but methods to assess the risk of lung carcinogenesis have not been developed. This study demonstrates a methodology for modeling lung cancer risk related to specific exposure levels as derived from an experimental study of 3D printer emissions for various types of filaments (ABS, PLA, and PETG). The emissions of 15 filaments were assessed at varying extrusion temperatures for a total of 23 conditions.

Three approaches were utilized for cancer risk estimation: (a) calculation based on PM2.5 and PM10 concentrations, (b) a proximity assessment based on the pulmonary deposition fraction, and (c) modeling based on the massweighted aerodynamic diameter of particles. The central tendency estimation of lung cancer risk for 3D printer emissions was found at the level of 14.74 cases per 10,000 workers in a typical exposure scenario (average cumulative exposure of 0.3 mg/m3 – years), with the lowest risks for PLA filaments, and the highest for PETG type.

Publication:

- Korchevskiy et al. (2023). Using particle dimensionality-based modeling to estimate lung carcinogenicity of 3D printer emissions. *Journal of Applied Toxicology*, 1-18. https://doi.org/10.1002/jat.4561



Size distribution characteristics of particulates released from natural ABS, PLA, and PETG filament exhibited similar trends with slight differences in peak particle diameter. Data presented were recorded during the stable emissive period at an extrusion temperature of 240ºC. The increased variability in emissions released from PLA may be related to the relatively high extrusion temperature; manufacturer recommendations typically prescribe printing of PLA at 220ºC or lower, while 240ºC is suggested for ABS and PETG.

Education and Outreach Activities

Not including social media engagement and *Pulse of the Planet* listenership, we interacted with over 4,000 individuals during this reporting period. A few highlights include:

- NanoEarth continued our partnership with syndicated radio producer Jim Metzner (multiple radio media major-award winner, plus multiple NSF, Grammy Foundation, and Fulbright grants recipient), who produced a NanoEarth-sponsored *Pulse of the Planet* long form podcast for our eighth year. This brings our total up to 62 NanoEarth-sponsored shows. NanoEarth's *Pulse of the Planet* episodes are built for public consumption and highlight the most interesting projects from external users, impactful research at other NNCI sites, and local site researchers, with those individuals personally interviewed for each episode. These episodes are available as podcasts on Stitcher.com, iTunes, and many other sites. The new episode featuring Dr. Nikolla Qafoku of Pacific Northwest National Laboratory discussing numerous nanoscale aspects of his soil research including the potential use of soil for carbon sequestration was released in May 2024. A full list of episodes with links to each program, which credit the National Science Foundation by name, are available on the NanoEarth website.

- For the second year in a row, NanoEarth provided instrument resources for participants of the REU from Concord University's Arctic REU program. Students completed research in Greenland, Michigan, New York, and at Virginia Tech.
- NanoEarth has participated in many broad scoping outreach events engaging students and the general public at science festivals, libraries, and schools. Events include hands-on activities for participants to explore how a material behaves on the macroscale is affected by its structure at the nanoscale including activities with ferrofluid, kinetic and magic sand, nano-fabric, heat transfer, and nitinol. The impact of these outreach activities goes beyond the participants. Virginia Tech undergraduate and graduate students serve as volunteers for many of these events. Through their service, volunteers learn how to interact with the general public, convey scientific information to individuals at different levels of understanding, and explain their research at a non-academic level.
- In addition to the off-site outreach, NanoEarth also regularly hosts events at our facilities. Events including tours, workshops, talks, and demonstrations, are tailored to the level, needs, and interests of the visiting group and often include demonstrations and guided hands-on experience on our instruments including our Transmission Electron Microscope (TEM), Focused Ion Beam (FIB), Scanning Electron Microscope (SEM), and Scanning Photoelectron Spectrometer Microprobe (XPS).
- NanoEarth piloted several workforce development initiatives based on successful programs at other NNCI sites. These fledgling workforce development activities were made possible by 1) the new instrument additions and upgrades described in our previous and current annual reports that are more easily operable by less experienced interns, and 2) being back at full operating staff which allows our team members more time for intern mentorship and training. The Nanotechnology Instrumentation Training Program (NanoTrain) focuses on Virginia Tech nanoscience undergraduate students. The facility also hosted two interns from New River Community College.

Societal and Ethical Implications Activities

NanoEarth participates in Societal and Ethical Implications (SEI) activities that are coordinated across the NNCI under the direction of Jamey Wetmore of the Nanotechnology Collaborative Infrastructure Southwest (NCI-SW). 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.

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. Following is a summary of NanoEarth I&E highlights in this reporting period:

- Four NanoEarth Industry Seminars and two additional external presentations were held:
    - Nathan Hancock and Cristina Jauset from Flagship Pioneering discussed venture creation for sustainability and summer opportunities with Flagship Pioneering on December 19, 2023.

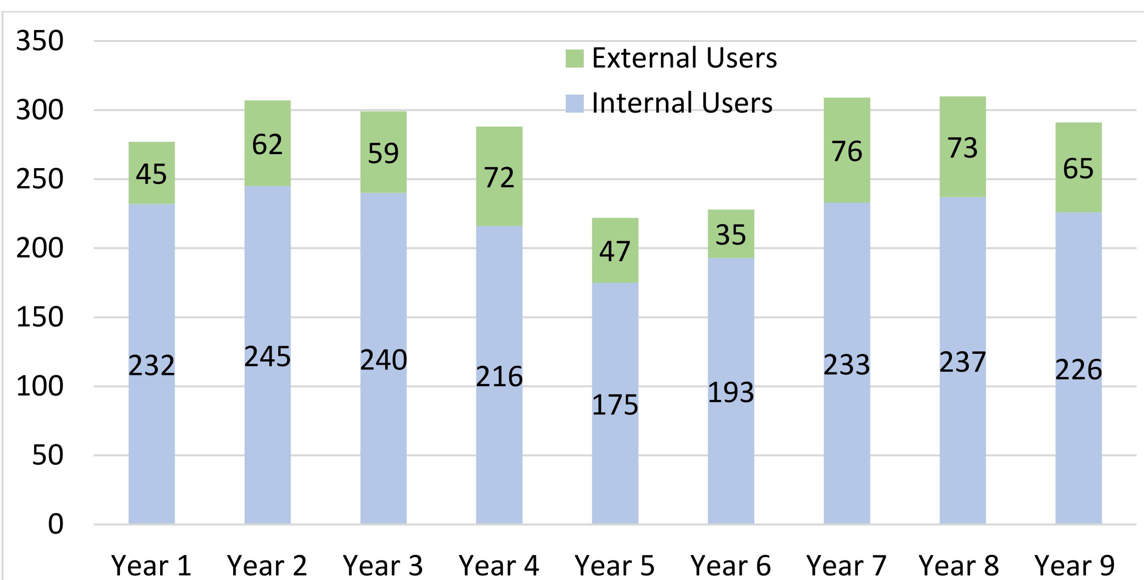
  - Ryan Fuierer of Oxford Instruments introduced WITec Apyron and automated confocal Raman microscopy on January 16, 2023.
  - Darcy Gentleman of United States Pharmacopeia discussed science collaboration to build public regard of and support for research on April 16, 2024.
  - Jeff Wade of SWVA Biochar LLC discussed biochar for environmental applications and carbon sequestration on April 23, 2024.
  - Jamie Lead from GeoMat LLC discussed nanotechnology for remediation on September 19, 2024.
  - Rick Kempinski and Karrigan Turn from Activate along with John Slack of Rhoic discussed the Activate fellowship opportunity as well as John's entrepreneurship journey (which includes an Activate fellowship) translation nano-enabled technologies for CO_2 capture on September 20, 2024.

- M. Hull served as an invited panelist for:
  - The American Society of Mechanical Engineer's webinar "Opportunities in Nanotechnology". The title of Hull's lecture was "*X/Nano: The enabling potential of a career in nanoscience*". February 8, 2024.
  - The 9th Annual Uplifting Black Men (BMEN) Conference. The title of the panel was "Entrepreneurship & Community Development". February 24, 2024.
  - The NNI symposium, Enabling the Nanotechnology Revolution: Celebrating the 20th Anniversary of the 21st Century Nanotechnology Research and Development Act. The focus of the panel was on commercialization of nanotechnologies. March 5, 2024.
- M. Hull served as co-instructor for the ASU Winter School on Emerging Technologies. The title of Hull's lecture/activity was "Pain-to-Pitch 180". Hull attended the winter school and interacted with faculty and students on January 9, 2024. Approximately 15 students participated.
- Ongoing industry engagements included Hoover Color (Hiwassee, VA), GeoMat LLC (Columbia, SC), EAM Consulting LLC (Spring Green, WI), AcumenIST (Belgium), CSI: Create. Solve. Innovate. LLC (Blacksburg, VA), Micronic Technologies (Bristol, VA), GP Nichols & Company (Knoxville, TN), Natural Immunogenics (Sarasota, FL), and ITA International (Blacksburg, VA).
- Through his role as EiR, Dr. Hull mentored two faculty members who are considering start-ups and contributed to the mentorship of 18 entrepreneurial students via the Nanotechnology Entrepreneurship Challenge (NTEC).
- NanoEarth's Associate Director for Innovation and Entrepreneurship Matthew Hull continues to take what he developed at NanoEarth to establish and grow the NNCI Innovation Ecosystem in his role as AD, I&E for the entire NNCI.

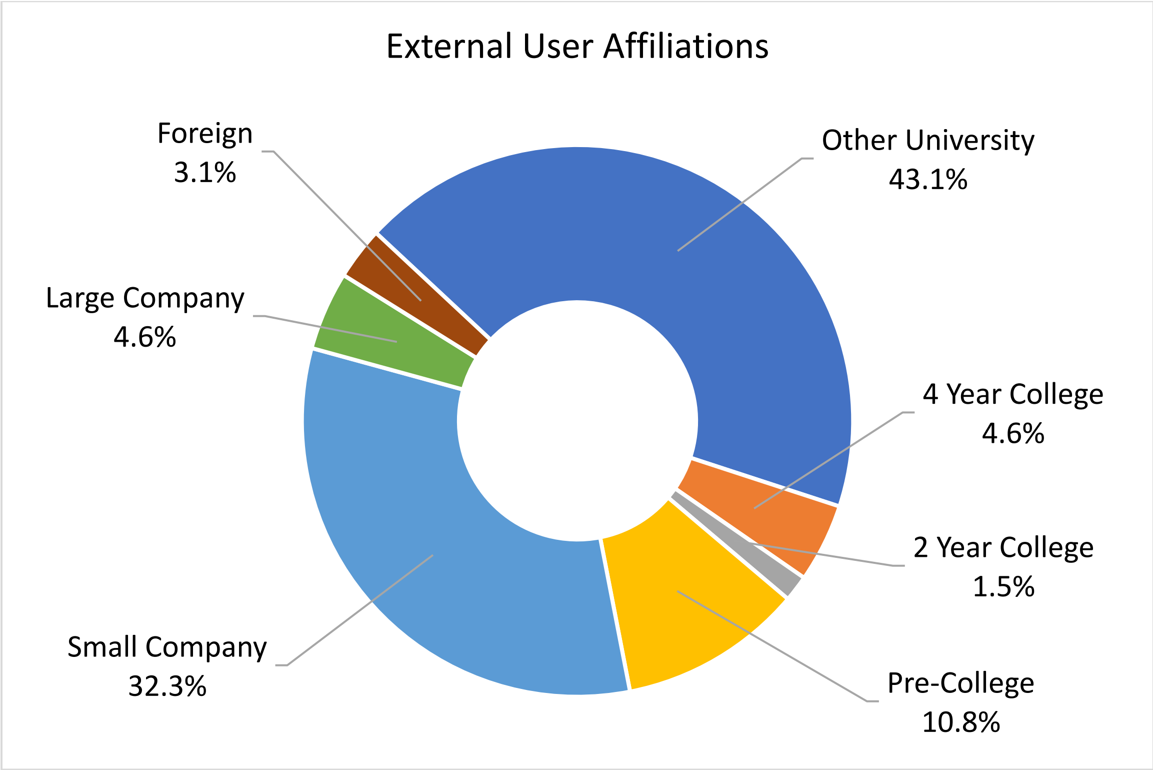
- The 2024 NTEC cohort consisted of 15 teams from 7 separate NNCI sites. Graduate student Freddy Garcia and undergraduates Beeta Zamani and Laura Charria from San Diego Nanotechnology Infrastructure (SDNI) won the top award for their "Portable High Resolution Ultrasound Device for Point-of-Care Brain Stroke Diagnosis and Intervention".

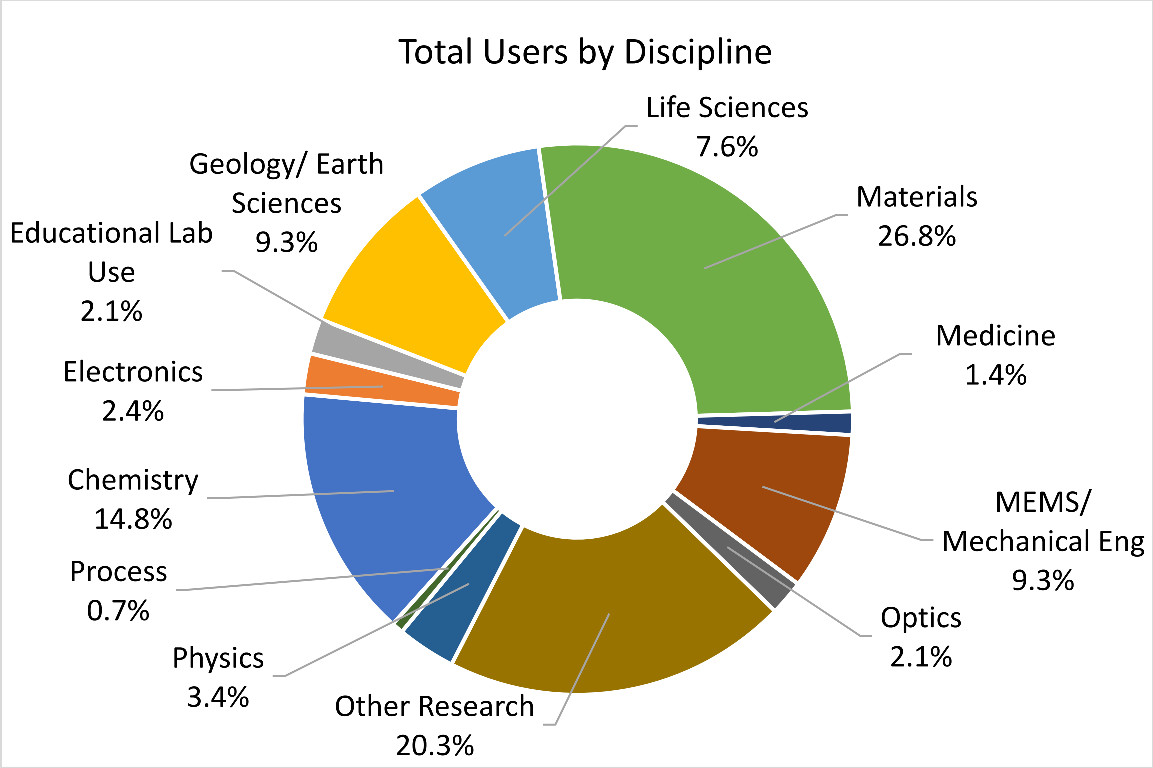
NanoEarth Site Statistics

Yearly User Data Comparison									
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**
Total Cumulative Users	277	307	299	288	222	228	309	310	291
Internal Cumulative Users	232	245	240	216	175	193	233	237	226
External Cumulative Users	45 (16%)	62 (20%)	59 (20%)	72 (25%)	47 (21%)	35 (15%)	76 (25%)	73 (24%)	65 (22%)
Total Hours	7,627	18,056	16,455	15,291	10,710	11,706	18,736	15,884	16,135
Internal Hours	6,196	14,277	14,073	11,622	8,174	9,748	15,882	13,597	14,222
External Hours	1,431 (19%)	3,779 (21%)	2,382 (14%)	3,669 (24%)	2,536 (24%)	1,958 (17%)	2,854 (15%)	2,286 (14%)	1,913 (12%)
Average Monthly Users	78	90	93	91	61	83	100	92	84
Average External Monthly Users	9 (12%)	14 (15%)	13 (14%)	18 (20%)	10 (16%)	13 (16%)	20 (20%)	15 (17%)	13 (16%)
New Users Trained	277	134	94	80	49	72	123	99	93
New External Users Trained	45 (16%)	27 (20%)	0 (0%)	0 (0%)	0 (0%)	3 (4%)	10 (8%)	10 (10%)	5 (5%)
Hours/User (Internal)	27	58	59	54	47	51	68	57	63
Hours/User (External)	32	61	40	51	54	56	38	31	29



NanoEarth Year 9 User Distribution


External User Affiliations
Foreign
3.1%
Other University
43.1%
Large Company
4.6%
4 Year College
4.6%
2 Year College
1.5%
Small Company
32.3%
Pre-College
10.8%


Total Users by Discipline
Life Sciences
7.6%
Geology/ Earth Sciences
9.3%
Materials
26.8%
Educational Lab Use
2.1%
Medicine
1.4%
Electronics
2.4%
Chemistry
14.8%
MEMS/ Mechanical Eng
9.3%
Process
0.7%
Optics
2.1%
Physics
3.4%
Other Research
20.3%

13. Program Plans for Year 10

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) remained the same as those 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 10, the CO will continue to support Subcommittees and Working Groups, the NNCI website, the NNCI Annual Conference, as well as the 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 10.

A number of specific activities planned for Year 10 are highlighted below:

- *NNCI Website*: The CO will continue to add new and revise existing content to the nnci.net webpage.
- *NNCI Annual Conference:* The 10th NNCI Annual Conference will be hosted by SENIC and held at Georgia Tech in October 2025. Discussions are currently ongoing regarding the agenda for this final conference.
- *REU Convocation*: The Year 10 REU Convocation will be hosted by SDNI and held at University of California-San Diego, August 4-5, 2025, as an in-person event.
- *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.
- *Coordination with Microelectronics Commons Hubs:* Each of the funded Microelectronics Commons Hubs have some affiliation with an NNCI site university. As indicated above (Section 7.6), the role of the Microelectronics and Semiconductors Research Community will be to help coordinate the relationship between NNCI and the Hubs, and this effort will continue during Year 10.
- *Staff Exchange Program*: Originally proposed by the Global & Regional Interactions Subcommittee, the CO will continue to support a staff exchange program in Year 10. Some use of this mechanism has occurred by request in Years 8 and 9 and was described above. Funds to support this program have been included in the CO 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 2025.
- *Data Collection and Reporting:* The CO will continue to collect statistical data on network usage and report this data to the NSF as part of the annual reporting. We will continue 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.

- *Collaborations with Nanoscale Science Research Centers (NSRCs):* As described above in Section 9, a portion of the 2024 NNCI Annual Conference was dedicated to exploring avenues to better interact and collaborate with the five DOE nanolabs. This work has continued with the creation of a new NNCI-NSRC working group in January 2025 and will continue through the end of NNCI (and beyond).
- *NNCI International Relationships:* Discussions began at the 2024 International Conference on Research Infrastructures (ICRI) to explore interest in a global network (of networks) for nanofabrication facilities. A “kickoff” meeting with delegations from NNCI, EuroNanoLab, ARIM (Japan), CMC Microsystems (Canada), and the Australian National Nanofabrication Facility will be held in conjunction with the ENRIS conference in May 2025 (Bologna, Italy).
- *Prioritization of NNCI CO Funds:* With additional 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. In Year 10, supplemental funding, beyond the budgeted allotment, will be provided to the SEI program (for support of Science Outside the Lab) and Innovation/Entrepreneurship program (for support of NTEC).